2024

Final Report SPR-FY22(009)

Accelerated Bridge Construction (ABC) Decision Tool

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This report was funded in part through grant from the U.S. Department of Transportation Federal Highway Administration. The views and opinions of the authors expressed herein do not necessarily state or reflect those of the U.S. Department of Transportation.

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A Report on Research Sponsored by

Nebraska Department of Transportation

and

Nebraska Transportation Center

University of Nebraska – Lincoln

June 2024

DOCUMENTATION PAGE

1. Report No. SPR-FY22(009)	**2. Government Accession No.**	**3. Recipient's Catalog No.**
4. Title and Subtitle Accelerated Bridge Construction (ABC) Decision Tool Final Report		**5. Report Date** August 2024 **6. Performing Organization Code**
7. Author(s) Phil Barutha, Marc Maguire, Elio Saldana, Fray F. Pozo-Lora.		**8. Performing Organization Report No.** 26-1122-0113-001
9. Performing Organization Name and Address Board of Regents, University of Nebraska – Lincoln		**10. Work Unit No.** **11. Contract**
12. Sponsoring Agency Name and Address Nebraska Department of Transportation Research Section 1400 Hwy 2 Lincoln, NE 68502		**13. Type of Report and Period Covered** Final Report November 2024 **14. Sponsoring Agency Code**
15. Supplementary Notes -		

16. Abstract

This report investigates the creation and assessment of a decision-making tool developed to aid the Nebraska Department of Transportation (NDOT) in determining the suitability of the Accelerated Bridge Construction (ABC) method for bridge replacement projects. The tool utilizes the Analytic Hierarchy Process (AHP) to integrate different criteria, including Average Daily Traffic (ADT), Average Daily Truck Traffic (ADTT), detour time, railroad impact, economy of scale, and the use of typical details, which were found to be paramount in the decision-making process across the state. A sensitivity analysis was conducted to evaluate the tool's performance and identify the most significant factors influencing the implementation of ABC for average Nebraska bridges. After testing the tool on a dataset of 123 local bridges needing replacement, it identified 10 confirmed candidates for ABC, 38 requiring further evaluation, and 75 more suitable for traditional construction methods. Additionally, the developed tool was compared with two existing decision-making tools from other states, showing similar results in 80% of the bridge replacement cases.

17. Key Words	**18. Distribution Statement** No restrictions. This document is available through the National Technical Information Service. 5285 Port Royal Road Springfield, VA 22161		
19. Security Classification (of this report) Unclassified	**20. Security Classification (of this page)** Unclassified	**21. No. of Pages** 68	**22. Price**

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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This report has been reviewed by the Nebraska Transportation Center for grammar and context, formatting, and compliance with Section 508 of the Rehabilitation Act of 1973.

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Acknowledgments

This research is supported by the Nebraska Department of Transportation and the U.S. Department of Transportation Federal Highway Administration. The authors would like to extend special appreciation to the Nebraska Department of Transportation and the U.S. Department of Transportation Federal Highway Administration and their support. In addition, the authors would like to thank all the State DOTs which have shared information about Accelerated Bridge Construction.

Chapter 1 Introduction

1.1 Background and Problem Statement

Accelerated bridge construction (ABC) is defined by the FHWA as bridge construction that uses innovative planning, design, materials, and construction methods in a safe and cost-effective manner to reduce onsite construction time when building new bridges or replacing and rehabilitating existing bridges (Culmo, 2011). One of the main difficulties that transportation asset managers encounter is efficiently prioritizing the replacement of a substantial inventory of deteriorating bridges, all while considering the growing budgetary limitations. Considering indirect costs, like traffic delays caused by construction closures, adds complexity to the decision-making process. The bridge network is a vital link to the state transportation network and to economic development. The large investments in bridge repair and replacement and the impact of their closures on the socio-economic vitality allow for opportunities to explore new construction techniques, planning approaches, and policies for their management (Alipour et al., 2018).

ABC uses both new technology and innovative project management techniques to mitigate the effects of bridge construction on the public, reduce construction costs, promote traffic and worker safety, and improve bridge durability due to standardized and controlled construction conditions (Saeedi et al., 2013). Oftentimes long detours, costly use of temporary structures, remote site locations, and limited construction periods present opportunities for using ABC methods to provide more practical and economical solutions to those using conventional construction methods (Culmo, 2011). Nine transportation agencies have seen ABC techniques reduce bridge construction time and save over $30 million (FHWA, 2006). Additionally, ABC techniques on different bridge elements have improved the durability of bridge structures

(Hosteng et al., 2016; Phares & Cronin, 2015). ABC offers benefits to transportation agencies; however, many agencies are hesitant to implement ABC due to perceived risks and higher initial costs (Kang et al., 2016).

Another factor contributing to the low adoption of ABC is the unavailability of decision-making processes that would help agencies select candidate bridges and appropriate ABC techniques (Alipour et al., 2018). At the national level, multiple tools are available to aid with ABC decision support. Among these methods, the most widely used approach is the ABC-AHP decision tool developed by the FHWA (2012). This method is based on the analytic hierarchy process (AHP) that uses pairwise comparisons to evaluate the importance of defined factors relative to other factors using a numerical scale. The ABC-AHP decision tool consists of three components: the overall goal of the decision, a hierarchy of criteria by which the alternatives are evaluated, and the available alternatives (Doolen et al., 2011). The alternatives evaluated are ABC or conventional methods against two levels of main elements a bridge construction project could relate to, with the first level being direct costs, indirect costs, schedule constraints, site constraints, and customer service. The second level consists of elements that impact the first level. This decision tool is used for a specific bridge project.

