A COMPREHENSIVE DECISION SUPPORT TOOL FOR ACCELERATED BRIDGE CONSTRUCTION CONSIDERING SOCIAL EQUITY

Quarterly Progress Report
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ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

Submitted to:
ABC-UTC
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1. Background and Introduction

The suitability of using accelerated bridge construction (ABC) techniques in bridge construction projects has potential interdependencies with several social and environmental factors related to communities affected by the bridge project in addition to economic, safety, and technical factors related to the design and construction of bridges. Decision-makers and bridge owners (e.g., Departments of Transportation- DOTs) demand assurance that the ABC techniques are thoughtfully implemented since many of the projects have limited budget, time constraints, and construction limitations. State DOTs across the country utilize different decision-making approaches, ranging from complex to simple processes, to determine the suitability of ABC methods in bridge projects. Connecticut DOT (CTDOT) uses a middle-ground multi-criteria decision-making approach entitled "ABC Decision Matrix" based on a spreadsheet tool to aid decision makers in adopting ABC methods. The CTDOT ABC Decision Matrix is a relatively simple, yet effective, tool that considers the impacts of ABC on road users and the environment and accounts for total project costs but offsets ABC costs with the costs that can be reduced or eliminated with ABC. However, there are some issues that affect the comprehensiveness, accuracy and widespread use of the tool. The objective of this research is to extend the CTDOT ABC Decision Matrix to (1) consider the benefits of ABC on roadway safety and risk of accidents, (2) consider the impacts and contributions of ABC on social equity and environmental justice in communities, especially underserved ones, (3) include quantitative measures for the evaluation of decision criteria where possible, and (4) leverage a systematic method for the determination of relative importance (weights) of criteria. A case study will be used to demonstrate the applicability of the improved tool. The improved ABC decision making tool will be more comprehensive, less subjective (more accurate), and more flexible to be used by state DOTs.

2. Problem Statement

The suitability of ABC techniques has potential interdependencies with several natural hazards, (e.g., floods), social, and environmental factors in urban areas in addition to economic, safety, and technical factors related to the design and construction of bridges (Jia et al., 2018). Decision-makers (e.g., state DOTs) need to assure that the ABC techniques are thoughtfully viewed since many of the projects include construction limitations and have only access to limited budget and time (Chaphalkar et al., 2013). Flood-related factors can contribute to bridge scour, the biggest cause of bridge failure in the United States, and a major cause of increased construction and maintenance costs of bridges in the United States (FDOT, 2005; Wang et al., 2017). Construction of a bridge can potentially generate additional flood issues because of the alterations to natural streams and rivers including temporary flow diversions during construction. Reducing the construction time through ABC methods can potentially minimize the risk of flooding due to temporary flood diversions during the construction phase.

Social equity in the context of urban infrastructure can be defined as equal resources and opportunities that infrastructure systems provide for urban communities. Incorporating social equity in infrastructure planning results in the elimination or reduction of disparate access to amenities and services among different community groups, including ethnic minorities, low-income groups, people with disabilities, and the elderly among the other groups (Dhakal et al., 2021). Environmental justice is the fair treatment and involvement of all people with regard to environmental policies and requires the same degree of protection from environmental and health hazards for everyone (EPA, 2022). ABC has implications in social equity and environmental justice that can be incorporated into the decision-making process for evaluating the suitability of adopting ABC methods in bridge projects. For example, social and demographic factors such as high crime rates and high population densities can cause interruptions to the bridge construction process, increasing the construction time. Adopting the ABC method can help reduce the chance of those interruptions. More importantly, ABC can help the revitalization of these urban neighborhoods (e.g., improving economic conditions in low-income neighborhoods by addressing traffic issues that used to affect the businesses and property values). Finally, the reduced construction time due to adopting ABC techniques would result in more public consent because the everyday life of residents will be less affected by construction processes. Environmental issues such as high air temperatures and low air quality are potential threats to human health and can cause health issues for the workforce and increase the construction time of projects. Workers exposed to high levels of air pollutants, such as particulate matter and ozone, are at increased risk of respiratory diseases, cardiovascular diseases, and other health issues (Ritz and Wilhelm, 2008; Shahsavani et al., 2019). In addition, working in high temperatures can lead to heat exhaustion, heatstroke, and other heat-related illnesses (Kjellstrom et al., 2019). The use of ABC techniques can help minimize these environmental risks to workers by reducing the amount of time they are exposed to these hazards. Prefabricated bridge elements and systems, for example, can be assembled off-site in controlled environments, reducing the need for on-site work and the associated exposure to air pollution and high air temperatures (PACO Steel and Engineering Corp., 2015). In addition, the use of ABC techniques can reduce traffic congestion and associated vehicle emissions during construction, improving air quality in the surrounding area (NCHRP, 2018). Therefore, using ABC methods can minimize these threats to the workforce. Moreover, ABC can contribute to the accelerated revitalization of these urban neighborhoods (e.g., faster achievement of good air quality by addressing traffic issues in a densely populated urban area). To address the existing inequalities built into urban communities and create better communities for all, social equity and environmental justice should be incorporated into civil infrastructure planning (APA, 2022), including the decision the making about the suitability of ABC projects.

The suitability of ABC techniques also has potential interdependencies with work zone safety, which is an important aspect of infrastructure construction projects. Work zone accidents and fatalities are a significant concern for state DOTs, as they not only endanger workers but also pose risks to motorists and pedestrians (Li et al., 2019). The use of ABC techniques can potentially minimize work zone risks by reducing the amount of time required for on-site construction and traffic disruption (Mallela and Rege, 2018). For instance, prefabricated bridge elements and systems can be assembled off-site and transported to the construction site, reducing the time workers spend in the work zone and the risks associated with heavy equipment and traffic (PACO Steel and Engineering Corp., 2015). State DOTs need to carefully evaluate the potential interdependencies of various factors related to ABC suitability and ensure that decision-making processes consider these factors comprehensively. To summarize, ABC techniques have the potential to impact various factors related to bridge construction projects, including work zone safety, social equity, and environmental justice. Incorporating these factors into the decision-making process for evaluating the suitability of adopting ABC methods can increase public consent while meeting technical and economic considerations, improving the overall success of infrastructure projects.

3. Objectives and Research Approach

The overall goal of this research is to improve the CTDOT ABC decision making tool to obtain an improved tool that is more comprehensive, less subjective, and more flexible to be used by other state DOTs. The specific objectives of this research are:

(1) Considering the benefits of ABC on roadway safety and incorporating the risk of accidents as new quantitative criteria in the tool

(2) Considering the contributions of ABC to social equity and environmental justice as new quantitative criteria in the tool

(3) Developing quantitative measures for the evaluation of decision criteria where possible

(4) Developing a systematic method for determining the relative importance (weights) of criteria

(5) Demonstrating the application of the improved tool in a case study.

4. Description of Research Project Tasks

The planned activities in this project are toward improving the CTDOT ABC decision making tool. The improved tool extends the benefits of ABC to improving roadway safety (reducing the risk of accidents) and considers social equity and environmental justice in the decision-making process. Hence, it will be more comprehensive than the CTDOT and other existing ABC decision making tools. Moreover, the improved tool quantifies some of the qualitative evaluations in the existing CTDOT tool, reducing the subjective aspects of the decision process and increasing the accuracy of the results. Finally, the improved tool will develop a procedure to determine the relative weights of criteria, making the tool flexible to be used by other state DOTs. Once the improved tool is developed, its application will be demonstrated in a bridge construction project.

The research tasks in this project are designed to address the overall goal and specific objectives of the project. Figure 1 shows the research tasks and their interrelationship as a flowchart. More details about each task are presented below.

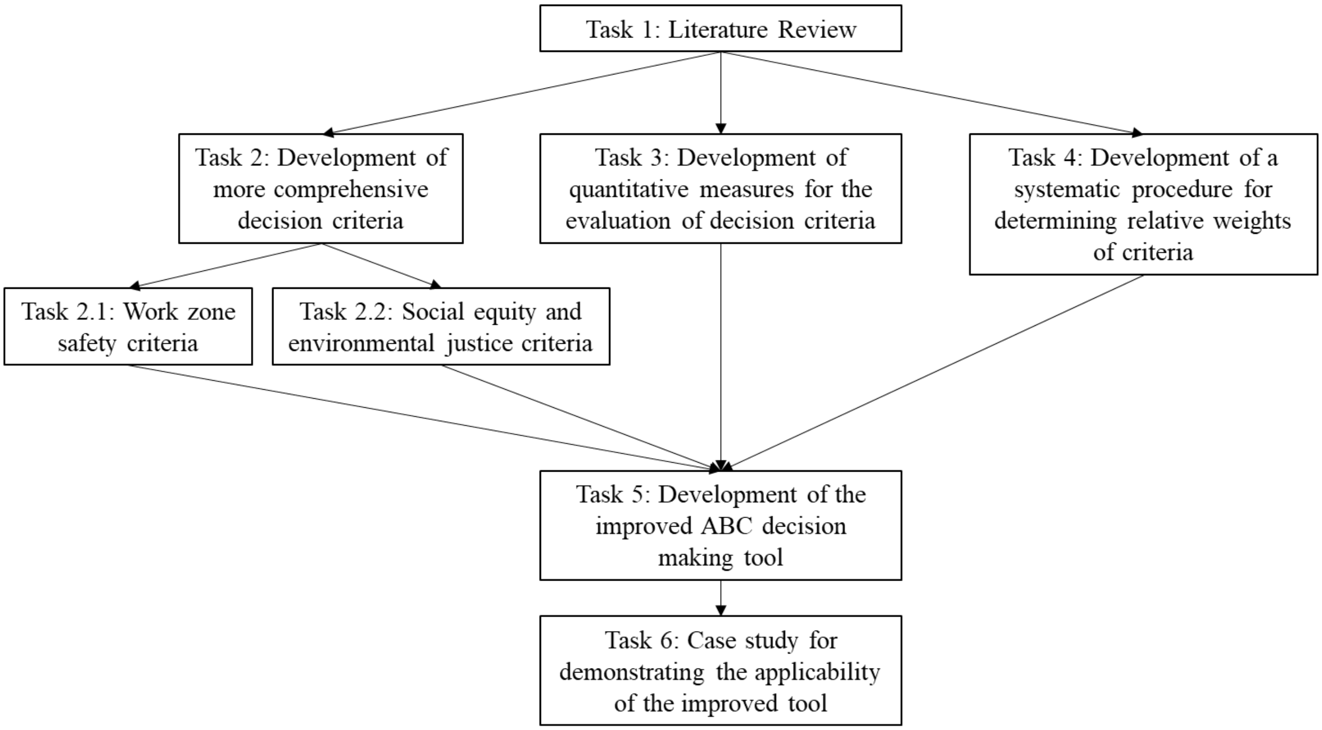


Figure 1. Flowchart of the proposed methodology that shows the research tasks and their interrelationships.

Task 1 – Literature Review

The project includes a literature review to identify the existing state of the knowledge and practice about 1) ABC decision making tools from different DOTs and 2) incorporating social equity and environmental justice in infrastructure planning.

ABC Decision Making Tools Review

FHWA ABC Decision Making Guidance

ABC projects decision making tool is developed based on a Prefabricated Bridge Elements and System (PBES) by FHWA. In this method, a flowchart and matrix integrate a set of decision criteria to choose between conventional and ABC alternatives, Figure 2, and Table 1. After answering all the questions in the matrix, if many of the answers are yes, the project should use PBES. If not, PBES should not be applied.

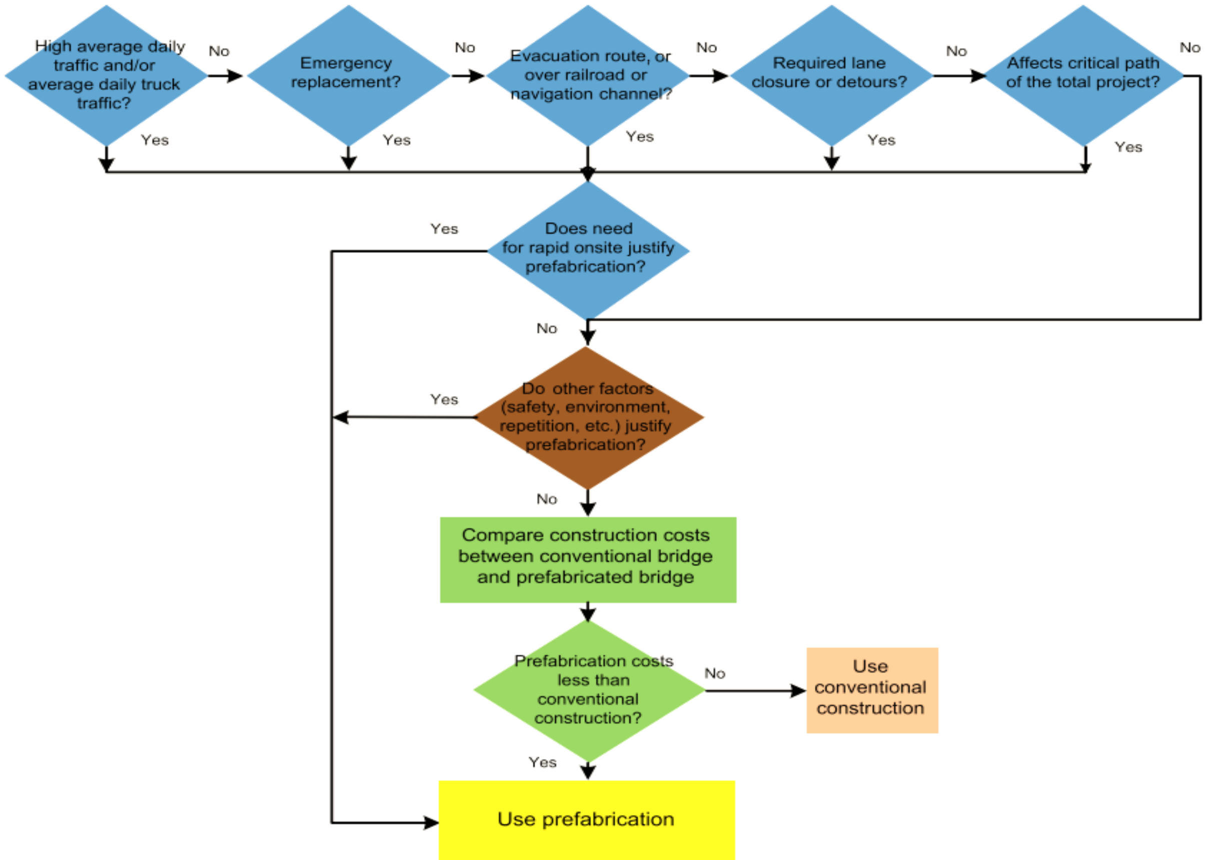


Figure 2. FHWA ABC Decision Making Flowchart (FHWA, 2006)

Table 1. FHWA ABC Decision Making Matrix (FHWA, 2006)

Question	Yes	Maybe	No
Does the bridge have high average daily traffic (ADT) or average daily truck traffic (ADTT), or is it over an existing high-traffic-volume highway?			
Is this project an emergency bridge replacement?			
Is the bridge on an emergency evacuation route or over a railroad or navigable waterway?			
Will the bridge construction impact traffic in terms of requiring lane closures or detours?			
Will the bridge construction impact the critical path of the total project?			
Can the bridge be closed during off-peak traffic periods, e.g., nights and weekends?			
Is rapid recovery from natural/manmade hazards or rapid completion of future planned repair/replacement needed for this bridge?			
Is the bridge location subject to construction time restrictions due to adverse economic impact?			
Does the local weather limit the time of year when cast-in-place construction is practical?			
Do worker safety concerns at the site limit conventional methods, e.g., adjacent power lines or over water?			
Is the site in an environmentally sensitive area requiring minimum disruption (e.g., wetlands, air quality, and noise)?			
Are there natural or endangered species at the bridge site that necessitate short construction time windows or suspension of work for a significant time period, e.g., fish passage or peregrine falcon nesting?			
If the bridge is on or eligible for the National Register of Historic Places, is prefabrication feasible for replacement/rehabilitation per the Memorandum of Agreement?			
Can this bridge be designed with multiple similar spans?			
Does the location of the bridge site create problems for delivery of ready-mix concrete?			
Will the traffic control plan change significantly through the course of the project due to development, local expansion, or other projects in the area?			
Are delay-related user costs a concern to the agency?			
Can innovative contracting strategies to achieve accelerated construction be included in the contract documents?			
Can the owner agency provide the necessary staffing to effectively administer the project?			
Can the bridge be grouped with other bridges for economy of scale?			
Will the design be used on a broader scale in a geographic area?			
Totals:			

In December 2009, the Oregon Department of Transportation (ODOT) working with several other states (California, Iowa, Minnesota, Montana, Texas, Utah, and Washington) launched an FHWA-sponsored AHP-based tool for identifying whether ABC should be applied to a specific project or not. This tool considered five main criteria: direct cost, indirect cost, schedule constraints, site constraints, and customer service. The Oregon State University ABC AHP decision tool was developed using Microsoft Visual Studio. NET. This method has a set of decision criteria Analytical Hierarchy Process (AHP) to plan if ABC is an economical and reasonable choice for the defined bridge or not. The AHP process involves three basic stages, a flowchart, matrix, and considerations section which may be used individually or in combination. Figure 3 shows a screenshot from the ABC-AHP user interface. The final stage considers AHP calculations, which produce an output value used for the purposes of decision-making. For the first step, preliminary inputs are shown in Table 2.

Table 2. ABC-AHP Decision Tool Inputs (FHWA, 2012)

Category	Subcategory
Direct Costs	Construction
	Maintenance of Transport
	Design and Construct Detours
	Right of Way
	Project Design and Development
	Maintenance of Essential Services
	Construction Engineering
	Inspection and Maintenance and Preservation
	Toll Revenue
Indirect Costs	User Delay
	Freight Mobility
	Revenue Loss
	Livability During Construction
	Road Users Exposure
	Construction Personnel Exposure
Schedule Constraints	Calendar or Utility or RxR or Navigational
	Marine and Wildlife
	Resource Availability
Site Constraints	Bridge Span Configurations
	Horizontal/Vertical Obstructions
	Environmental
	Historical
	Archaeological Constraints
Customer Service	Public Perception
	Public Relations

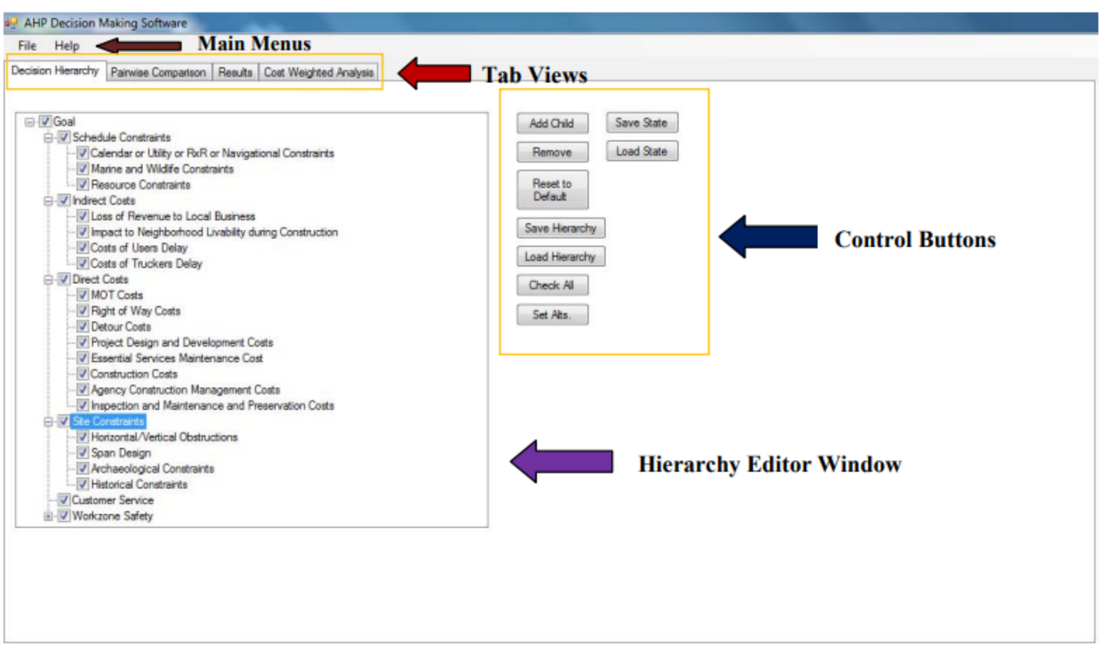


Figure 3. ABC-AHP Decision Tool (FHWA, 2012)

For the second step, each criterion is ranked pairwise comparison. Figure 4 shows an example displaying the use of ABC or conventional construction.

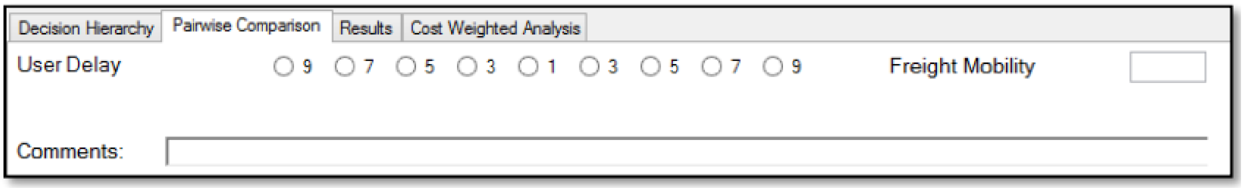


Figure 4. ABC/Conventional Construction Ranking (FHWA, 2012)

After stage 2, the assessment process should move to the last step, which uses AHP theory to determine if ABC techniques should be used for bridge construction projects or not.

California DOT ABC Decision Making Guidance

Caltrans, which manages more than 50,000 miles of California's highway and freeway lanes, provides the ABC manual for California. The ABC Caltrans decision making guide consists of a questionnaire and a flowchart, Figures 5 and 6. The questionnaire is a qualitative evaluation of how ABC techniques could lessen or eliminate the effects of construction on the whole project. The questionnaire should be completed by the PE and the Technical Liaison Engineer (TLE), the district project engineer, and the project development team. To get the rating, all questions should be scored and then summed up. In the next step, through the flowchart, it is determined whether an ABC alternative should be developed or not.

Project Delivery: Design Impact Questionnaire

Given: Construction Impact Time (CIT), and Construction Completion Time (CCT)

Structure Type: *CIP, Precast, or other types of construction*

Questions	# of Items	No 1	2	3	4	Yes 5	Priority Low 1	High 2	Score
General	6								
1. Is this an emergency bridge replacement?									0
2. Is bridge on an emergency evacuation route or over railroad/waterway?									0
3. Is there a funding requirement to accelerated project delivery?									0
4. Is rapid recovery or completion of planned repair/replacement needed?									0
5. Is the bridge construction a critical path of the total project?									0
6. Are there significant economic benefits if construction is completed ahead of schedule?									0
								Individual Category Score =	0
Traffic	5								
7. Bridge carries high ADT or ADTT?									0
8. Bridge over existing high ADT or ADTT facility?									0
9. Bridge construction significantly impact traffic? (Does it have high user-delay costs?)									0
10. Can the bridge be closed during off-peak traffic periods?									0
11. Will the traffic control plan be significantly impacted?									0
								Individual Category Score =	0
Construction	3								
12. Do worker safety concerns at the site limit conventional methods? (e.g. adjacent power lines or over water?)									0
13. Is the bridge location subject to construction time restrictions due to adverse economic impact?									0
14. Does the site create problems for conventional construction methods? (e.g. falsework, concrete delivery, etc.?)									0
								Individual Category Score =	0
Utilities	2								
15. Are there existing utilities/Railroad that impact the construction window?									0
16. Are there existing utilities/Railroad that impact construction operations?									0
								Individual Category Score =	0
Environmental	4								
17. Is the site environmentally sensitive area requiring minimum disruption? (e.g. wetlands, air quality, and noise?)									0
18. Are there natural or endangered species at the bridge site? (Shorten construction window needed?)									0
19. Local weather limit the time of year for construction?									0
20. Is the bridge on or eligible for the National Register or Historic Places, or a designed landmark structure?									0
								Individual Category Score =	0
								Total Score =	**0**

ABC structure alternative is recommended for the APS if either:

i) Total score > 120

ii) Individual category score makes it eligible for ABC alternative

(PDT to decide which individual category(ies), if any, can activate the ABC recommendation)

Notes: 1) A high priority score of 2 is used for items of most importance.

2) 1.5 should be used for moderate priority

Figure 5. Caltrans ABC Decision Making Model

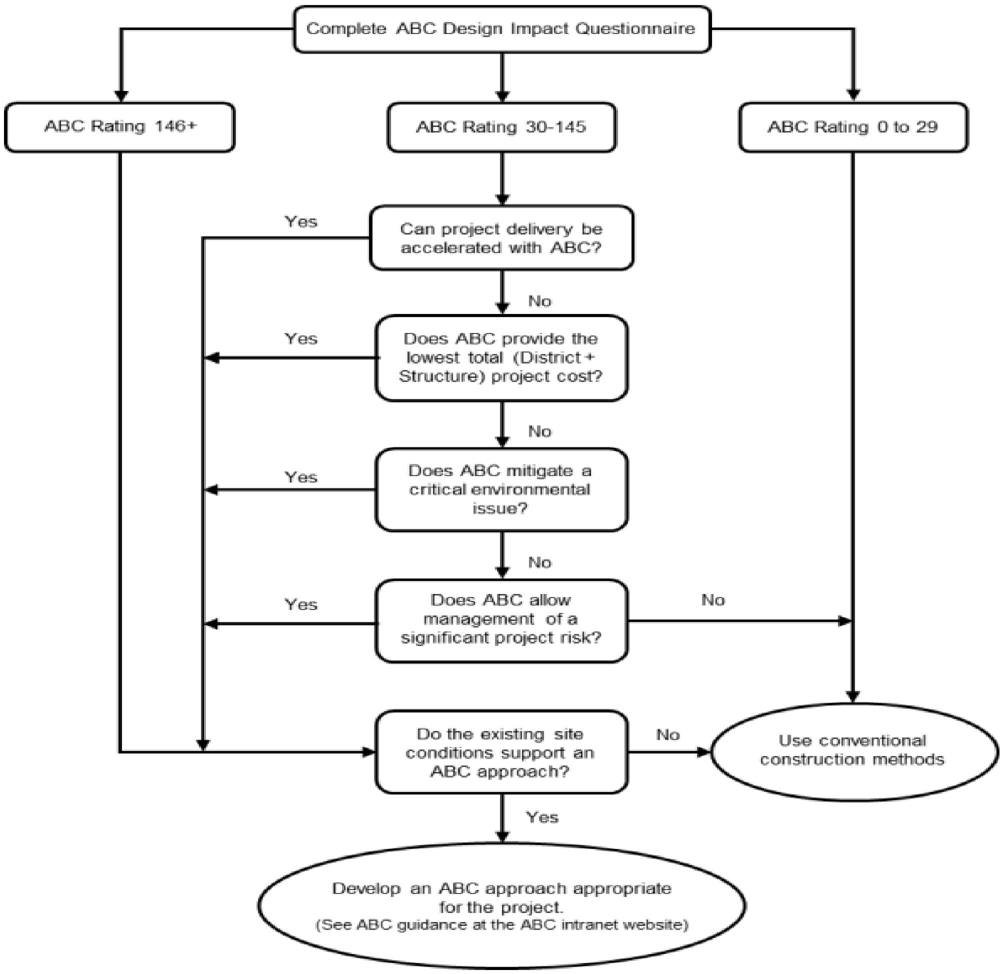


Figure 6. Caltrans ABC Decision Flowchart

Oregon DOT ABC Decision Making Guidance

A decision-making software tool for deciding whether to use ABC techniques was created based on the AHP process, which is used in the preliminary stages of the design process. The first step is to have a series of pairwise comparisons among the criteria. After collecting the data, the AHP method should be applied. Figure 7 shows the applied criteria direct cost, indirect cost, schedule constraints, site constraints, and customer service. Figure 8 introduces the mechanism of the ABC-AHP software.

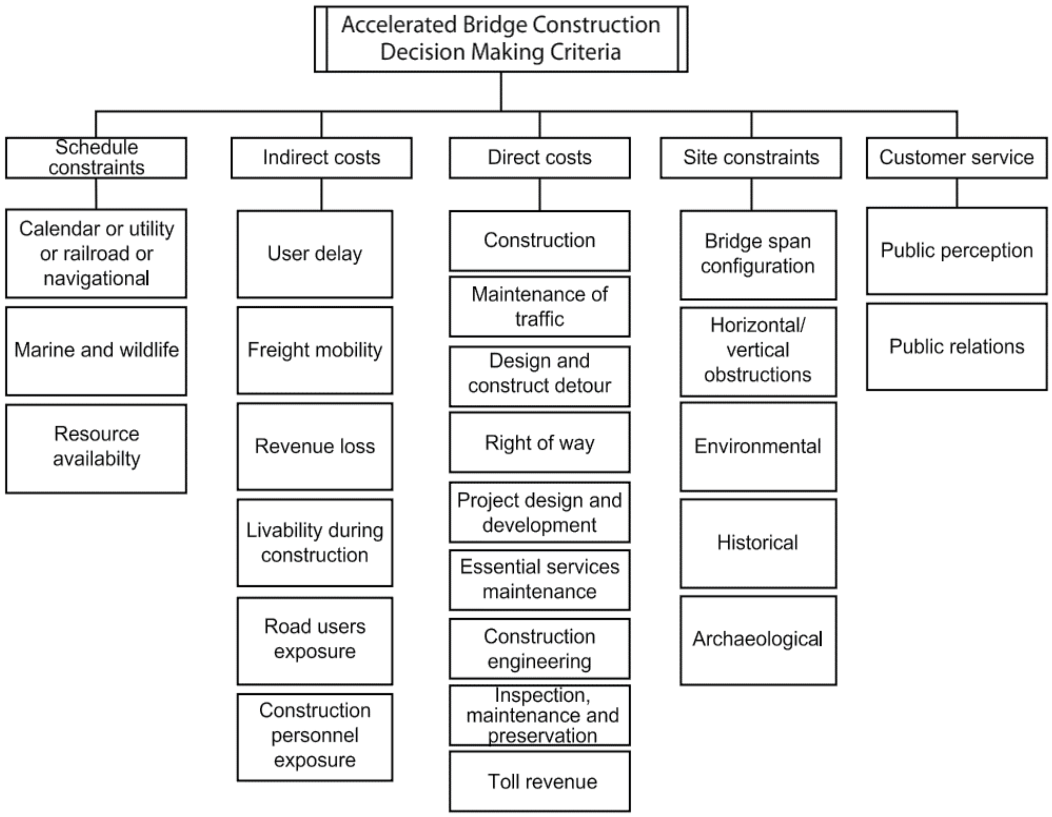


Figure 7. Hierarchy of ABC Decision Making Criteria

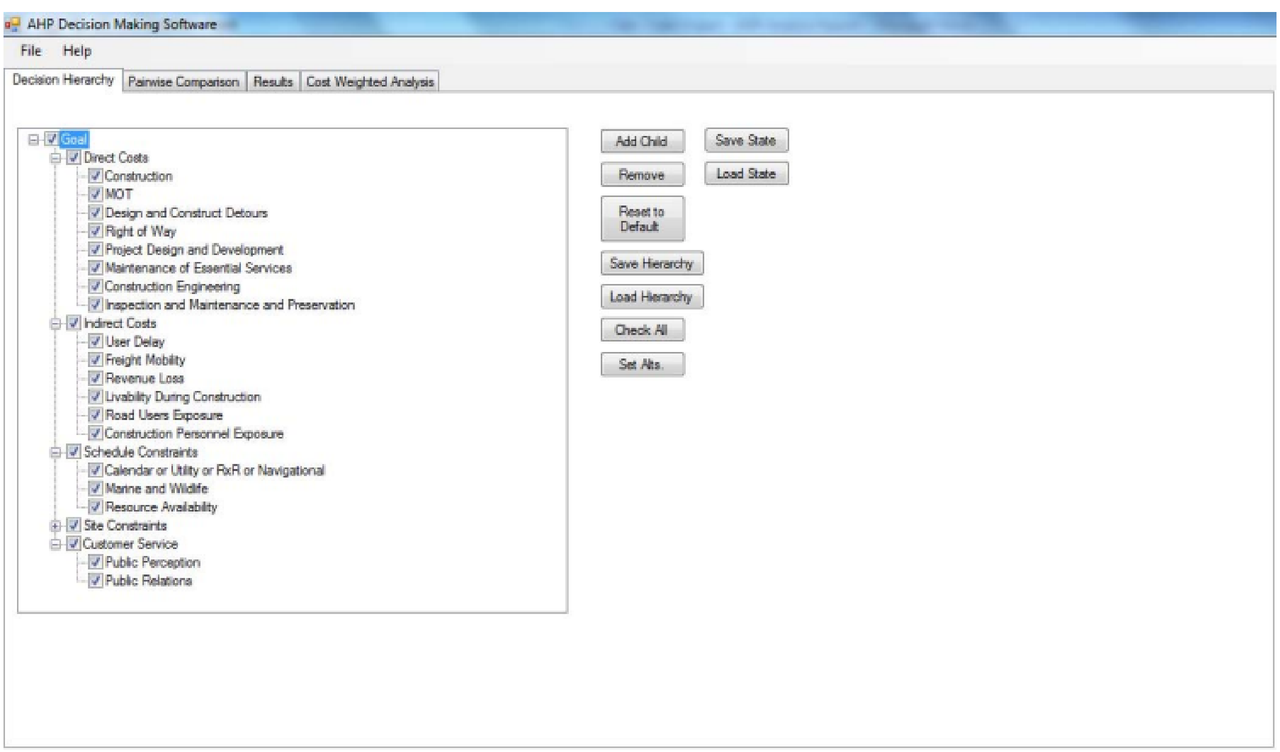


Figure 8. ABC-AHP Decision Tool, Microsoft .NET Framework

Texas DOT ABC Decision Making Guidance

Some DOTs have captured the framework of other states or FWHA and modified that to develop their specific practices and needs. TxDOT uses an ABC Decision flowchart and software launched by FWHA that addresses yes/no ABC to be considered in the construction approach, Figure 9.