In addition to FHWA, various state Department of Transportation (DOT) agencies have decision processes to determine the suitability of ABC on bridges needing to be replaced, rehabilitated, or newly constructed. A preliminary review of documents reveals decision processes in place in states nationwide ranging from Connecticut to Minnesota and Iowa to Utah and Oregon. The FHWA ABC-AHP decision tool was developed from the decision tool originally implemented by Oregon DOT. Minnesota DOT uses a three-stage decision process to prioritize ABC bridges, while Connecticut DOT utilizes a decision matrix with weighted factors of importance to compare ABC and conventional methods.

ABC techniques have a great potential to minimize traffic disruptions during bridge replacements and construction, promote traffic and worker safety, and improve the overall quality of the built bridges. Despite major advances in the design and construction of ABC techniques, some agencies are hesitant to use ABC techniques due to risks during construction and perceived higher initial costs. In addition, oftentimes, the current decision process used to determine and prioritize the candidate bridges for this type of construction can be based solely on average annual daily traffic (AADT), where this may be prudent to evaluate based on several factors. A decision-making framework incorporating important factors in determining the suitability of ABC in Nebraska will allow NDOT to find the best-fit candidate bridges to maximize the benefits of Accelerated Bridge Construction.

1.2 Objectives and Scope

The main objective of the study is to develop a decision-making framework to help inform NDOT on the applicability of ABC methods on the various bridges within the transportation network of Nebraska. The study will obtain data specific to Nebraska and develop a decision model to compare the use of ABC compared to traditional methods using factors weighted on the importance of achieving agency objectives. Weighted factors include direct costs, user impacts, average daily traffic, site conditions, safety, and other pertinent factors impacting construction methodology. The specific factors and weighting were determined in coordination with NDOT during the research study. The project will result in the development of an ABC Decision Tool that will serve as a framework to allow NDOT to rigorously determine and prioritize the use of ABC on candidate bridges in need of replacement or new construction, which will provide the agency with the most value. The developed decision tool is intended to be used early in the preliminary project development phase to evaluate design and construction methodology alternatives.

1.3 Report Organization

The research presented in this report is comprised of four main chapters and a conclusions chapter addressing the main goals attained in this report. The content of the chapters is summarized in the following list:

- Chapter 2: In this chapter, the authors present a brief review of the ABC method, the techniques that can be used to develop a decision tool, and the most common approaches used to develop a decision tool among several United States departments of transportation (DOTs) and the factors they implement.
- Chapter 3: The authors present the development of the decision tool in this chapter, perform a sensitivity analysis of the tool, and determine the characteristics of bridges needing replacement in the state of Nebraska (as provided by the local DOT).
- Chapter 4: In this chapter, the authors compare the selection of factors and weights, as well as the performance of the developed tool with existing tools of other DOTs.
- Chapter 5: The summary and conclusions of the study are gathered and presented, and future research recommendations are given.

Chapter 2 Literature Review

2.1 Introduction

Accelerated bridge construction (ABC) is a construction approach that, compared to traditionally constructed bridges, uses modern design techniques, construction materials, planning, and methods safely and economically to lower the construction time in situ when building, replacing, or rehabilitating bridges (Culmo, 2011). By implementing ABC, contractors can improve the constructability on site, normally reducing the project delivery time, optimizing the material quality and durability, and enhancing the safety of the workers and motorists during construction. Moreover, ABC reduces the impact on traffic, the duration of construction on-site, and weather-related construction delays. Moreover, if ABC is done carefully, it can also lessen the environmental impacts of the construction, the impact on existing roadway alignment, and the utility relocation and right-of-way takes.

Despite the previously mentioned advantages, ABC is not frequently used in many states due to the lack of proper selection techniques and familiarity with the system. In fact, according to the ABC Project and Research Databases (https://utcdb.fiu.edu/search), only 126 have been constructed in the USA to the date of writing this report, and none have been built in the states of Alabama, Arkansas, Maine, Mississippi, Montana, North Dakota, Nebraska, Nevada, Oklahoma, Rhode Island, Tennessee, and West Virginia. This number is likely a low-end assessment, but it underscores the lack of such projects. The main concern when selecting ABC over traditionally constructed bridges is whether selecting the system is feasible and economical. To determine that, other Department of Transportation (DOTs) and the Federal Highway Administration (FHWA) have created decision-making tools and matrices to make the initial screening more straightforward. In this chapter, the authors introduce the ABC methodology, explain how other

DOTs decide whether to use ABC, and explain the wide array of methods utilized in the literature to construct a decision-making tool to select a construction method.

2.2 Accelerated Bridge Construction (ABC)

2.2.1 Overview

Accelerated Bridge Construction has three distinctive features: Prefabrication, reduction of on-site construction activities, and implementation of innovative construction techniques. Prefabrication allows building bridge components off-site and then transporting them to the construction site once they have reached adequate strength and connecting them using various techniques. This, in turn, drastically reduces road closure times and enhances site safety for workers and motorists. All of this is possible due to the implementation of innovative techniques that include high-quality materials synergistically incorporated with modern construction methods and technologies that expedite the construction process. Figure 2.1 summarizes the previously mentioned advantages of using ABC in the construction and rehabilitation of bridges. Many transportation departments have seen how ABC techniques help them reduce bridge construction time and save more than $30 million dollars compared to traditionally constructed bridges (FHWA, 2006). In addition, ABC has also helped increase the durability of bridge components when compared to their traditional counterparts (Hosteng et al., 2016; Phares & Cronin, 2015).

ABC offers benefits to transportation agencies; however, many agencies are hesitant to implement ABC due to perceived risks and high initial costs. Another factor contributing to the less frequent adoption of ABC is the lack of decision-making processes that would help agencies with the selection of candidate bridges and appropriate ABC techniques (Alipour et al., 2018).