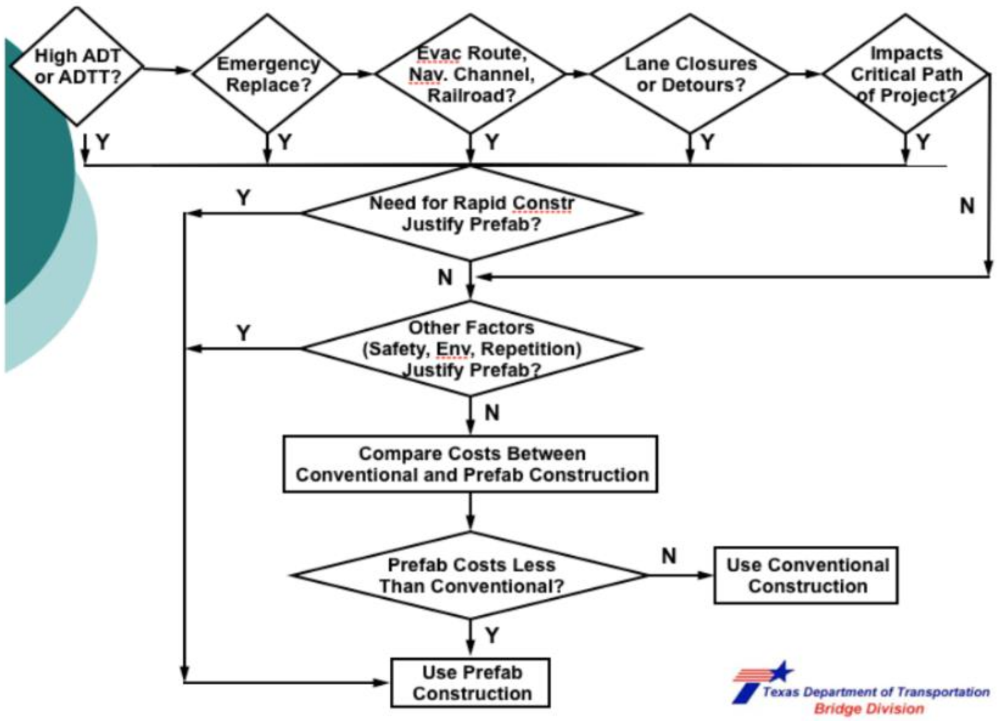


Figure 9. TxDOT ABC Decision Flowchart

Utah DOT ABC Decision Making Guidance

Utah DOT as one of the first states in the US that applied ABC techniques as an alternative to conventional bridge construction developed a framework consisting of several decision measures such as ADT, detour time, evacuation route, economy of scale, applicability to standards, worker safety, environmental issues, railroad impacts, and weather limitations. These criteria are entered within given ranges. For example, if the average daily traffic is 17,000, the input for ADT is considered 4 on a scale from 0 to 5. In the next step, individual inputs are weighted. The initial weighting factors, ultimate indicator, and cost considerations of the UDOT decision tool are displayed in Figure 10. This flowchart shown in Figure 11 is used to provide directions on the use of ABC for the project.

Utah Department of Transportation 4501 South 2700 West Salt Lake City, UT 84114	Project:	Hypothetical Bridge Project		
	By:	MPC	Checked:	BLB
	Date:	8/30/2010		8/30/2010
	Sheet No.	1	of	3
ABC Rating Procedure				**June 2010**

Enter values for each aspect of the project. Attach applicable supporting data.

Average Daily Traffic Combined on and under Enter 5 for Interstate Highways	5	0 1 2 3 4 5	No traffic impacts Less than 5000 5000 to 10000 10000 to 15000 15000 to 20000 More than 20000
Delay/Detour Time	2	0 1 2 3 4 5	No delays Less than 5 minutes 5-10 minutes 10-15 minutes 15-20 minutes More than 20 minutes
Bridge Classification	1	1 3 5	Normal Bridge Essential Bridge Critical Bridge
User Costs	4	0 1 2 3 4 5	No user costs Less than $10,000 $10,000 to $50,000 $50,000 to $75,000 $75,000 to $100,000 More than $100,000
Economy of Scale (total number of spans)	2	0 1 2 3	1 span 2 to 3 spans 4 to 5 spans More than 5 spans
Use of Typical Details	1	1 3 5	Complex geometry or unfavorable site conditions Some complexity, but favorable site conditions Simple geometry and favorable site conditions
Safety	5	1 2 3 4 5	Short duration impact with simple MOT scheme Short duration impact with multiple traffic shifts Normal duration impact with multiple traffic shifts Extended duration impact with multiple traffic shifts Extended duration impact with complex MOT scheme
Railroad Impacts	0	0 3 5	No railroad or minor railroad spur One mainline railroad track Multiple mainline railroad tracks

Utah Department of Transportation 4501 South 2700 West Salt Lake City, UT 84114	Project:	Hypothetical Bridge Project		
	By:	MPC	Checked:	BLB
	Date:	8/30/2010		8/30/2010
	Sheet No.	2	of	3
ABC Rating Procedure				**June 2010**

Note: Do not adjust weight factors without prior consultation with UDOT Structures Division Project Manager

ABC RATING SCORE FACTORS AND WEIGHTS

	Score	Weight Factor	Adjusted Score	Maximum Score	Adjusted Score
Average Daily Traffic	5	10	50	5	50
Delay/Detour Time	2	10	20	5	50
Bridge Classification	1	5	5	5	25
User Costs	4	10	40	5	50
Economy of Scale	2	3	6	3	9
Use of Typical Details	1	3	3	5	15
Safety	5	10	50	5	50
Railroad Impacts	0	5	0	5	25
		Total Score	174	Max. Score	274

ABC Rating Score: 64

Cost Considerations:

Calculate the following costs for use in determining the lowest total project cost

TOTAL PROJECT COST EVALUATION

	Alternative #1	Alternative #2
Construction Costs	$2,500,000	$3,000,000
User Costs	$1,000,000	$250,000
Total Project Cost	**$3,500,000**	**$3,250,000**

Figure 10. UDOT ABC Decision Making Matrix

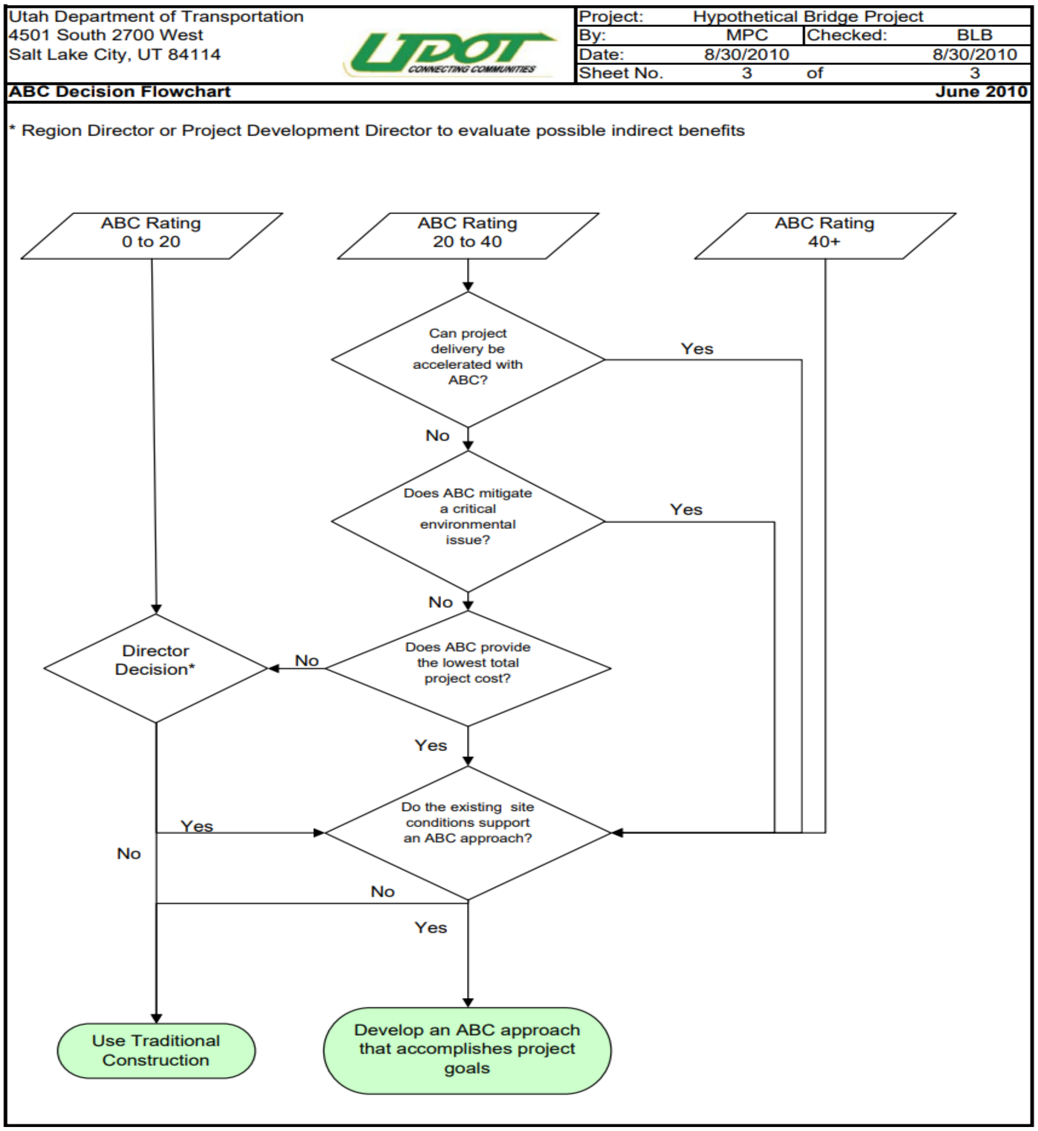


Figure 11. UDOT ABC Decision Flowchart

Washington DOT ABC Decision Making Guidance

Washington DOT uses a two-step method: 1) a multi-criteria decision matrix to calculate an ABC rating score for each project, and 2) a flowchart for further evaluation of the suitability of ABC for all projects (even for those with extremely low ABC rating scores). In other words, the questionnaire and flowchart determine how well-suited a project may be for ABC. In addition, questionnaires and flowcharts exist in both the decision matrix and the flowchart should be used together. To use the flowchart, the ABC score should be determined from the questionnaire. Ultimately, the flow chart will determine whether the ABC approach is recommended or not. Figures 12 and 13 are steps that may be used for each bridge project to determine whether it is recommended for ABC or not.

ABC DESIGN IMPACT QUESTIONNAIRE				
Project: Date: Completed by:		(R) Relevance Range 0 = NA 1 (Low) to 5 (High)	(P) Priority Rating 1 = Low 2 = Med 3 = High	(RxP) Score
Category	**Decision Making Question**			
Construction Time	Are there weather limitations for conventional construction?			
	Is there restricted construction time due to environmental schedules?			
	Is there restricted construction time due to economic impact?			
	Has the District expressed the desire to complete the bridge construction in one season?			
	Is the bridge construction on a critical path of the total project?			
Environmental	Does ABC avoid, minimize, or mitigate a critical environmental impact or sensitive environmental issue?			
User Costs and Delays	Does the bridge carry or is it over a route with high ADT and/or ADTT?			
	Would ABC significantly improve the traffic control/maintenance plan?			
	Are only short-term closures allowable?			
	Will conventional bridge construction cause a significant delay/detour time?			
	Will bridge construction have an adverse impact on the local economy?			
Site Conditions	Are there existing railroads that impact the construction window or construction activities?			
	Are there existing utilities that impact the construction window or construction activities?			
	Does the site create problems for conventional construction methods?			
	Is the bridge over a waterway?			
Risk Management	Does ABC improve worker safety?			
	Does ABC improve traveler safety?			
	Does ABC allow management of a particular risk? If yes, identify risk here:			
Other	Will repetition of elements allow for economy of scale?			
		ABC Rating		

Figure 12. WisDOT ABC Decision Matrix

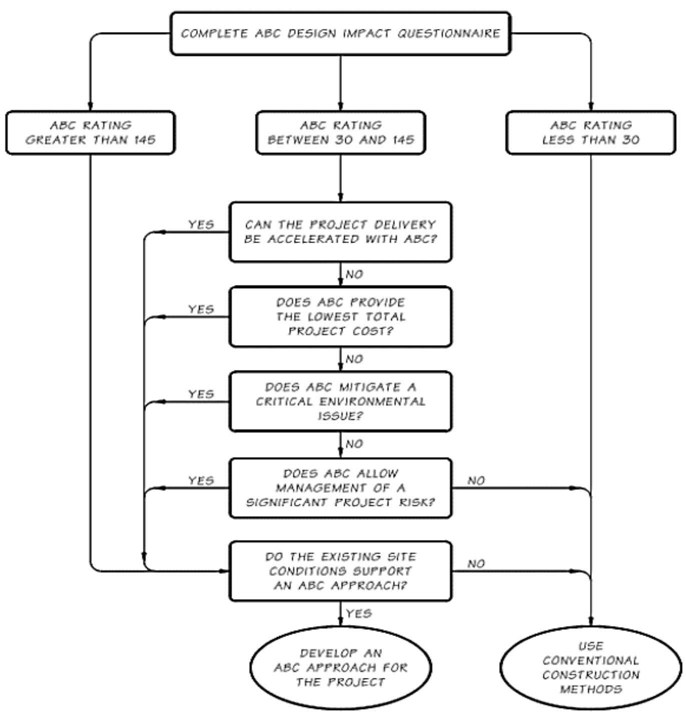


Figure 13. WisDOT ABC Decision Flowchart

Iowa DOT ABC Decision Making Guidance

Iowa DOT presented a two-stage decision-making process for ABC technique implementation for an individual project. The method then sends candidates with a high potential for achievable use of the ABC process, and through a simpler and more thorough decision-making process helps determine the use of the ABC strategy. The primary stage of Iowa DOT decision preparation includes processes similar to the UDOT documents which contain five principal inputs with defined weighting variables, as shown in Figure 14. The inputs work in this way, just like the inputs in the UDOT, and a given weight variable is used to assign relative importance to each input. At this point, the same mathematical operations are performed to obtain the ABC rating score.