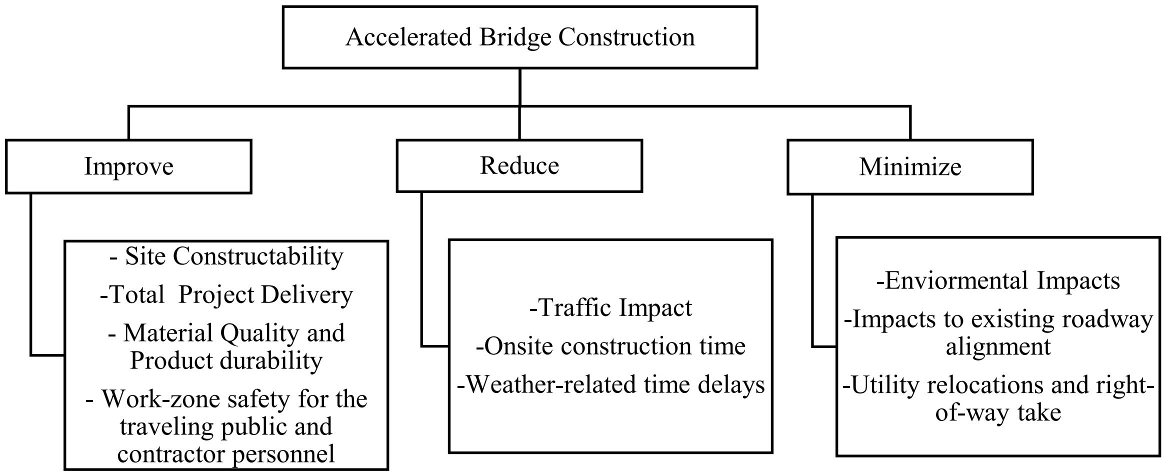


Figure 2.1 Three key aspects of ABC and their benefits. Adapted from (Culmo, 2011).

2.2.2 ABC Construction Techniques

This research project does not investigate specific techniques to be applied to ABC projects but has identified various ABC methods to further describe its construction processes and materials. The following list defines different ABC techniques frequently used in the industry and their features according to the ABC FWHA Manual, Illinois Tollway, Iowa DOT, Connecticut DOT, Utah DOT, Florida DOT, Oregon DOT, and CalTrans.

- Prefabricated Bridge Elements and Systems: PBES is the most common technique used by the ABC. Prefabricated elements are manufactured in a controlled environment off-site and assembled in place at the bridge site. The main advantage of PBES is the reduction of project site duration for concrete forming, installation of rebar, and concrete placement. After elements are fabricated off-site, they can be moved to any place. A staging area with adequate space and clearance to place the prefabricated elements may be required.
- ABC Connections: Durability issues can be improved considering the type of connections and detailing requirements. When using this technique, it is important to simplify details

to make construction faster and to reduce the risk of different elements not fitting together. The most common ABC connections used are:

- Grouted Splice Couplers
- Concrete Closure Joints
- Traditional Post-tensioning
- Grouted Post-tensioning
- Welded Connections
- Bolted Connections

- ABC Materials: The selection of situation-appropriate or high-performance materials helps to increase the service life and durability of the structure for each project. The most common materials are:
    - Ultra-High-Performance Concrete (UHPC)
    - Expanded Polystyrene (EPS) Geofoam
    - High-Performance-Concrete (HPC) Mix Design
    - Stainless reinforcement bars in the deck
- Installation Method: Selecting an appropriate installation method benefits contractors and increases the speed at which bridges are removed and installed. The most common ABC installation methods used on the ABC project are:
    - Lateral sliding
    - Self-Propelled Modular Transporter (SPMT) transport
    - Longitudinal launches
    - Crane-based projects

- Accelerated Foundation Construction Methods: This includes construction methods that reduce the time for foundation installation. The most common foundation installation methods used are:
  - Continuous Flight Auger (CFA) piles
  - Rapid embankment construction
- ABC Project Delivery Methods: This technique can reduce the time required for planning, designing, and bidding on the project. ABC project delivery and innovative contracting are ways to accelerate bridge construction. Two common innovative contracting methods for ABC are:
  - Design-Build (DB)
  - Construction Manager General Contractor (CM/GC)
- Contracting: To accelerate bridge construction during the planning stage, contracting provisions might be incorporated into the project delivery method, given the right conditions, application, and support. The most common contracting provisions used on ABC projects are:
  - Best Value Selection
  - A+B and A+B+C Bidding
  - Incentive/Disincentive (I/D) Clause
  - Lane Rentals
  - Advance Contracts
  - Alternative Design/Alternate Bid (AD/AB)

2.2.3 ABC in the US

According to the ABC UTC Project Database, the first ABC project was the Fremont Bridge in Oregon in 1973. Since then, multiple studies have mildly attempted to compile all ABC projects built in the USA. However, not all bridges built using the ABC method are recorded in these studies. Jia et al. (2018) reported only 65 bridges from 1998 until 2013. The ABC UTC Project database reports 126 bridges from 1973 to 2023 and does not list Nebraska as a state where the ABC method has been used (see Figure 2.2) although there are examples outlining the successful use of the ABC method in the state, such as the S080 42350, 3N Greenwood Interchange in Cass County. Another example is the state of Missouri, which has over 150 ABC-built bridges, but studies have only displayed 1-3 ABC bridges in their compilations. This situation makes it difficult to evaluate the adoption of ABC in bridge construction and test new decision tools on projects already completed.

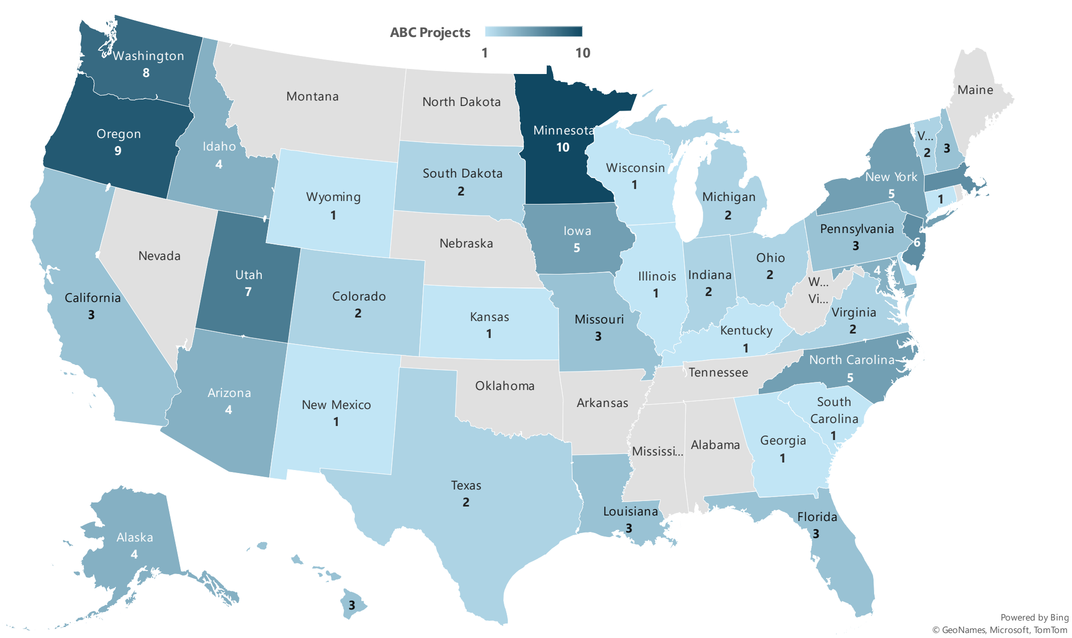


Figure 2.2 Map showing the number of ABC construction projects throughout the USA, as reported in the ABC UTC Project Database.

2.2.4 Selection Criteria

DOTs in the US may have difficulty selecting ABC over traditional bridge construction methods based on three selection criteria—economics, project urgency and deadlines, and the traffic impact on the project area. The resources allocated each year towards infrastructure spending as a share of the GDP have been stagnant for several years (CBO, 2018), making it hard for DOTs to prioritize bridge renovation and reconstruction around the US. Taxpayers often have many expectations when it comes to infrastructure spending, including transparency, efficient use of funds, and completion of projects in the promised timeline with the least negative impact on their lives (Greenstone & Looney, 2011). ABC normally meets two of those three taxpayer criteria, but their direct cost tends to be as high as traditionally constructed bridges and, in many cases, more expensive (Hadi et al., 2017). However, when adding up the indirect costs related to driver delays, freight mobility, revenue loss, and road safety, the use of ABC tends to yield more economical bridges on average (see Table 2.1). That means, globally, motorist indirectly finance a portion of the traditional construction of bridges with their spending on additional commute cost, exposure to construction zone hazards, and drive time when compared to ABC. Thankfully, DOTs and the FHWA have developed tools that aid in selecting a new ABC bridge type considering many factors, including the ones mentioned above, and giving an importance factor or weight to each of those factors so that direct and indirect costs are involved in the decision-making process. Still, many of these tools may not reflect local preferences, and new tools may be required to account for them so that the bridge construction method can be selected appropriately. This includes familiarity with the local industry, which is constructed with prefabricated elements, weather-related impacts, and local government constraints.

Table 2.1 ABC vs. conventional bridges average analysis performed by Hadi et al. (2017)

Item	ABC vs. Conventional
Total General Conditions	-45.57%
Total Permanent Wall	-0. 29%
Total Substructure End Bents	-7.60%
Total Substructure Piers	-7.55%
Total Superstructure	3.31%
TOTAL DIRECT COST	-2.45%
TOTAL INDIRECT COST	-58.53%
TOTAL PROJECT COST	**-24.72%**

2.3 Multi-Criteria Decision-Making Techniques

2.3.1 Overview

Decision-making is one of the main tasks of state DOTs when it comes to investing taxpayer funds allocated for infrastructure. This task involves handling a large amount of information, local necessities, and a limited amount of funds to supply the need for the repair and replacement of highway bridges. The literature contains a wide array of decision-making techniques that can be used to develop decision tools, which many institutions have adopted with the intent of relieving this apprehension. Decision-making tools can be classified as “single” and “hybrid” approaches. Single approaches involve using a unique method or tool to decide, for example, whether to conduct ABC over traditional construction using an analytical hierarchical process (AHP) only, while a hybrid approach entails combining multiple methods or tools to leverage the strength of each one to obtain an optimal solution for a new bridge. The literature contains numerous examples of single approaches, such as the AHP, data envelopment analysis (DEA), elimination and choice reflecting reality (ELECTRE, by its French acronym), technique for order of preference by similarity to ideal solution (TOPSIS), and hybrids, such as hybrid AHPs, fuzzy sets (FSs), analytic network process (ANP), and complex proportional assessment (COPRAS), among others (see Table 2.2). The most used decision tools are the AHP (in either hybrid or single mode), followed by fuzzy sets and TOPSIS (Jato-Espino et al., 2014). The AHP is a multicriteria decision-making technique that helps set priorities among quantitative and qualitative variables (Saaty, 1980). According to the author, the "purpose is to develop a theory and provide a methodology for modeling unstructured problems in the economic, social, and management sciences… establishing a framework which incorporates both philosophy and mathematics." The seven pillars of AHP are 1) Ratio scales, proportionality, and normalized ratio scales; 2) Reciprocal paired comparisons; 3) Sensitivity that can be extended to dependence and feedback; 4) Homogeneity and clustering; 5) Synthesis that can be extended to dependence and feedback; 6) Rank preservation and reversal; and 7) Group judgments. Based on these aspects, the user can produce an AHP by performing seven simple steps:

I. Define the goal
II. Structure the hierarchy
III. Perform comparison
IV. Construct the comparison matrix
V. Compute the priority vectors
VI. Check for consistency
VII. Aggregate the results

Fuzzy sets (FSs) are present in hybrid approaches to relieve the distrust that other methods generate related to their ability to incorporate uncertainty and vagueness in data (Jato-Espino et al., 2014). In set theory, elements obey a dichotomy of whether they belong to a set.