The second stage involves the ABC-AHP Decision method previously discussed. However, IDOT completes the time-consuming process of using the ABC-AHP Decision method for those candidates that have already shown high scores for ABC.

Concept Measure Scores

Concept Measure	Score		
Average Annual Daily Traffic Combined value of 100% on and 25% under = 18,300	4	0 1 2 3 4 5	No traffic impacts Less than 5000 5000 to less than 10,000 10,000 to less than 15,000 15,000 to less than 20,000 20,000 or more
Out of Distance Travel Value in miles = 9	2	0 1 2 3 4 5	No detour Less than 5 5 to less than 10 10 to less than 15 15 to less than 20 20 or more
User Costs Value in $ = $76,585.50	4	0 1 2 3 4 5	No user costs Less than $10,000 $10,000 to less than $50,000 $50,000 to less than $75,000 $75,000 to less than $100,000 $100,000 or more
Economy of Scale Value is total number of spans = 3	1	0 1 2 3	1 span 2 or 3 spans 4 or 5 spans 6 spans or more

ABC Rating Score Factors and Weights

Concept Measure	Score	Weight Factor	Adjusted Score	Maximum Score	Adjusted Score
Average Annual Daily Traffic	4	10	40	5	50
Out of Distance Travel	2	10	20	5	50
User Costs	4	10	40	5	50
Economy of Scale	1	5	5	3	15
		Total Score	105	Max. Score	165
		Calculated ABC Rating Score	64		
		ABC Rating Score	64		

Figure 14. IDOT ABC Decision Matrix

Minnesota ABC Decision Making Guidance

The three-stage decision making guidance introduced by MnDOT. Stage 1, Figure 15, consists of a primary screening and rating based on a set of questions. The score for each of the criteria should be calculated, and then, normalized to a recommendation of Yes or No for further investigation. Bridges with a Yes should be considered for stage 2. Through stage 2, more subjective issues are covered. Complex traffic control schemes, long detours, extended duration, or significant user impacts due to bridge construction, culverts, and shoulders to maintain traffic on the existing route or the detour route are defined in Stage 2. This stage should be filled out and recorded by the District Project Manager, with assistance from the district bridge engineer, traffic engineer, resident engineer, and the bridge preliminary plans unit and regional bridge construction engineer. After a conclusion at stage 2, further consideration through stage 3, figure 16, is warranted. In this stage, alternative contracting methods which may help the ABC activities are also discussed. After thoroughly reviewing the questions, the district project manager, in conjunction with other appropriate experts and the bridge office should make a final decision. Example responses may include:

“A suitable detour is available, and the traffic demands at this site do not warrant the use of ABC.”

Or

“Roadway user impacts and safety make ABC a viable alternative.”

Or

“Use of a lateral slide (or other ABC alternative) will be further investigated.”

Stage 1 - Selection of Accelerated Bridge Construction Projects

MnDOT Decision Making Tool (DMT) v9 07/22/2013

Score computed using Bridge Management Data (5 Criteria):

Daily Vehicle Operating Costs - Dependent on Bridge Length			**30% Wt.**
"On Bridge" AADT and HCAADT Only	**Distribution**	**Score**	**Criteria**
Bridge Length Factor:	16.0%	0	No user costs
Total Length from 10'-100' = 1.0	16.7%	1	Less than $4,150
Total Length from 100'-300' = 1.2	16.9%	2	$4,150 to $9,250
Total Length from 300'-500' = 1.6	16.8%	3	$9,251 to $18,100
Total Length greater than 500' = 2.0	16.9%	4	$18,101 to $44,000
	16.7%	5	More than $44,000

User Cost Formula = (AADT x $0.31/mile + HCAADT x $0.64/mile) x Detour Length x Br Length Factor

Average Annual Daily Traffic (AADT)			**20% Wt.**
Combined "On and Under" Bridge	**Distribution**	**Score**	**Criteria**
	16.2%	0	Less than 2,400
	16.7%	1	2,401 to 6,650
	16.9%	2	6,651 to 13,500
	16.7%	3	13,501 to 31,000
	16.7%	4	31,001 to 75,000
	16.9%	5	More than 75,000

Heavy Commercial Average Annual Daily Traffic (HCAADT)			**10% Wt.**
Combined "On and Under" Bridge	**Distribution**	**Score**	**Criteria**
	16.0%	0	Less than 165
	16.7%	1	166 to 485
	16.7%	2	486 to 1,085
	16.9%	3	1,086 to 1,950
	16.7%	4	1,951 to 3,750
	16.9%	5	More than 3,750

Detour Length			**30% Wt.**
Detour Length on Similar Functional Class Rdwy	**Distribution**	**Score**	**Criteria**
	15.9%	0	No Detour
	9.8%	1	Less than 1 mile
	24.2%	2	1-2 miles
	17.9%	3	2-7 miles
	16.2%	4	7-14 miles
	15.9%	5	More than 14 miles

Traffic Density			**10% Wt.**
AADT “On” Bridge	**Distribution**	**Score**	**Criteria**
Vehicles per Day/Ft of Bridge Roadway Width	16.0%	0	Less than 35
	16.7%	1	36-78
	16.9%	2	79-138
	16.9%	3	139-240
	16.7%	4	241-470
	16.7%	5	More than 470

****Scores normalized to 100 point maximum. Bridges with score ≥ 60 selected for Stage 2. ****

Figure 15. MnDOT Decision Making Tool, First Stage

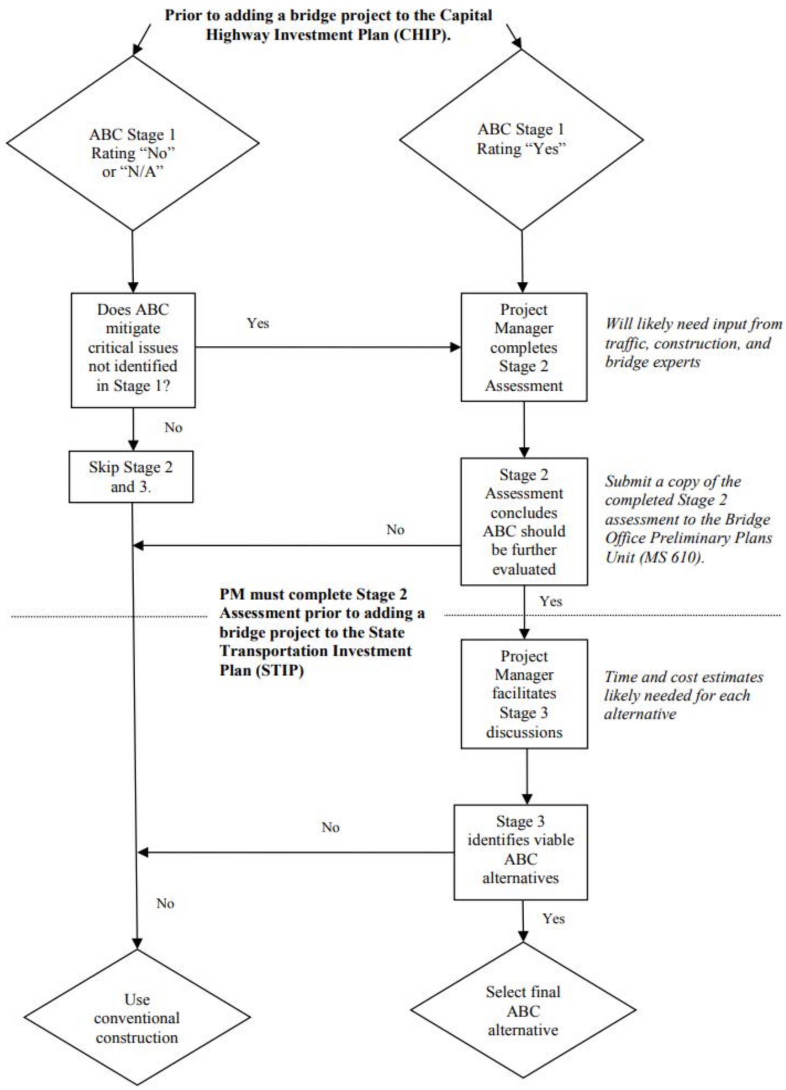
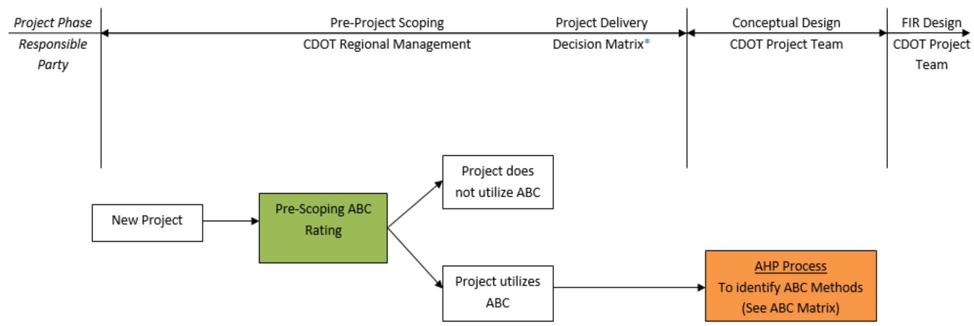


Figure 16. MnDOT Decision Making Flowchart

Colorado ABC Decision Making Guidance

This is a two-phase approach for ABC decision-making that combines both qualitative and quantitative decision making. The ABC Decision Flowchart applies the ABC rating score and then addresses Yes/No factors that are considered before making a final decision on the construction approach, Figure 17. Factors include project schedule, environmental concerns, total project cost, site conditions, and high-level indirect costs such as political capital, safety, or impacts on stakeholders. Together, the ABC Rating Procedure and ABC Decision Flowchart are used to make a final determination of the appropriate construction methods for each project. If ABC applies to the project the second step in the evaluation process is applying the AHP software.



**Contracting methods can work hand in hand with ABC delivery. Depending on the particular goals of the project and complexity of the ABC method some contractual tools maybe more beneficial than others. For each project, the Delivery Decision Matrix should be completed after the Pre-scoping ABC Rating form has been completed. Some contractual tools are listed below:*

Innovative Contracting Tools	A+B Contract Provision	Contract in Calendar Days	Fixed Completion Date Contract	Incentive-Disincentive Provision	Lane Rental Provision	Value Engineering Specification	Design Build Contract Delivery Method	CM/GC Contract Delivery Method

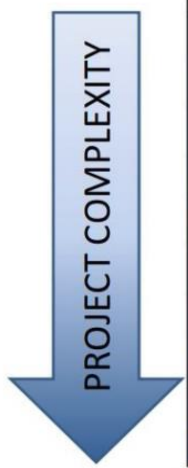
Figure 17. CDOT Decision Matrix Workflow

If the rating is between 0 and 20, the regional director should decide if ABC is needed or not. If the ABC rating is above 50, ABC should be used if it leads to a lower project cost. Finally, if it is between 20 and 50, further examination is needed by another set of questions. The ABC Matrix, Figure 18, provides suggestions for accelerated construction techniques that may be applied depending on the complexity of the project.

COLORADO Department of Transportation

Accelerated Bridge Construction Matrix

This matrix provides suggestions and previously utilized methods for accelerated bridge construction. It is not all inclusive nor intended to dictate any particular method.



Substructure	Approach, Embankment & Backfill	Superstructure	Superstructure Placement
	Pre-fabricated approach slabs	Adjacent Girders[2]	
	Flowfill	Precast Deck Panels (partial depth)[2]	
Pre-fabricated Pier Caps	Expanded Polystyrene (EPS) Geofoam	Pre-fabricated pedestrian bridge[2]	
Pre-fabricated columns		Pre-fabricated box culvert[2]	
Pre-fabricated foundations		Precast Deck Panels (full depth)[2]	
Geosynthetic Reinforced Soil (GRS) Abutment[1]		Modular Girder and Deck elements[2]	
Pre-fabricated wingwalls/backwalls[2]		Post-tensioned concrete through beams[2]	Heavy Lift Cranes
Continuous Flight Auger Piles (CFA)		Pre-fabricated truss or arch span[2]	Skid or Slide In
			Longitudinal Bridge Launch
			Self Propelled Modular Transport (SPMT)

[1] FHWA Every Day Counts Initiatives

[2] Prefabricated Bridge Elements and Systems (PBES)

ABC Costs *ABC method construction costs generally increase with project complexity. However, many methods of ABC may reduce the overall project cost, specifically where ABC methods can eliminate or reduce detours or traffic control.*

Figure 18. CDOT ABC Matrix

Arizona ABC Decision Making Guidance

ADOT uses a two-stage decision-making method, where a matrix questionnaire should be used as guidance in calculating the related scores. The ABC decision matrix rating score used in the ADOT guideline shown in Figure 19, varies from 0 to 100 identifying the viability of an individual project in considering ABC. The higher the score, the better for ABC. Once the score is calculated, the ABC decision flowchart should be followed, Figure 20.

ADOT ABC Decision Making Matrix

Category	Decision-Making Item	Possible Points	Points Allocated	Scoring Guidance
Railroad	Railroad/ Rail Transit under Bridge?	4		0 No track under bridge 2 Minor track under bridge 4 Major track(s) under bridge
Construction Impacts	ADT (Combined ADT on and under bridge)	10		1 ADT under 10,000 3 ADT 10,000 to 25,000 5 ADT 25,000 to 50,000 6 ADT 50,000 to 75,000 7 ADT 75,000 to 100,000 10 ADT 100,000+
	Allowable Lane Closure (Roadway on Bridge)	4		0 Long Term Lane Reduction Allowed During Construction 4 No Long Term Lane Reduction Allowed During Construction
	Allowable Lane Closure (Roadway under Bridge)	4		0 Long Term Lane Reduction Allowed During Construction 4 No Long Term Lane Reduction Allowed During Construction
	Allowable Bridge Closure (Roadway on Bridge)	6		0 Bridge Can closed - Viable Detour Available 6 Bridge Cannot be Closed
	Allowable Roadway Closure (Roadway under bridge)	4		0 Roadway under can be closed 4 Roadway under cannot be closed
	Permanent Align Shift w/ single phase an option	3		0 A permanent alignment shift is achievable to facilitate construction 3 A permanent alignment shift is achievable, but undesirable.
	Is phased construction with widening an option?	8		0 Widening will fit updated standards or future roadway improvements 6 Widening achievable, but undesireable due to unused investment 8 No alternatives available for widening
	Impact to Local Access (Local business access, Local resident access etc.)	6		0 Minor or no impact to access 3 Moderate impact to access 6 Major impact to access
Project Duration	Impacts Critical Path of the Total Project?	8		0 Minor or no impact to critical path of total project 4 Moderate impact to critical path of the total project 8 Major impact to critical path of the total project
	Restricted Construction Time (Environmental schedules, Economic Impact-e.g. local business access, special events, etc.)	10		0 No construction time restrictions 3 Minor construction time restrictions 6 Moderate construction time restrictions 10 Major construction time restrictions
	Seasonal Limitations for conventional construction?	4		0 No seasonal limitations for conventional construction 4 Seasonal limitations for conventional construction
Environment	Does ABC mitigate a critical environmental impact or sensitive environmental issue?	5		0 ABC does not mitigate an environmental issue 2 ABC mitigates a minor environmental issue 3 ABC mitigates several minor environmental issues 4 ABC mitigates a major environmental issue 5 ABC mitigates several major environmental issues
Safety	Safety (Workers Concerns)	8		0 Short duration impact 4 Normal duration impact 8 Extended duration impact
	Safety (Traveling Public Concerns)	8		0 Short duration impact 4 Normal duration impact 8 Extended duration impact
Economy of Scale	Bridge Economy of Scale (repetition of components in a bridge or bridges in a project) (Total spans=sum of all spans on all bridges on the project)	4		0 1 total span 1 2 total spans 2 3 total spans 3 4 total spans 4 5+ total spans
Risk Management	Does ABC allow management of a particular risk?	4		0-4 Use judgement to determine if risks can be managed through ABC that arent covered in other topics
	Total Possible	100		
		Sum of Points:	0	