However, real decision-making situations involve ambiguity and partial truth. Therefore, FSs address this problem by allowing values to participate partially in a given set. FSs have been combined several times in the literature to aid other decision-making techniques, such as ANP, TOPSIS, ELECTRE, and SAW.

Table 2.2 Summary of decision-making methods found in the literature, adapted from (Jato-Espino et al., 2014)

Abbreviation	Method	Approach
AHP	Analytic hierarchy process	Single and hybrid
ANP	Analytic network process	Single and hybrid
COPRAS	Complex proportional assessment	Single and hybrid
DEA	Data envelopment analysis	Single
Delphi	Delphi	Single
DRSA	Dominance-based rough set approach	Single and hybrid
ELECTRE	Elimination et choix traduisant la realité	Single
FSs	Fuzzy sets	Single and hybrid
GST	Grey system theory	Single and hybrid
GT	Game theory	Single and hybrid
HOQ	House of quality	Single and hybrid
IFSs	Intuitionistic fuzzy sets	Single and hybrid
MAUT	Multi-attribute utility theory	Single and hybrid
MAVT	Multi-attribute value theory	Single and hybrid
MCS	Monte Carlo simulations	Single and hybrid
MEW	Multiplicative exponential weighting	Single and hybrid
MIVES	Modelo integrado de valor para evaluaciones sostenibles	Single and hybrid
PROMETHEE	Preference ranking organization method for enrichment of evaluations	Single and hybrid
SAW	Simple additive weighting	Single and hybrid
SIR	Superiority and inferiority raking	Single and hybrid
SMAA	Stochastic multiobjective acceptability analysis	Single and hybrid
TOPSIS	Technique for order of preference by similarity to ideal solution	Single and hybrid
UT	Utility theory	Single and hybrid
UTA	Utilités additives	Single and hybrid
VIKOR	Visekriterijumska Optimizacija I kompromisno resenje	Single and hybrid

Finally, TOPSIS is a single approach created by Hwang & Yoon (1981) as part of their work on the applications of multiple attribute decision-making (MADM) methods. Like the AHP, TOPSIS is used to identify the "best option" among a group of different alternatives based on their distance to the "ideal" and "negative-ideal" solution instead of merely finding a score and determining whether it passes a certain threshold. Therefore, the best option would be the one closer to the ideal solution and farthest to the negative-ideal solution.

2.3.2 Applications

The previous three methods have been used several times in the literature to develop decision-making tools. One of the first applications of AHPs in construction can be traced back to Skibniewski & Chao (1992), who explained how the technique could be used to decide whether to use new machinery or construction approaches in the industry. When it comes to DOT decision-making tools for selecting ABC, AHPs dominate their use at almost 100% in both single and hybrid approaches (Saeedi et al., 2013).

Rahman et al. (2012) used TOPSIS to develop a decision tool based on the knowledge-based decision support system (KDSS) approach to aid in the selection of roofing materials in the United Kingdom. Şimşek et al. (2013) successfully used TOPSIS to optimize mixture proportions of high-strength self-consolidating concrete in Turkey. Malekly et al. (2010) developed a hybrid TOPSIS (FSs + HOQ + TOPSIS) to select optimal bridge superstructures early in the design process. These researchers implemented FSs and HOQ in the first stage to shape user demands into design criteria, which was ultimately used to implement a Fuzzy TOPSIS in the final stages of the optimal bridge type selection. Golestanifar et al. (2011) combined AHP, FSs, and TOPSIS to evaluate and find the most suitable tunnel excavation method using seven criteria. Firstly, a combination of AHP and FSs was implemented to factor in the excavation method and the rock characterization, and then TOPSIS was used to rank three different options.

<u>2.4 ABC Selection Using Decision-making Tools using AHP</u>

As mentioned before, AHPs are the dominant method in the international literature, with multiple applications at the DOT level in the US. AHP uses multiple criteria to aid in deciding on an infrastructure construction method, such as ABC or traditionally constructed bridges. Aside from including criteria, AHP also quantifies the qualitative trade-offs and relationships between the criteria using a hierarchy of criteria. The AHP uses a multi-level hierarchical structure of objectives, criteria, and alternatives to support a complex decision (see Figure 2.3). The AHP approach can be used to extract ratio scales from both discrete and continuous pairwise comparisons in multilevel hierarchy structures. The AHP can also be used to establish measures in both physical (tangibles) and social (intangibles) domains. The AHP simple scheme consists of three main levels: the overall goal of the decision (objective), the criteria by which the alternatives will be evaluated, and the available alternatives (criteria 1, 2, 3, etc). The decision is affected by the organization hierarchy in gradual steps from general, in the upper levels, to particular, in the lower levels. This structure makes it possible to judge the importance of the elements at a specific level with respect to some or all the elements at the level directly above.