Figure 19. ADOT ABC Decision Matrix

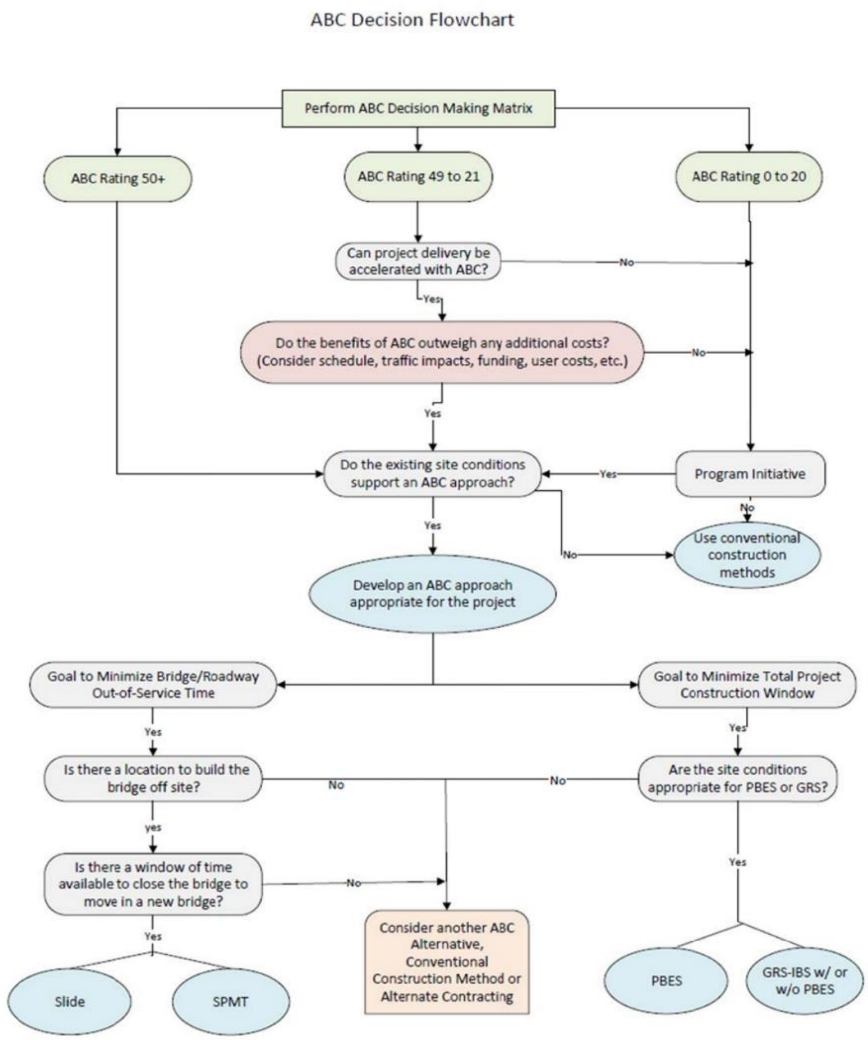


Figure 20. ADOT ABC Decision Flowchart

Wisconsin DOT ABC Decision Making Guidance

A decision process introduced by WisDOT is a two-stage process, where a decision matrix, Figure 21, should be sued to determine a total score, and then, the obtained score is used to follow the decision flowchart, Figure 22. The tool considers several types of criteria to help the right decision making. This method introduces specific ABC alternatives through the decision flowchart.

% Weight	Category	Decision-Making Item	Possible Points	Points Allocated	Scoring Guidance
17%	Disruptions (on/under Bridge)	**Railroad on Bridge?**	8		0 No railroad track on bridge 4 Minor railroad track on bridge 8 Major railroad track on bridge
		Railroad under Bridge?	3		0 No railroad track under bridge 1 Minor railroad track under bridge 3 Major railroad track(s) under Bridge
		Over Navigation Channel that needs to remain open?	6		0 No navigation channel that needs to remain open 3 Minor navigation channel that needs to remain open 6 Major navigation channel that needs to remain open
8%	Urgency	**Emergency Replacement?**	8		0 Not emergency replacement 4 Emergency replacement on minor roadway 8 Emergency replacement on major roadway
23%	User Costs and Delays	**ADT and/or ADTT** (Combined Construction Year ADT on and under bridge)	6		0 No traffic impacts 1 ADT under 10,000 2 ADT 10,000 to 25,000 3 ADT 25,000 to 50,000 4 ADT 50,000 to 75,000 5 ADT 75,000 to 100,000 6 ADT 100,000+
		Required Lane Closures/Detours? (Length of Delay to Traveling Public)	6		0 Delay 0-5 minutes 1 Delay 5-15 minutes 2 Delay 15-25 minutes 3 Delay 25-35 minutes 4 Delay 35-45 minutes 5 Delay 45-55 minutes 6 Delay 55+ minutes
		Are only Short Term Closures Allowable?	5		0 Alternatives available for staged construction 3 Alternatives available for staged construction, but undesirable 5 No alternatives available for staged construction
		Impact to Economy (Local business access, impact to manufacturing etc.)	6		0 Minor or no impact to economy 3 Moderate impact to economy 6 Major impact to economy
14%	Construction Time	**Impacts Critical Path of the Total Project?**	6		0 Minor or no impact to critical path of the total project 3 Moderate impact to critical path of the total project 6 Major impact to critical path of the total project
		Restricted Construction Time (Environmental schedules, Economic Impact – e.g. local business access, Holiday schedules, special events, etc.)	8		0 No construction time restrictions 3 Minor construction time restrictions 6 Moderate construction time restrictions 8 Major construction time restrictions
5%	Environment	**Does ABC mitigate a critical environmental impact or sensitive environmental issue?**	5		0 ABC does not mitigate an environmental issue 2 ABC mitigates a minor environmental issue 3 ABC mitigates several minor environmental issues 4 ABC mitigates a major environmental issue 5 ABC mitigates several major environmental issues
3%	Cost	**Compare *Comprehensive* Construction Costs** (Compare conventional vs. prefabrication)	3		0 ABC costs are 25%+ higher than conventional costs 1 ABC costs are 1% to 25% higher than conventional costs 2 ABC costs are equal to conventional costs 3 ABC costs are lower than conventional costs
18%	Risk Management	**Does ABC allow management of a particular risk?**	6		0 - 6 Use judgment to determine if risks can be managed through ABC that aren't covered in other topics
		Safety (Worker Concerns)	6		0 Short duration impact with TMP Type 1 3 Normal duration impact with TMP Type 2 6 Extended duration impact with TMP Type 3-4
		Safety (Traveling Public Concerns)	6		0 Short duration impact with TMP Type 1 3 Normal duration impact with TMP Type 2 6 Extended duration impact with TMP Type 3-4
12%	Other	**Economy of Scale** (repetition of components in a bridge or bridges in a project) (Total spans = sum of all spans on all bridges on the project)	5		0 1 total span 1 2 total spans 2 3 total spans 3 4 total spans 4 5 total spans 5 6+ total spans
		Weather Limitations for conventional construction?	2		0 No weather limitations for conventional construction 1 Moderate limitations for conventional construction 2 Severe limitations for conventional construction
		Use of Typical Standard Details (Complexity)	5		0 No typical standard details will be used 3 Some typical standard details will be used 5 All typical standard details will be used
			Sum of Points:	0	(100 Possible Points)

Figure 21. WisDOT ABC Decision Matrix

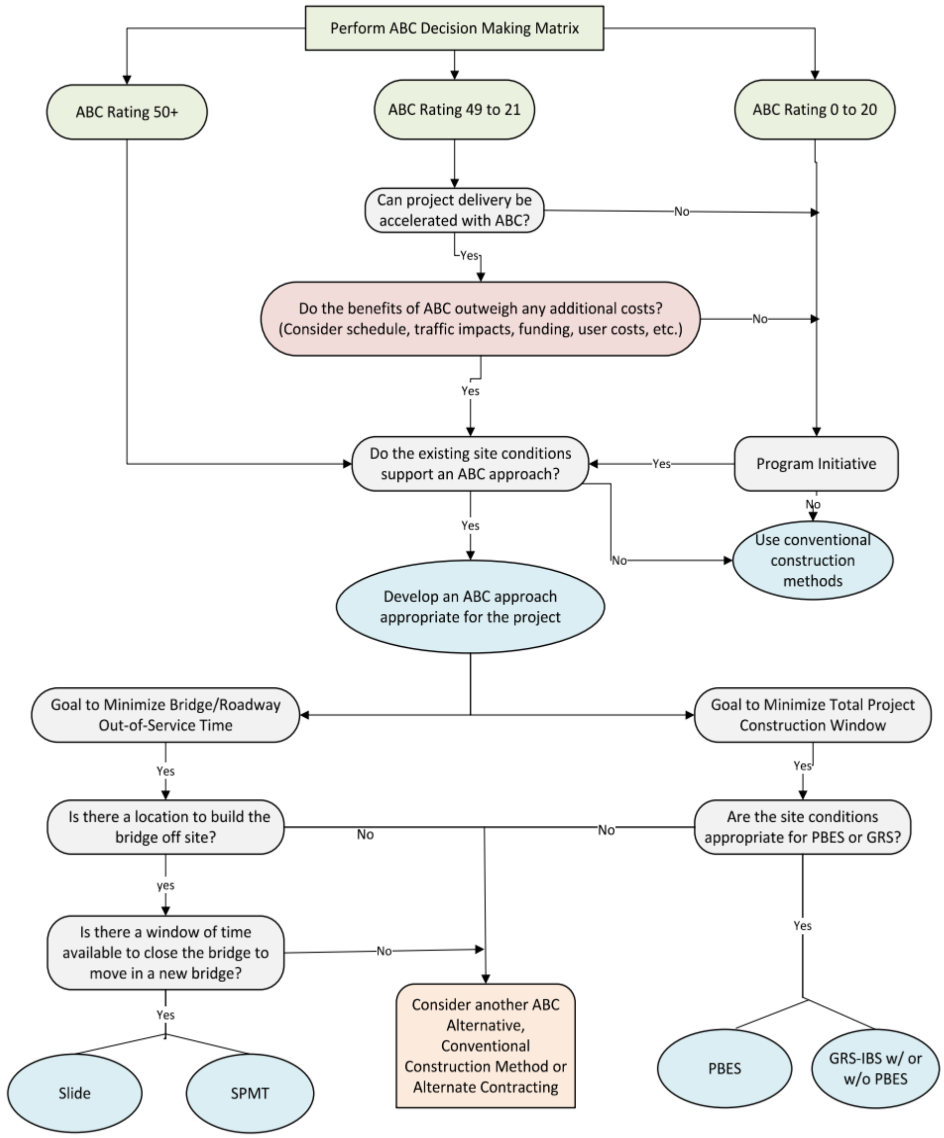


Figure 22. WisDOT ABC Decision Flowchart

South Dakota DOT ABC Decision Making Guidance

The process of the ABC decision tool for SDDOT consists of three existing tools developed by other agencies: 1) the ABC-AHP (Analytical Hierarchy Process) Decision Tool published by FHWA (FHWA, 2012), 2) the ABC decision-making process used by UDOT (UDOT, 2010), and 3) the ABC decision-making process used by Iowa DOT (Iowa DOT, 2012). For SDDOT, the decision-making tool is a two-stage process. In the seconds, more detailed computations are considered. The layout and orientation of the two stages of the decision-making process are displayed in Figures 23 and 24.

Project No.	PCN 02AB		
Inputs			
Average Daily Truck Traffic	51		
Mileage Rate	37.5		
Average Annual Daily Traffic (AADT)	1	0	No traffic impacts
Combined value of 100% on and 25% under		1	Less than 5000
structure:		2	5000 to less than 10000
746		3	10000 to less than 15000
		4	15000 to less than 20000
		5	20000 or more
Out of Distance Travel (OODT)	1	0	No detour
Detour distance in miles*:		1	Less than 5
0.25		2	5 to less than 10
*Note: OODT should not be 0 if DRUC formula		3	10 to less than 15
is to be used, as DRUC will then be $0.		4	15 to less than 20
		5	20 or more
Daily Road User Costs (DRUC)	1	0	No user costs
(AADT+2*ADTT)(OODT)(Mileage Rate)=		1	Less than $100
$79.50		2	$100 to less than $500
*Note: If OODT is 0, SDSU DRUC Tool can be used		3	$500 to less than $750
to estimate DRUC for Stage 1.		4	$750 to less than $1000
		5	$1000 or more
Economy of Scale (EOS)	2	0	1 span
Total number of repeatable of spans:		1	2 or 3 spans
4		2	4 or 5 spans
		3	6 spans or more

ABC Rating Score Factors and Weights

	Score	Factor	Adjusted Score	Max. Score	Adjusted Score
AADT	1	10	10	5	50
OODT	1	10	10	5	50
DRUC	1	10	10	5	50
EOS	2	10	20	3	30
		Total Score:	50	Max. Score:	180
		ABC Rating Score:		**28**	

Project No.			
Inputs			
Direct Costs	3	0	$100000 or more additional cost
Input approximate costs for superstructure,		1	$75000 to less than $100000 additional cost
substructure, and/or placement:		2	$50000 to less than $75000 additional cost
$32,000		3	$25000 to less than $50000 additional cost
		4	$0 to less than $25000 additional cost
		5	Lesser cost than conventional
Indirect Costs	2	0	No user costs
Transfer info from Daily Road User Cost tool:		1	Less than $100
$120		2	$100 to less than $500
.		3	$500 to less than $750
		4	$750 to less than $1000
		5	$1000 or more
Non-ABC Conventional Costs	3	0	$0 to less than $50/SF of bridge
Transfer info from SDDOT cost data per sq. ft.		1	$50 to less than $75/SF of bridge
of bridge:		2	$75 to less than $100/SF of bridge
$112		3	$100 to less than $125/SF of bridge
		4	$125 to less than $150/SF of bridge
		5	$150 or more/SF of bridge
Schedule Constraints	1	0	No schedule constraints
i.e. emergency repairs, seasonal deadlines, etc.		1	Slight schedule constraints
		2	Moderate schedule constraints
		3	Substantial schedule constraints
Site Constraints	1	0	No site constraints
i.e. critical path, geographic constraints, etc.		1	Slight site constraints
		2	Moderate site constraints
		3	Substantial site constraints

ABC Rating Score Factors and Weights

	Score	Weight Factor	Adjusted Score	Max. Score	Adjusted Score
DC	3	10	30	5	50
IC	2	10	20	5	50
NCC	3	10	30	5	50
SchC	1	10	10	3	30
SC	1	10	10	3	30
		Total Score:	100	Max. Score:	210
		ABC Rating Score:		**48**	

Figure 23. SDDOT ABC Decision Matrix

After the criteria have been selected and entered into the evaluation tool, the assigned score for each input is multiplied by each predetermined weighting factor to obtain the project adjusted score. The maximum adjusted scores are summed as are the project adjusted scores, and the total project adjusted score divided by the maximum adjusted score is the output indicator for the project being analyzed by the evaluation tool.

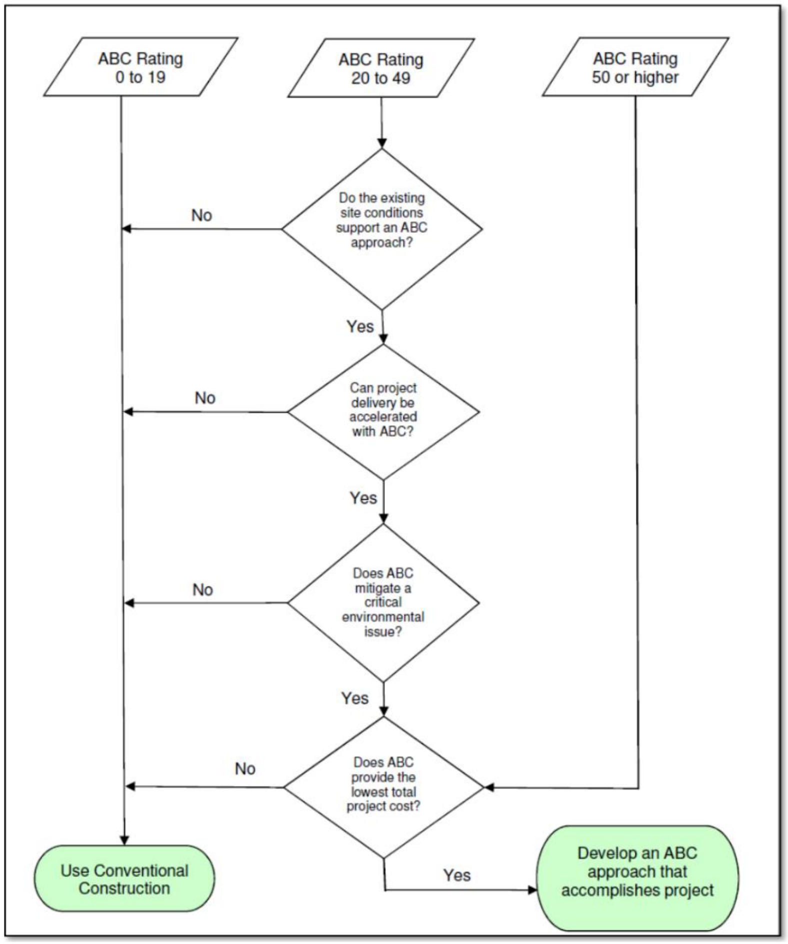


Figure 24. SDDOT ABC Decision Flowchart

Connecticut DOT ABC Decision Making Guidance

Connecticut DOT (CTDOT) used a middle-ground approach to develop a spreadsheet-based tool entitled "ABC Decision Matrix," Figure 25, that uses the SAW method to calculate ABC rating scores for different projects. Adopting some aspects of the Utah method and building on the methods used by other states, the ABC Decision Matrix is a relatively simple and well-received tool based on the impacts of ABC on road users and the environment that accounts for total project costs but offsets ABC costs with the costs that can be reduced or eliminated with ABC. The CTDOT ABC Decision Matrix is a spreadsheet tool that evaluates the suitability of adopting ABC techniques by calculating an ABC rating score between 0 to 100 for each bridge construction project. The tool uses the SAW method for calculating the ABC rating scores by considering ten criteria (i.e., average daily traffic, user impact reduction, bridge location, use of typical details, work zone geometry, site conditions, railroad impacts, cost analysis, environmental/water handling, and waterway limitations). Evaluation of each criterion is used based on a score of 0 to 5. If the calculated final ABC rating score is greater than 60, the use of ABC techniques will be recommended. When the final ABC score is smaller than 50, conventional construction methods will be preferred. If the final score is found to be between 50-60, further evaluation will be recommended for considering ABC. The CTDOT method uses a multi-criterion, yet simple-enough, process that makes it appropriate and applicable to different bridge construction projects.

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CTDOT ABC Decision Making Process Oct-17

Site Information

Project Description:

Prop. ABC Method:

Conventional Construction Method:

Roadway on Bridge

Average Daily Traffic		vehicles per day
Conventional Construction		
Delay Time (Per Delay Time Sheets)		minutes
Construction Impact Duration		Days
Aggregate Impact Time	0	Person Days
ABC		
Delay Time (Per Delay Time Sheets)		minutes
Construction Impact Duration		Days
Aggregate Impact Time	0	Person Days

Roadway Below Bridge

Average Daily Traffic		vehicles per day
Conventional Construction		
Delay Time (Per Delay Time Sheets)		minutes
Construction Impact Duration		Days
Aggregate Impact Time	0	Person Days
ABC		
Delay Time (Per Delay Time Sheets)		minutes
Construction Impact Duration		Days
Aggregate Impact Time	0	Person Days

Percent Reduction in Aggregate Impact Time

Conventional Construction		
Total Aggregate Impact Time	0	Person Days
ABC		
Total Aggregate Impact Time	0	Person Days
User Impact Reduction	#DIV/0!	

Note: Negative value indicated that ABC has more impact

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CTDOT ABC Decision Making Process Oct-17

Preliminary Cost Evaluation

Estimated conventional construction project cost =		
Required Bridge		
Overbuild	$0	
Total conventional bridge cost	$0	
Estimated CE&I Costs per month		
Field office monthly cost		
CE&I staff monthly cost (field plus main office)		
Total CE&I Monthly Cost =	$0	

Notes: Small field office = $xxx per month
Medium office = $xxx per month
Large office = $xxx per month
Staff = $20,000 per person per month

Net time savings for ABC =		months
Estimated Percent Premium for ABC =		
MPT savings with ABC		
Things that you can eliminate from conventional construction by using ABC		
Overbuild for staging	$0	
Temporary bridge	$0	
Temporary signal	$0	
Other	$0	
Total MPT Savings with ABC	$0	

Cost analysis

Premium for ABC =	$0
CEI Cost Savings =	$0
MPT savings with ABC =	$0
Net cost change for ABC =	$0
ABC is less expensive than conventional	
Net percentage of conventional cost =	#DIV/0!

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CTDOT ABC Decision Making Process Oct-17

ABC Rating procedure

Enter values for each aspect of the project. Attach back-up data if applicable

Average Daily Traffic		0	No traffic impacts
Combined traffic on and under		1	Less than 10000
		2	10000 to 40000
		3	40000 to 70000
		4	70000 to 100000
		5	More than 100000
User Impact Reduction	#DIV/0!	0	Zero
Calculated by spreadsheet		1	1% to 20%
		2	21% to 40%
		3	41% to 60%
		4	61% to 80%
		5	81% to 100%
Bridge Location		0	Rural Bridge away from town center
Stakeholder Impact		1	Rural bridge near town center
		2	Suburban bridge away from town center
		3	Suburban bridge near major traffic generators
		4	Urban Bridge near major traffic generators
		5	Urban Bridge near emergency services
Use of Typical Details		1	Complex and unfavorable geometry
		2	Curved and skewed bridges
		3	Curved bridges
		4	Skewed Bridges
		5	Simple geometry well suited for typical details
Work Zone Geometry		1	Short duration project with good geometry & flow
Detour quality and/or		2	Short duration project with moderate geometry & flow
MPT Quality		3	Average project duration with average geometry & flow
		4	Long duration project with moderate geometry & flow
		5	Long duration project with complex geometry & flow
Site Conditions		0	significant limitations on work
Utilities/ROW/Env. Compliance		1	moderate construction limitations for portions of the work
		2	
		3	minor construction limitations
		4	
		5	No Restrictions
Railroad Impacts		0	No Railroad (entry of 0 = not considered in score)
		1	Freight Siding (Less than 1 train per week)
		2	Light Freight (1 Train per week to 1 Train per day)
		3	Heavy Freight (More than 1 Train per day)
		4	Commuter rail
		5	Electrified Commuter Rail

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Cost Analysis		0	>30%
Factor =	#DIV/0!	1	20% < Factor < 30%
Net percentage of conventional cos		2	10% < Factor < 20%
Negative value means that ABC ha		3	5% < Factor < 10%
less net cost when compared to		4	0% < Factor < 5%
conventional construction		5	Factor <0%
Envir. /Water Handling		0	No Restrictions (entry of 0 = not considered in score)
		1	minor construction limitations
		2	
		3	moderate construction limitations for portions of the work
		4	
		5	significant limitations on work
Waterway Limitations		0	No impact (entry of 0 = not considered in score)
		1	Minor impacts
		2	
		3	Seasonal recreational impacts
		4	Significant recreational impacts
		5	Significant commercial impacts

ABC Rating

	Score	Weight Factor	Adjusted Score	Maximum Score	Adjusted Score
Average Daily Traffic	0	10	0	5	50
User Impact Reduction	#DIV/0!	30	#DIV/0!	5	150
Bridge Location	0	5	0	5	25
Use of Typical Details	0	5	0	5	25
Work Zone Geometry	0	8	0	5	40
Site Conditions	0	5	0	5	25
Railroad Impacts	0	5	0	0	0
Cost Analysis	0	30	0	5	150
Envir. /Water Handling	0	5	0	0	0
Waterway Limitations	0	5	0	0	0
		Total Score	#DIV/0!	Max. Score	465

ABC Rating #DIV/0!

ABC Rating Scale	
60-100	Use ABC
50-60	Consider ABC
0-50	Do not use ABC

Note: Weight factors determined by CTDOT. Do not adjust factors without prior consultation.

Figure 25. CTDOT ABC Decision Tool

ABC Decision Making Tools Conclusion

The outcome of ABC rating tools is to generate a comparative rating for the ABC activities' decision-making. Many different methodologies for ABC project decision-making have been used by state DOTs. Towards this, the FHWA had a qualitative decision-making tool like PBES where answering questions about specific project characteristics was the baseline of decision-making process. Although this framework was a good starting point for ABC's decision-making, it did not help with the economic impact of selecting ABC over traditional methods. Later, another approach was presented for ABC evaluation over traditional methods. This method incorporated some major factors extracted through observation. Then using the simple additive weighted method, it was weighted by experts. Examples of such methods are the ones used by WisDOT, MnDOT, and ADOT. The third method is based on AHP introduced in December 2009. Oregon Department of Transportation (ODOT) working with several other states (California, Iowa, Minnesota, Montana, Texas, Utah, and Washington) launched an FHWA-sponsored AHP-based tool for identifying whether ABC should be applied to a specific project or not. From the brainstorming work of ABC decision-making tools, it is determined that:

1) Factors that were used in decision-making were a combination of quantitative and qualitative data.
2) The weight of factors in some methods is unchangeable. At the same time, in many cases, the indirect cost has an interactive relationship with other factors.

3) They lack the consideration of factor dependence or risk overlapping scoring.
4) The hierarchies of the ABC-AHP can only be in the range of 1 to 9 and some parts no real data can be inputted in this tool. This makes the tool inflexible.
5) The grading of some models relies on decision makers to provide interpretation. Because the comparisons are performed by personal or subjective judgments, some degree of inconsistency may occur.
6) The individual factors were pre-weighted within the tool and cannot be revised.
7) The potential ABC types and conventional construction were not considered to identify if more than one ABC technique is feasible and compared to the conventional construction method for each.

Road Safety Review

According to the Fatality Analysis Reporting System (FARS), more than 500 fatalities in motor vehicle traffic crashes occurred in work zones in 2010. FHWA defined Safety as a significant reduction in traffic fatalities and serious injuries on all public roads (FHWA, 2012). Based on a review of the literature, this criterion is often indirectly calculated, with functional deficiencies typically linked to traffic safety (clear deck width, vertical and horizontal clearance). In the NCDOT P5.0, safety is identified by crash information for a given highway segment. Crash density (20%), crash severity (20%), critical crash rate (20%), and safety benefits (40%) are used in the prioritization of roadway projects. In addition, the crash frequency and severity index are used in the prioritization of highway intersection projects (NCDOT, 2018). Many studies indicated that the zone crash rates are likely to increase up to 70 percent when there is a work zone in place. On the other hand, worker safety concerns at the site which limit conventional methods, e.g., working adjacent to power lines. In general, construction safety increases with reduced exposure time during construction. Construction site safety will be increased due to the introduction of ABC methods (limit traffic interference to a period of two weeks or less). In addition, minimizing the need for future maintenance will reduce traffic flow, congestion, and crashes.

Safety also contributes to driver behavior at highway construction or maintenance zones. Statistics show that many crashes in work zone areas occurred in lane closure areas where there were mixed drivers, workers, and barriers. In Michigan, more than 40% of work zone crashes occurred in lane closure areas (Michigan State Police, 1999). several studies introduced Geometric rating (roadway width or horizontal clearance), Vertical clearances, Functional obsolescence, Inventory or operating rating, Crash density, Crash severity, and Critical crash rate typically utilized measures for safety (NCHRP Report 530 (Patidar et al., 2007), Indiana DOT (Sinha et al., 2009), North Carolina DOT (NCDOT, 2018))

Social Equity and Environmental Justice Review

ABC activities are generally safer than conventional construction in terms of environmental issues because much of the construction can be done offsite. Quality can be mitigated because the construction is often completed in a more controlled situation. In this regard, ABC decision making needs new criteria to be added to the tool to incorporate the benefits of ABC in improving social equity and environmental justice in community groups affected by the bridge project. Examples of social and environmental data that can potentially be used for this purpose are as follows:

Social data: Income, Population density, Elderly population density, Land Use, and Crime rate.

Environmental data: Air temperature, air quality, normalized difference vegetation index (NDVI), and tree canopy.
Environmentally vulnerable areas, like urban areas where air and water quality and noise pollution are challenges, put a limit on the amount of construction work that can be done on-site, or the time work in a season. Offsite prefabrication and rapid onsite installation can be done with limited impact on the site. Many researchers combined rainfall intensity with population density for risk analysis. Some other studies added more social indicators to their methodology, however, there is still a limited number of studies that explored the integration of temperature, NDVI, traffic load, and road accessibility with flood risk factors namely rainfall intensity. Table 3 summarizes the common and different decision criteria used by state DOTs tools. Tables 4 and 5 represent some of the recent MCDA flood-based studies that considered flooding risk integrated with social equity and environmental justice. ABC provides the contractor with more flexibility when environmental restrictions are an issue. In terms of social factors, social and cultural heterogeneity changes in different urban communities, and then, many various methodologies can be applied to assess social vulnerability at each scale and system.

Table 3. Decision Criteria of Qualitative decision-making Tools

State DOT	**Air Quality**	**Noise pollution**	**Endangered species**	**Historical places**	**Natural recourse e.g., wetlands**	**Weather e.g., humidity**
California	*	*	*	*	*	
FHWA	*	*	*	*	*	
Washington			*	*		*
Oregon	*	*	*	*	*	*
Connecticut				*	Occasionally[1]	Occasionally[2]
Virginia	*	*				

Table 4. MCDA flood-based studies considered flooding risk integrated with social equity and environmental justice

Reference	**Indicators**	**Environmental Criteria**	**Social Equity Criteria**	**Results**
Mondoro et al., 2018	DEM, Land cover	Potential for environmental pollution	Potential for social inequities in access to flood protection measures, social vulnerability	Developed a methodology for MCDA-based flood risk management that considers social equity, environmental justice, and equipment durability due to cavitation for bridge adaptation under climate changes
Karageorgou and Thaler, 2019	DEM, Land cover, Bridge network	Impact on ecosystems	Potential for the displacement of vulnerable populations, distribution of benefits	Results of MCDA study used to inform the development of flood risk management plan

[1] Generally, in-water work is required
[2] If construction seasons control construction method

Reference	Indicators	Environmental Criteria	Social Equity Criteria	Results
			and costs across different communities	
Lam et al., 2020	DEM, Slope, Land cover, Bridge network	Impact on vulnerable populations, such as low-income households and elderly residents	N/A	Identified flood risk reduction measures that balance environmental sustainability, economic viability, and equipment durability due to cavitation
Rezaei et al., 2020	DEM, Slope, Land cover, Bridge network, Socioeconomic indicators	Potential for environmental pollution, impact on ecosystems	Potential for social inequities in access to flood protection measures, social vulnerability	Identified flood management strategies that promote social equity, environmental sustainability, and equipment durability due to cavitation
Chen et al., 2021	DEM, Slope, Bridge network	Impact on ecosystems, potential for environmental pollution	Potential for social inequities in access to flood protection measures, social vulnerability	Developed a framework for evaluating flood risk management options that integrate environmental justice, social equity considerations, and equipment durability due to cavitation

Table 5. MCDA studies considered social equity

Reference	Land use	Population density	Gender	People age	Employment rate	Income rate	Building type	Building density
Messener & Meyer, 2005		*	*	*				
Turner et al., 2003	*	*						
Zou et al., 2013	*	*						
Fernandez et al., 2016		*	*	*	*	*	*	*
Tanguay et al., 2020	*	*	*	*	*	*		

Task 2 – Decision Criteria

The existing CTDOT tool includes multiple decision criteria such as traffic conditions, user impact reduction (time), site conditions, and cost. However, the decision criteria can be expanded to incorporate the contribution (i.e., benefits) of ABC to important problems such as roadway safety, social equity, and environmental justice. This agrees with the FHWA's definition of ABC's intrinsic benefits which include improvements in safety, social, and environmental impacts (FHWA, 2021).