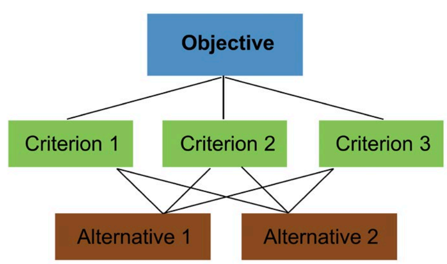


Figure 2.3 Illustration of a multicriteria AHP (Saeedi et al., 2013).

2.4.1 Decision Factors

The determination of when ABC is appropriate can be a complex decision. The process involves multiple decision criteria such as ADT, detour time, evacuation route, economies of scale, applicability to standards, worker safety, environmental issues, railroad impacts, and weather limitations. The individual decision criteria factors may have differing weights of importance in meeting agency objectives. In addition, the project characteristics of each of the bridges may influence the application of ABC at each bridge location within the network. Some characteristics identified through the literature review that will have an impact on the planning process of the ABC decision-making are:

- Site Constraints: It can have a significant impact on the practice of the various ABC techniques. Also, site constraints can have an impact on the construction time and cost.
    - Water Crossings: In certain situations, bodies of water can obstruct the project construction.
    - Highway Grade Separations: Bridges that span over roadways can make up a large portion of the bridge structure. Commonly, roadways, as opposed to railroad crossings, under the bridge provide more flexible construction methods.
    - Railroad Crossing: As an advantage, rail transport can accommodate larger and heavier elements than roadways. However, access to the railroad sometimes is limited and subject to rigid time schedules.
    - Geotechnical Constraints: Aspects such as the capacity of the soil to resist construction load and stability of the soils under equipment combined with the SPMT installation can reduce the project duration.
- Staging Areas: Most roadways will have shipping limitations on the size and weight of the prefabricated elements, so allowing contractors to prefabricate elements in a near-site staging/fabrication yard could be a good option to reduce project duration. Also, the staging area opens opportunities for large-scale prefabrication and installation with SPMTs.
- Traffic Management: This is the first reason the ABC technique is selected. Shifting traffic is a challenge and a complex decision for many roadway projects. In some cases,

the lane areas accommodated on the new bridge are overbuilt during construction to reduce the impact on traffic. Other criteria that are important to evaluate are detours, construction staging, and temporary bridges.

- Right-of-Way Issues: Challenges associated with right-of-way are present in most projects, and ABC may be a way to reduce these constraints depending on the situation.
- Utilities: The impact of utilities on the installation of prefabricated elements and systems can be significant. FHWA recommends that agencies consider relocating utilities in a separate pre-construction contract.
- Local Government Constraints: The community impact of a construction project can be important. Adding local government to the project to understand weaknesses is helpful for the decision-making process.

In a review of state DOT agencies' policy documents, Alipour & Shane (2019) identified the factors used in decision-making criteria to prioritize the use of ABC. Table 2.3 presents the results of analyzing DOT tools in the Alipour & Shane (2019) study (CA, IA, MN, OR, UT, WA, and WI) along with CO and CT, which were added for comparison.

Table 2.3 Decision-making criteria implemented in tools developed by different states, adapted from Alipour & Shane (2019).

Parameter	CA	CO	CT	IA	MN	OR	UT	WA	WI
Average daily traffic (ADT)	X	X	X	X	X		X	X	X
Out of distance travel/detour length	X		X			X	X	X	
Delay/detour time		X	X		X		X		
Bridge classification	X			X	X		X	X	X
User costs	X	X	X	X		X	X	X	X
Economy of scale		X					X		
Use of typical details			X			X	X		
Safety	X	X					X	X	X
Railroad impacts		X	X						X
Accessibility of navigation channels	X		X					X	X
Weather-related impacts	X					X		X	X
Environmental impacts	X		X					X	
Preference of the districts	X					X		X	
Traffic and maintenance	X							X	
Utility impacts			X			X			
Historical impact									
Traffic density			X	X	X	X			X
Construction cost			X			X	X		
Right of way						X			
Toll revenue						X			
Revenue loss						X			X
Construction personnel safety						X			
Physical constraints		X	X						X
Emergency replacement								X	X
Impact to economy	X	X		X			X		

A recent study by Abdul Nabi & El-adaway (2020) presented additional factors associated with modular construction. This study conducted a systematic review analysis of modular construction studies conducted between 2009 and 2019, compiled 50 decision-making factors from the studies, and used social network analysis to quantify literature gaps that need further research. ABC is one type of modular construction specifically applied to bridges; however, some decision-making factors presented in that study may not apply to it. Table 2.4 shows an adaption of the modular construction factors associated with ABC divided by category. These factors require weight to establish their importance and whether or not it should be used in a decision tool. Without weights, all the factors would be worth the same amount, and expensive projects would be justified even when the economics suggest otherwise.

Table 2.4 Identified decision-making factors associated with ABC. Adapted from Abdul Nabi & El-adaway (2020)

Category	Factors associated with ABC
Cost and profitability	Direct labor, overhead, supervision, transportation, initial capital, crane and equipment, and material cost.
Time-related issues	Activity sequencing, site disruptions
Quality-related issues	Quality control, inspection at precast plant, local experience, and aesthetics.
Safety-related issues	On-site safety performance, exposure to hazards, and planning.
Environmental-related issues	Environmental impact, waste management, green practices.
Design and engineering	Standardization of details and construction tolerances.
Resources and technology	Productivity, use of modern technology and materials, efficiency of construction equipment including cranes, logistics, and local experience.
Regulatory and organizational aspects	Project delivery method and cultural perspective (resistance to change).

2.4.2 Weights and Scores

Paired comparisons in the Analytic Hierarchy Process (AHP) involve evaluating pairs of similar elements. The scale of values used to express the strength of these evaluations is presented in Table 2.5. This scale has been proven to be effective in numerous applications by various individuals and is also supported by theoretical justification for its use in comparing similar elements (Saaty & Vargas, 2012).