Task 2.1 – Road Safety Criterion

To incorporate the benefits of ABC in improving the work-zone safety for the traveling public, the tool should consider the reduction in the risk of crashes in the corridor where the bridge will be constructed (or replaced). This will be addressed by adding a criterion based on crash cost analysis to calculate the contribution of safety to the benefit-cost ratio of ABC as compared to conventional methods. The proposed safety criterion will quantitatively evaluate the benefits of ABC methods in improving work zone safety compared to the safety conditions when using conventional bridge construction methods. Benefits from ABC on roadway safety can be evaluated based on past observations of crash density and severity (e.g., crash data from the National Highway Traffic Safety Administration- NHTSA) and future crash predictions (e.g., using statistical or machine learning methods). These methods have been investigated in a recent ABC-UTC project entitled "Work Zone Safety Analysis, Investigating Benefits from Accelerated Bridge Construction (ABC) on Roadway Safety [ABC-UTC-2016-C3-FIU03]" and a Ph.D. dissertation by Mokhtarimousavi (2020) at FIU. The road safety criteria in this project will be based on the findings of Mokhtarimousavi (2020) and the ABC-UTC project mentioned in this project. In addition, a limited survey will be conducted from some state DOTs to identify the existing crash data types at different state DOTs. The survey aims to gather valuable information on Crash Data Types, Crash Cost Values, and Contributing Factors used by state DOTs. This information will be used to improve the ABC Decision Matrix tool to make it more comprehensive, less subjective, and more flexible to be used by different state DOTs. The survey seeks to identify the methodologies used by state DOTs to estimate crash cost values and identify contributing factors. Specifically, it will gather information on the specific crash data types collected by state DOTs, the injury scales used for crash severity, the crash cost values development methods, and the frequency of updating crash data records. The results of the survey will be used to inform the type of crash data used in the improved tool, thereby increasing the widespread use of the improved ABC tool by different state DOTs.

Benefit-cost Analysis of ABC Implementation

Roadway safety benefit-cost analysis plays a crucial role in enhancing traffic safety in transportation/bridge construction work zones. Timely completion of construction projects is crucial for all stakeholders, as delays can increase costs and cause inconvenience to the public. Traditional methodologies for planning and scheduling infrastructure projects can cause delays, but new techniques like ABC have been developed to reduce construction time. To assess the benefits of safety improvements resulting from ABC implementation, crash costs can be used to quantify the reduction in impacts of crashes. Within this study's scope, the computation process of Work Zone Road User Costs (WZ RUC) is based on the assessment of monetized components of crash costs resulting from work zone activities at bridge locations (Oyedele et al., 2019).

Safety Benefits

The safety benefits of the ABC method can be calculated by determining the cost savings resulting from reducing the construction duration and the associated crashes, compared to the additional expenses associated with implementing the ABC method. Crash costs allow for a standardized way to compare the benefits and costs of different highway safety improvement projects. This is because they provide a common metric that can be used to estimate the costs associated with crashes, which can then be used to evaluate the potential benefits of safety improvement projects. This calculation is represented by Equation (1) and is used to demonstrate how the ABC method's safety benefits outweigh its surplus expenses (Oyedele et al., 2019; FHWA, 2019).

$$Safety\ Benefit = \frac{X * annual\ average\ crash\ cost\ for\ conventional\ method\ per\ bridge}{cost\ of\ ABC\ implementation - cost\ of\ conventional} \quad \text{Eq. (1)}$$

where X is the number of days reduced in the work zone duration.
The economic and societal costs of vehicle crashes vary depending on several factors such as the extent of damage, injuries, response, and long-term effects. As a result, it is difficult to determine the exact costs of each crash as they occur, and future crashes may not have the same costs even if they occur at the same location. Additionally, inconsistent injury scales used in state crash reports can cause issues when estimating crash costs. There are several methods for estimating crash costs and injuries, each with its advantages and disadvantages. Economists use injury scales from crash reports to estimate crash cost values because the severity of a crash has a significant impact on the resulting costs. By using injury scales, economists can assign a value to each type of injury and estimate the total cost of the crash based on the number and severity of injuries sustained. This provides a standardized method for estimating crash costs across several types of crashes and allows for a more accurate cost-benefit analysis of safety improvement projects. Most law enforcement agencies use the KABCO scale to classify "suspected" injuries based on visual assessments and verbal complaints of pain. In contrast, medical professionals use the MAIS scale to classify severity based on a medical diagnosis of expected lethality. However, most highway safety practitioners do not have access to individual medical records and instead rely on crash data classified by KABCO severity level. To help with this, FHWA has developed a guide that outlines a five-step process for developing KABCO crash costs.

Table 6. Crash unit cost[1] values in the FHWA Safety BCA Guide and Tool (FHWA, 2016)

Severity[2]	Comprehensive Crash Unit Cost (2016 dollars)
K	$11,295,400
A	$655,000
B	$198,500
C	$125,600
O	$11,900

Crash Severity

The calculation of crash costs typically relies on the severity of the crash, which is determined by injury scales. In other words, the costs associated with a crash are determined by the severity of the injuries sustained by those involved in the crash. The KABCO scale is commonly used in police crash reports to classify the severity of both the crash and resulting injuries. However,

[1] Cost values per crash/injury
[2] Crash severity

differences can arise when reviewing how each state defines the severity attributes of KABCO. KABCO is defined as following definitions by FHWA:

Fatal Injury (K): stands for any injury that leads to the victim's death within a period of 30 days (about 4 and a half weeks) following the crash.
Incapacitating Injury (A): refers to a severe injury other than a fatality. This can include injuries such as broken bones, severed limbs, and other injuries that typically require hospitalization and transportation to a medical facility.
Non-incapacitating Evident Injury (B): refers to minor injuries or non-disabling injuries that are apparent at the crash scene. Examples of such injuries include lacerations, scrapes, bruises, and other similar injuries.
Possible Injury (C): refers to any injury that is reported or claimed but is not classified as a fatal, incapacitating, or non-incapacitating injury.
No Injury/PDO[1] (O): s indicates a person has sustained bodily harm because of the motor vehicle crash, but the injury's severity is unknown.

State DOTs Practices for Crash Unit Cost

We developed a questionnaire, which is listed in Appendix A, to gather information on the crash unit costs that state DOTs use in safety analyses. We invited state DOTs to participate in the survey and based on their responses, we can update and apply the crash unit cost to the improved ABC decision-making tool. By updating the crash unit cost into the improved ABC decision-making tool, we can provide state DOTs with a more accurate estimate of the economic benefits of implementing ABC practices.

Task 2.2 – Social Equity and Environmental Justice Criteria

Social Equality and Environmental Justice Index (SEEJ)

This research introduced and developed the Social Equality and Environmental Justice (SEEJ) index to incorporate the benefits of ABC in improving social equity and environmental justice in community groups affected by bridge construction projects. The SEEJ index encompasses two social equality indicators, namely household median income, and population density. Furthermore, the SEEJ index integrates an environmental justice measure in the form of the apparent (feel-like) temperature (Heat Index or Wind Chill Index). Efforts have been made to develop social and environmental criteria based on readily available national datasets to increase the tool's applicability to all state DOTs. To integrate the SEEJ index into the CTDOT ABC Decision Matrix (spreadsheet tool), two new tabs have been developed and integrated with the existing tool. The Social Equity tab is the first step and includes two sections for user data entry. The first section of the Social Equity tab is the primary input point for user data in this enhanced tool. It requires the user to provide information on the population density of the zip code where the bridge project is located. This is a critical factor in determining the social impact of the project, as population density has a direct correlation with access to essential resources, employment, and transportation options (Kolko, J., 2019). The second section of the Social Equity tab pertains to the median household income of the zip code where the bridge project is located. This factor is important in determining the potential impact of the project on the economic well-being of the affected communities. Table 7 illustrates the user inputs for these

[1] PDO stands for "Property Damage Only". It refers to incidents where there is no personal injury involved, but only damage to property. For example, a car accident where no one is hurt, but there is damage to the vehicles involved.

sections of the Social Equity tab. To facilitate access to relevant data resources, each tab in the updated tool includes a link that takes the user directly to the data source when clicked. This feature saves the user time and effort in searching for the required data, as it provides direct access to the relevant information needed for the evaluation.

Table 7. User inputs for social equity sections

Data	Unit	Link
Population Density	people per mi^2	http://www.usa.com/
Median Household Income	$	http://www.usa.com/

The second tab in the enhanced tool is dedicated to Environmental Justice and includes two distinct sections. The first section is designed for inputting data related to the Heat Index, which is a measure of the temperature and humidity conditions that can affect human health and well-being. The second section of this tab is dedicated to the Wind Chill Index, which is a measure of the temperature and wind speed that can also impact human health and comfort. The heat index is a measure of how hot it feels when relative humidity is factored in with the air temperature. The wind chill index, on the other hand, measures how cold it feels when wind speed is factored in with the air temperature. In both cases, the impacts of extreme temperatures are likely to be felt most acutely by workers. To decide whether to use the heat index or wind chill index in each region, the annual average max temperature over the past five years, the relative humidity for the very latest year, and the annual average wind speed over the past five years should be read from the provided links. Table 8 illustrates the user inputs for these sections of the Environmental Justice tab. There are no user inputs on any cells rather than these, and the tool will select the alternatives for analysis, either heat index or wind chill index, or average temperature if neither heat index nor wind chill index is a factor. This indicates that the tool is designed to automate the decision-making process for selecting alternatives, rather than requiring manual input from the user. The following steps should be followed to determine which index (heat index, wind chill index, or average temperature) is most appropriate for a region:

1. Obtain historical weather data, including temperature, wind speed, and relative humidity, for the region using the zip code of the project location and provided links for online weather data.
2. The heat index and wind chill index for each year of the historical data using the appropriate formulas will be calculated by the tool. The heat index formula considers temperature and relative humidity, while the wind chill index formula takes into account temperature and wind speed.
3. The data to identify patterns and trends in temperature and weather conditions will be analyzed. Look for periods of high and low temperatures, as well as patterns in relative humidity and wind speed.
4. Compare the heat index and wind chill index values for each year to the actual temperature to determine which index provides a better representation of the perceived temperature. For example, if the heat index consistently shows a higher temperature than the actual temperature, it will be more appropriate for the region than the wind chill index.
5. Consider work zone factors, such as the work zone duration and schedule, and worker exposure, when selecting the most appropriate index. For example, if the work zone is in an area with a region susceptible to heat stress, the heat index may be more appropriate.

Similarly, if the work zone is in an area prone to cold weather conditions, the wind chill index may be more appropriate.

Table 8. User inputs for environmental justice sections

Data Point	Unit	Link to read the data
Annual average max temperature	degree Fahrenheit	https://www.weather.gov/wrh/climate
Relative humidity	%	https://power.larc.nasa.gov/data-access-viewer/
Annual average wind speed	mph	https://power.larc.nasa.gov/data-access-viewer/

These steps provide a comprehensive guide for utilizing the SEEJ index in the enhanced ABC spreadsheet tool. Snapshots of the SEEJ tabs in the enhanced tool are presented in Appendix B. To obtain accurate results from the tool, it is essential to ensure that the data entered, and the weights assigned are reliable.

Task 3 – Quantitative Measures for the Evaluation of Criteria

Quantitative evaluation of criteria reduces subjectivity in the decision-making process and creates more accurate results. While using quantitative evaluations is not possible for every decision criterion, efforts should be made to minimize the number of qualitative evaluations in the decision-making process. To address this concern, two types of activities will be performed in this task:

1) While the CTDOT ABC tool uses quantitative analyses for some criteria such as "Average Daily Traffic" "Cost," and "User Impact Reduction," qualitative measures (scores of 0 to 5) are still used by the tool to calculate the final ABC rating scores. Quantitative measures will be developed for evaluating these criteria in the improved ABC tool.

2) Qualitative evaluation of criteria in the CTDOT tool includes subjective aspects that affect the accuracy of the results. For example, the evaluation of the "Bridge location" criterion is performed by categorizing the bridge locations into six groups with assigned scores as follows: Score 0: Rural bridge away from town center, score 1: Rural bridge near town center, score 2: Suburban bridge away from town center, score 3: Suburban bridge near major traffic generators, Score 4: Urban bridge near major traffic generators, and Score 5: Urban bridge near emergency services. Here, it is not clear what "near" and "away" mean. Defining a numerical range of distances instead of using "near" and "away" can reduce the subjectivity in evaluations and facilitate the decision-making process. Also, "Urban," "Suburban," and "Rural" land uses may not be adequate for evaluating the benefits of ABC regarding the bridge location. Considering different land uses in each area (e.g., land use classes such as high-density residential, commercial, or green spaces for urban areas and those such as residential and agricultural for rural areas) can improve the evaluations. Another example would for the quantification of the "Environmental/ Water Handling Impacts" criterion. The CTDOT tool uses a subjective method based on evaluating "construction limitations" related to environmental and water handling issues for determining this criterion. Quantification of this criterion can be done by developing quantitative measures based on items such as Length/size of diversion pipes/channels, Number/size/type of required cofferdams, and Flood potential in the area based on factors such as precipitation, soil type, imperviousness, groundwater level, and proximity to coastlines. Similarly, quantitative evaluation of "construction limitations" regarding the "Site Conditions" criterion (e.g., utilities and ROW) could be performed by developing quantitative measures

based on the number of buildings or area of properties that cannot be acquired (for ROW) and type/size of utilities and their distance to the bridge location (for utilities).

Task 4 – Relative Weights of Criteria

The CTDOT tool uses a predetermined set of weight factors to consider the relative importance of different criteria for decision makers, limiting the applicability of the tool to CTDOT projects. Even within CTDOT, the predetermined weights may not be appropriate for all projects, depending on the specific problems at various locations. Also, the preferences of CTDOT decision makers may change over time, requiring a flexible method for adjusting the weights of criteria in the ABC decision making tool. Developing a systematic, yet adequately simple, procedure for determining relative weights of criteria can result in extending the applicability of the tool to other states. To address this need, two different systematic procedures for determining the relative weights of criteria based on 1) the hierarchical SAW method, and 2) the Analytic Hierarchy Method (AHP) will be developed. The latter will be more rigorous compared to the first method but provides more accurate results. PI Ebrahimian has experience performing both methods in other infrastructure problems (e.g., Ebrahimian et al., 2015; Ebrahimian and Rahimi, 2022). It should be noted that the improved tool will still consider the option of using predetermined sets of weight factors.

Analytic Hierarchy Process (AHP)

AHP is a widely recognized and extensively used decision-making method developed by Thomas L. Saaty in 1980 (Saaty, 1980). It provides a structured approach for dealing with complex decision problems that involve multiple criteria and alternatives. AHP is particularly effective in situations where decisions are subjective, conflicting, and involve both qualitative and quantitative factors (de Brito, M. M., & Evers, M., 2016).

To provide an option for determining the relative weights of criteria based on the preferences of each end user (e.g., state DOT) besides using predetermined weights (as is the case with the existing CTDOT tool), AHP is incorporated in the improved ABC tool. In this method, a pairwise comparison is used to derive the weights for the criteria in terms of their importance. The process is summarized in four steps:

1. Design the decision hierarchy.
2. Perform pairwise comparison between criteria.
3. Calculate the overall weight of each criterion based on the pairwise evaluations.
4. Check the consistency of the evaluations.

The result of the pairwise comparison on n criteria can be summarized in an (n*n) matrix A in which every element a_{ij} is the weight of the criteria, as given in Equation (2).

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ a_{21} & \cdots & a_{2n} \\ a_{n1} & \cdots & a_{nm} \end{bmatrix}, a_{ii}a_{ji} = \frac{1}{a_{ij}}, a_{ij} \neq 0 \qquad \text{Eq (2)}$$

For creating the pair-wise comparison matrix, Saaty (1980) employed an evaluation system to indicate how much one criterion is more important than another based on a scale of 1 to 9. Table 9 shows these numerical scale values and their corresponding definitions (Saaty, 1980).

Table 9. AHP scales for comparison (Saaty, 1980)

Intensity of Importance	Definition
1	Equal importance
3	Somewhat more important
5	Much more important
7	Very much more important
9	More important
2, 4, 6, 8	Intermediate values

Next, a mathematical process is performed to normalize and find the relative weights. If the pairwise comparisons are consistent, matrix A has rank 1. It should be noted that the quality of the outputs of AHP is highly related to the consistency of the pairwise comparisons. There are Consistency Index (CI) and Consistency Ratio (CR) defined to let the user know whether the evaluations are consistent or not. CI and CR are given in Equations 3 and 4.

$$CI = \frac{(\lambda max - n)}{(n-1)} \quad \text{Eq (3)}$$

$$CR = \frac{CI}{RI} \quad \text{Eq (4)}$$

where n is the number of criteria and λ_{max} is the largest eigenvalue (Malczewski, 1999). RI is the Random Inconsistency index that is dependent on the sample size, (Table 10). A reasonable level of consistency in the pairwise comparisons is assumed if CR < 0.10, while CR ≥ 0.10 indicates inconsistent judgments. It is recommended that if CR> 0.10, the pairwise comparisons should be revised (Saaty, 1980).

Table 10. Random Index (RI) used to compute consistency ratios.

n	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

Setting up an AHP analysis

1. The improved ABC tool consists of 12 main criteria, represented in Figure 26. Below are the instructions to perform the analysis and calculate the consistency ratio. Start by entering the name of the decision maker/participant involved in the evaluation process and the evaluation date in the designated cells or columns on your input sheet. This information will help identify the contributors and provide context for the analysis.
2. Locate Table 9, which provides the scales for the pairwise comparisons. Refer to this table to understand the preference scales and their corresponding values. This will ensure consistency and a common understanding when assigning values during the comparison process.
3. Identify the input sheet. These cells represent the pairwise comparison matrix or table. They need to be completed by the user. The matrix will capture the preferences or relative importance of each criterion about the others.

4. Fill in the yellow cells from left to right, following the pairwise comparison process. Compare each criterion against the others and assign a value based on the preference scale provided in Table 9. Use the values to indicate the strength of preference or relative importance. For example, the decisionmaker assesses that criteria X is "slightly more important" than Y in terms of profitability according to the preference scale provided in Table 9. In this case, the pairwise comparison between criteria X and Y would be assigned a value of 3 based on the preference scale.
5. Enter the corresponding value in the yellow cells to indicate the preference or relative importance of each criterion. This step will populate the pairwise comparison matrix with the assigned values.
6. In the case that there are multiple participants, repeat the pairwise comparison process for each decision maker/participant involved in the evaluation process. If there are multiple decision makers/participants, ensure that each one performs the pairwise comparisons separately. This ensures individual perspectives are captured.
7. Once the pairwise comparisons are completed for all decision makers/participants, the weighted geometric mean of the decision matrix elements for each participant will be calculated. This calculation combines individual preferences and generates weights for each criterion.
8. Check for inconsistencies in the pairwise comparisons. Identify the most inconsistent comparison and edit if necessary. Inconsistencies can occur when the assigned values contradict each other or create illogical relationships. Adjustments should be made to improve the consistency of the comparisons.
9. Go back to the sheet named "Summary" to see the result. The summary sheet will provide an overview of the weighted scores and rankings based on the completed pairwise comparisons.
10. Note: Alpha (α) represents the threshold for acceptable inconsistency in the pairwise comparisons. If the consistency ratio exceeds 0.10, it indicates a higher level of inconsistency and may require further examination or adjustments in the pairwise comparisons. By setting α to 0.10, you can use it as a guideline to assess the consistency of your pairwise comparisons and identify any significant inconsistencies that may need to be addressed in your decision-making process.

AHP Analytic Hierarchy Process

Only input data in the yellow fields.

n=		Number of criteria (2 to 12)	α:	0.10
N=		Number of Participants (1 to 5)		
p=		Selected Participant		

Objective	**AHP Weight Determination for upto 12 Criteria**
Author	
Date	

Result				
	Criterion	**Comments**	**Weights**	**Rank**
1	Average Daily Traffic		#DIV/0!	
2	User Impact Reduction		#DIV/0!	
3	Bridge Location		#DIV/0!	
4	Use of Typical Details		#DIV/0!	
5	Work Zone Geometery		#DIV/0!	
6	Site Conditions		#DIV/0!	
7	Railroad Impacts		#DIV/0!	
8	Cost Analysis		#DIV/0!	
9	Envir./Water Handeling		#DIV/0!	
10	Waterway Limitations		#DIV/0!	
11	SEEJ Index		#DIV/0!	
12	Safety		#DIV/0!	

Summary

Participant 1:	Priortization Matrix											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1											
2	#DIV/0!	1										
3	#DIV/0!	#DIV/0!	1									
4	#DIV/0!	#DIV/0!	#DIV/0!	1								
5	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1							
6	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1						
7	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1					
8	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1				
9	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1			
10	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1		
11	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1	
12	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	#DIV/0!	1
Sum	######	######	######	######	######	######	######	######	######	######	######	1.00

Figure 26. A screenshot of AHP pairwise comparisons that was incorporated into the ABC tool.

AHP Verification

To verify the developed AHP model in this project, it was implemented using the input data provided by Stefanidis and Stathis (2013) in an MCDA problem regarding natural factors of flooding and the results were compared. Figures 27 and 28 show the pairwise comparison matrix and the obtained values for relative weights of criteria, respectively (Stefanidis and Stathis, 2013).

	Land use	Rock erodibility	Watersheds slope	Main stream slope	Rock permeability	Watershed shape	Density of hydrographic network
Land use		3	3	5	5	5	5
Rock erodibility			2	4	4	5	5
Watersheds slope				2	3	4	4
Main stream slope					2	2	3
Rock permeability						1	2
Watershed shape							1
Density of hydrographic network							

Figure 27. Pairwise comparison matrix in (Stefanidis and Stathis, 2013)

Natural factor	Weight
Land use	0.375
Rock erodibility	0.235
Watersheds slope	0.153
Main stream slope	0.088
Rock permeability	0.058
Watershed shape	0.048
Density of hydrographic network	0.043
Consistency ratio (CR) $= 0.03 < 0.1$	

Figure 28. Relative weights of criteria and consistency ratio obtained from (Stefanidis and Stathis, 2013)

Figures 29 and 30 demonstrate a screenshot of the AHP tab in the ABC tool with the same input data as in Stefanidis and Stathis (2013). As seen, the calculated weights of criteria and consistency ratio by the ABC tool match the results from Stefanidis and Stathis (2013).

	Priortization Matrix						
	Land use	Rock erodibility	Watersheds slope	Main stream slope	Rock permeability	Watershed shape	Density of hydrographic network
Land use	1	3	3	5	5	5	5
Rock erodibility	0.33	1	2	4	4	5	5
Watersheds slope	0.33	0.50	1	2	3	4	4
Main stream slope	0.20	0.25	0.50	1	2	2	3
Rock permeability	0.20	0.25	0.33	0.50	1	1	2
Watershed shape	0.20	0.20	0.25	0.50	1.00	1	1
Density of hydrographic network	0.20	0.20	0.25	0.33	0.50	1.00	1

Figure 29. Screenshot of the AHP calculations in the ABC Tool using the input from Stefanidis and Stathis (2013).

	Normalized							
	Land use	Rock erodibility	Watersheds slope	Main stream slope	Rock permeability	Watershed shape	Density of hydrographic network	Avg
Land use	0.41	0.56	0.41	0.38	0.30	0.26	0.24	0.364
Rock erodibility	0.14	0.19	0.27	0.30	0.24	0.26	0.24	0.234
Watersheds slope	0.14	0.09	0.14	0.15	0.18	0.21	0.19	0.157
Main stream slope	0.08	0.05	0.07	0.08	0.12	0.11	0.14	0.091
Rock permeability	0.08	0.05	0.05	0.04	0.06	0.05	0.10	0.06
Watershed shape	0.08	0.04	0.03	0.04	0.06	0.05	0.05	0.05
Density of hydrographic network	0.08	0.04	0.03	0.03	0.03	0.05	0.05	0.044

	Avg
Land use	0.36
Rock erodibility	0.23
Watersheds slope	0.16
Main stream slope	0.09
Rock permeability	0.06
Watershed shape	0.05
Density of hydrographic network	0.04
CR	0.03

Figure 30. Screenshot of the AHP calculations and results in the ABC Tool using the input from Stefanidis and Stathis (2013).

Task 5 – Improved ABC Decision-Making Tool

The CTDOT spreadsheet tool will be improved by incorporating the output of Tasks 2 (2.1 and 2.2.), 3, and 4 into the tool.

Task 6 – Case Study

The improved ABC decision making tool will be applied to a case study to demonstrate the applicability of the improved tool. Examples of the application of the existing CTDOT ABC tool in two projects in the Towns of Waterford and Killingly, Connecticut (resulting in "go-for" and "no-go for" ABC, respectively) were presented by Fields and Culmo (2021) through an ABC-UTC online seminar. One of these projects, in consultation with advisory panel members, will be selected as the case study in this project. In addition to demonstrating the applicability of the improved tool, using this case study will provide the opportunity of comparing the results from the original and improved ABC tools.

5. Expected Results

The main output of this research would be an improved spreadsheet-based multi-criteria decision support tool to determine the suitability of bridge projects for adopting ABC techniques. In addition to technical criteria, the tool will consider the benefits of ABC in improving roadway safety as well as social equity and environmental justice in adjacent areas of bridge locations. The proposed tool would be more comprehensive and less subjective than the existing ABC decision making tools and flexible to be used by other state DOTs. Another output is a case study where the application of the developed tool will be demonstrated in a bridge construction project. Details of the development of the improved tool and the case study will be presented in a technical report.

The proposed research will provide an improved tool that will be applicable in determining the suitability of adopting ABC techniques in bridge construction projects, including the replacement of the bridge deck, superstructure, and the entire bridge. The construction method will consequently contribute to bridge specifications. The proposed tool will be flexible in determining the weights of different criteria, allowing the widespread use of the tool by different state DOTs.

6. Schedule

The progress of tasks in this project is shown in the table below.

Table 8. Activities and timelines over the project's period

Item	% Completed
Percentage of Completion of this Project to Date	70%

Activity	Description	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
Task 1	Literature review												
Task 2.1	Road safety criterion												
Task 2.2	Social equity and environmental justice criteria												
Task 3	Quantitative measures for the evaluation of criteria												
Task 4	Relative weights of criteria												
Task 5	Improved ABC decision making tool												
Task 6	Case study												
Task 7	Reporting												
			Work Performed										
			Work To Be Performed										

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Appendix A: Crash Data Types, Crash Cost Values, and Work Zone Safety Data Questionnaire

Crash Data Types, Crash Cost Values and Contributing Factors

Thank you for participating in this survey. The survey aims to gather information related to crash data and methodologies used by state DOTs to estimate crash cost values and identify contributing factors. It asks for the specific information collected by your state DOT regarding crashes, such as methodologies used to estimate crash cost values and contributed factors. The outcome of this survey is to improve Accelerated Bridge Construction (ABC) Decision Matrix to consider the benefits of ABC on roadway safety and risk of accidents to make tool more comprehensive, less subjective (more accurate), and more flexible to be used by state DOTs.
If you would like to learn more about the project, please visit https://abc-utc.fiu.edu/research-projects/fiu-research-projects/a-comprehensive-decision-support-tool-for-accelerated-bridge-construction-considering-social-equity/ or contact the PI of the project at alebrahi@fiu.edu or co-developer, Nasim Mohamadiazar, at nmoha031@fiu.edu.

* Required

1. Name: *

2. Which state DOT are you working with? *

3. What is your job title? *

4. Your Email Address: *

5. How does your state DOT develop the crash cost values?

- ◯ Uses the national/FHWA manual
- ◯ Use internal estimated crash cost values
- ◯ Uses other states' manual or publication

6. If you are using internal estimated crash cost values, please indicate the methods/tools you are using. *

7. Is your state crash cost tool/spreadsheet available online? If yes, please insert the address *

8. If your crash cost is based on other states tools or publications, please provide your reference state and the link to the tool or publication. *

9. How often does your state update the crash cost values?

10. What indices or factors are used for the Crash Cost updates by your state?

11. What types of crash data does your state DOT collect? Please select all that apply:

- ◯ Crash severity data (including fatalities, injuries, and property damage)
- ◯ Crash type data (including rear-end collisions, head-on collisions, side-impact collisions, and others)
- ◯ Information on the location of the crash data
- ◯ Information on the time of the crash
- ◯ Crash frequency data

12. Which injury scale does your state DOT use for crash severity?

- ◯ KABCO (fatal, suspected serious injury, suspected minor injury, possible injury, non apparent injury)
- ◯ Abbreviated Injury Scale (AIS; non, minor, moderate, serious, severe, critical, maximum injuries)
- ◯ Others

13. Please indicate what method for injury scale and crash severity recording does your state DOT use? *

14. How often do you update crash/injury data records by a time range?

- ◯ 0-3 years
- ◯ 5 years
- ◯ Yearly
- ◯ Seasonal
- ◯ Monthly

Appendix B: SEEJ INDEX

Connecticut Department of Transportation 2800 Berlin Turnpike, PO Box 317546 Newington, CT 06131-7846		Project: 0 By: 0 Checked: Date: Sheet No. 1 of 2
CTDOT ABC Decision Making Process		

ABC Rating procedure

Enter values for each aspect of the project. Attach back-up data if applicable

Instructions for use

This spreadsheet is to calculate SEEJ Index
For your measurements go to cells and enter the parameter(s)
Note1: the inputs could be read from the provided linkes
Note2: SEEJ Index= Social Equity+ Environmental Justice
Note3: Social Equity= Population Density+ Median Household Income
Note4: Environmental Justice= either Heat Index or Wind Chill Index

Social Equity
Calculated by spreadsheet

Term	**Units**	**Input**		
Population Density	people per mi^2		1	Less than 4000
			2	4000 to 8000
			3	8000 to 12000
			4	12000 to 16000
			5	More than 16000

Term	**Units**	**Input**		
Median Household Income	$		1	More than 60,000
			2	50,000 to 60,000
			3	40,000 to 50,000
			4	30,000 to 40,000
			5	Less than 30,000

Instructions for use
For your measurements go to each cell and enter the parameter(s).
In cell C24, enter the population density read from the link provided (for the very latest year/updated).
In cell D24, enter the category
In cell C37, enter the median household income read from the link provided (for the very latest year/updated).
In cell D37, enter the category
Note1: the population density and median household income could be read from the provided linkes.

Term	**to be entered**
Population Density	http://www.usa.com/
Median Household Income	http://www.usa.com/

ABC Rating procedure

Enter values for each aspect of the project. Attach back-up data if applicable

Instructions for use

This spreadsheet is to calculate SEEJ Index
For your measurements go to cells and enter the parameter(s)
Note1: the inputs could be read from the provided linkes
Note2: SEEJ Index= Social Equity+ Environmental Justice
Note3: Social Equity= Population Density+ Median Household Income
Note4: Environmental Justice= either Heat Index or Wind Chill Index

Procedure: See cell A46

Environmental Justice
Calculated by spreadsheet

Term	Units	Input		
Heat Index	°F			
		Temperature, °F		
		Relative Humidity, %		
		PARAMETER:Relative Humidity, %	PAST 5-YEAR	ANN
		RH	year 1	
		RH	year 2	
		RH	year 3	
		RH	year 4	
		RH	year 5	

Term	Units	Input		
Wind Chill Index	°F	**Temperature, °F**		
		Wind Speed, mph		
		PARAMETER:Wind Speed	PAST 5-YEAR	ANN
		V	year 1	
		V	year 2	
		V	year 3	
		V	year 4	
		V	year 5	

Instructions for use

For your measurements go to each cell and enter the parameter(s).
In cell O25, (monthly summarized data, average max values over the past five years).
In cell O26, (for the very latest year/updated).
In cell O37, (monthly summarized data, mean min values over the past five years).
In cell O38, enter the wind speed read from the link provided (for the very latest year/updated).
Note1: the tepmerature and relative humidity could be read from the provided linkes.
Note2: the Heat Index or Wind Chill Index were alculated by spreadsheet.
In cell P24 enter the category read from cell Q23
Note3: Apply either Heat Index or Wind Chill Index considering Map 1
Note4: for the convertion of lat/log to Latitude & Longitude to Address

Term	to be entered
Temperature	https://www.weather.gov/wrh/climate
Relative Humidity	https://power.larc.nasa.gov/data-access-viewer/
Wind Speed	https://power.larc.nasa.gov/data-access-viewer/...