Given a comparison matrix using the AHP model, the principal eigenvector is normalized to yield a unique estimate of the ratio scale underlying the judgments. To check the consistency of the pairwise comparison matrix, it is necessary to use:

$$a_{ij}a_{jk} = a_{ik}$$ **Error! Bookmark not defined.**(2-1)

To avoid the human judgment and reduce the undesirable inconsistency, Saaty suggested a consistent reciprocal matrix:

$$\lambda_{max} = n$$ **Error! Bookmark not defined.**(2-2)

The Consistency Index (CI) is used to measure the consistency of the matrix (Saaty 1980):

$$CI = \frac{\lambda_{max} - n}{n - 1}$$ **Error! Bookmark not defined.**(2-3)

The CI is compared to a Random Index (RI) and is used to calculate the Consistency Ratio (CR). RI is obtained by randomly generating the reciprocal matrices using the fundamental scale and getting the random consistency index to see if it is below a threshold:

$$CR = \frac{CI}{RI} \langle = 10\%$$ **Error! Bookmark not defined.**(2-4)

If the value of the Consistency Ratio is smaller or equal to some predetermined threshold, in this case 10%, then the inconsistency is acceptable. If the consistency Ratio is greater than 10%, the subjective judgment needs to be revised.

Table 2.5 Elementary scale used to score a factor per Saaty & Vargas (2012).

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
2	Weak	-
3	Moderate importance	Experience and judgment slightly favor one activity over another
4	Moderate plus	-
5	Strong importance	Experience and judgment strongly favor one activity over another
6	Strong plus	-
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	-
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix

2.4.3 Existing Decision Tools and Frameworks

2.4.3.1 FHWA

The most famous decision tool in the ABC decision-making process is the FHWA tool, developed by Saeedi et al. (2013) to aid Oregon DOT in selecting new ABC bridges. The tool is based on the AHP technique and has five main criteria and 30 sub-criteria that help prioritize many variables inside and outside the direct cost of using ABC. Unlike many other tools, the FHWA tool possesses negative and positive scales that penalize or boost the final score. Moreover, the tool comes in executable format instead of the traditional spreadsheet format, which is more user-friendly. However, at the same time, this removes the possibility of major modifications without requesting it from the developers.

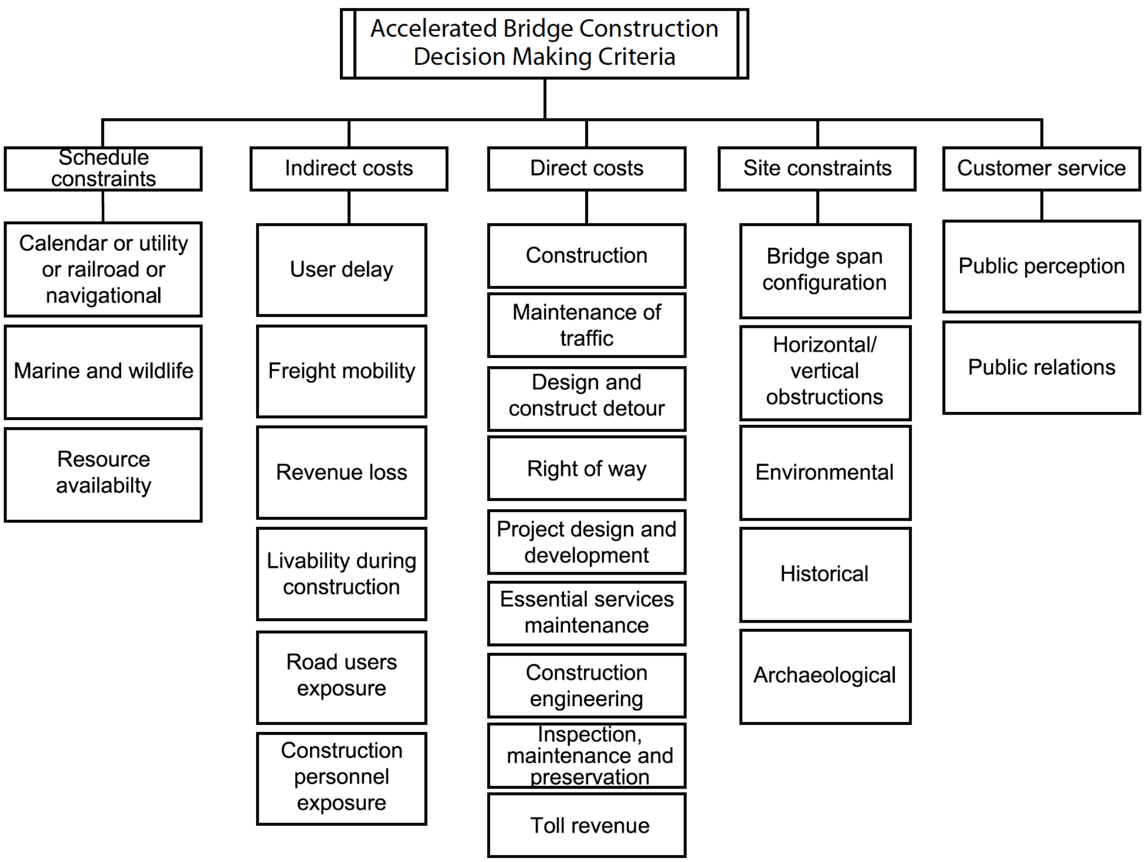


Figure 2.4 Hierarchy of ABC decision-making criteria proposed by Saeedi et al. (2013)

2.4.3.2 CALTRANS

The California DOT has developed a two-step, multi-criteria qualitative/quantitative decision-making tool to evaluate the feasibility of implementing ABC (CALTRANS, 2021). The first step of the process consists of qualitatively assessing the potential of ABC for minimizing construction impacts on the whole project. The questionnaire, shown in Figure 2.5, considers the construction, environmental impact, user cost and delays, site conditions, risk management, and economy of scale. Each of these categories has questions associated with them ranging from no relevance (0 points) to high relevance (5 points), and then they are multiplied by a weight from 1-3 depending on their priority. The final score or ABC rating is the sum of the products of the "relevance" times the "priority." Each question must be responded to in cooperation with the professional engineer (PE), the technical liaison engineer (TLE), the district PE, and the project development team (PDT), who will use their experience to respond to each question. In addition to the score, the construction time will also play a role in selecting the bridge.

With the ABC rating score, the user then enters the flowchart presented in Figure 2.6, and depending on the score range, the user selects an option. The minimum weighted score to consider using ABC is 30/285 points, but the final decision is the responsibility of the district. Each construction method will also be evaluated to determine their total working days, which includes the mobilization, the bridge construction completion time (CCT), the specific bridge construction impact times (CIT), and the road work. Therefore, the fastest ABC method needs to be selected to compute the construction time and then compared to the traditional construction. This will aid the engineering team in deciding whether to use the ABC method, which gives the least disruption to the community.

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 2.5 Snapshot of CAL TRANS ABC decision-making questionnaire (CALTRANS, 2021)

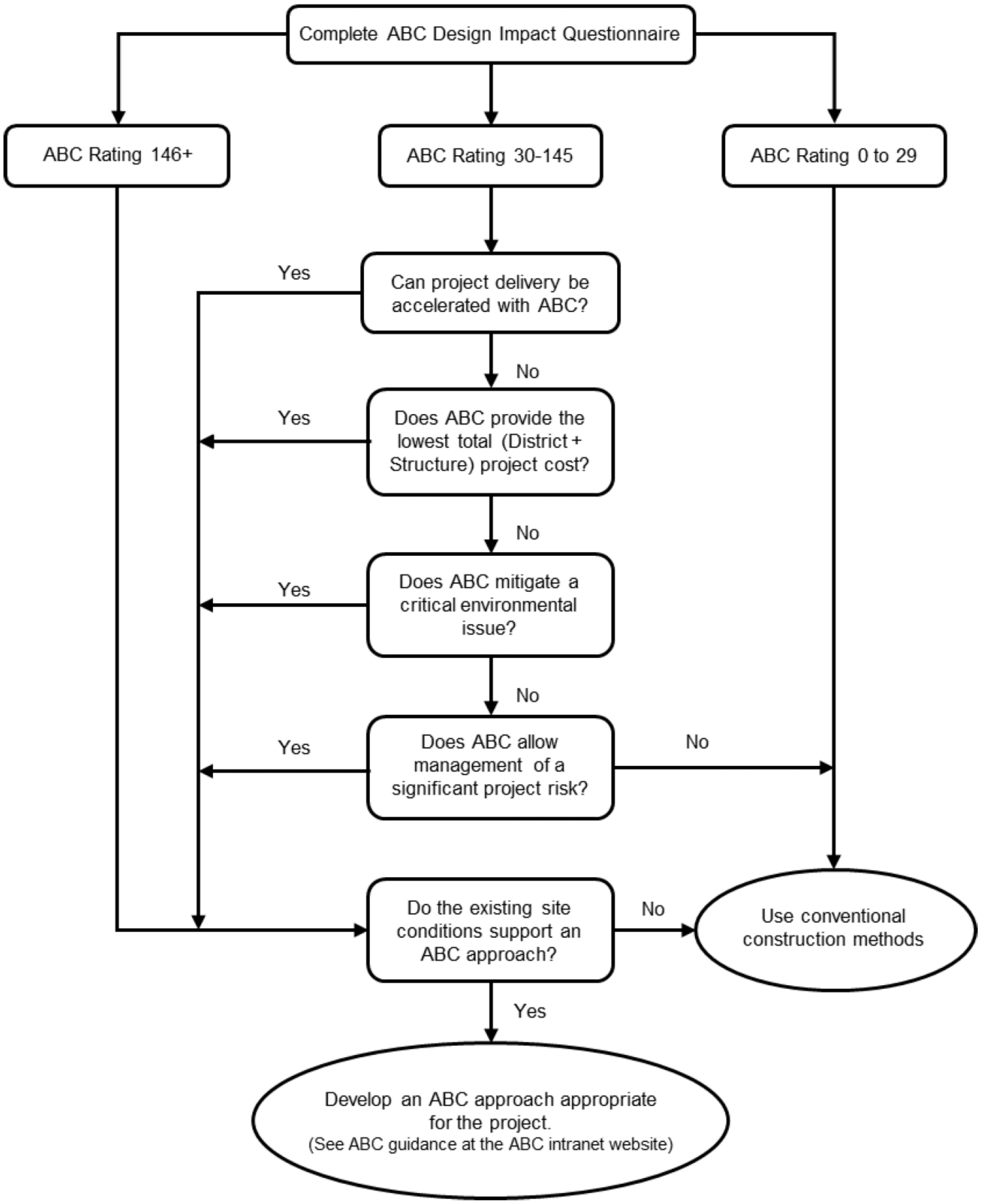


Figure 2.6 CALTRANS ABC decision-making flowchart (CALTRANS, 2021)

2.4.3.3 Colorado DOT

Like CALTRANS, Colorado DOT has developed a two-step approach to evaluate the use of ABC. The first phase is called "pre-scoping" and consists of applying a simple spreadsheet to determine whether it is convenient to use ABC based on local standards, while the second phase consists of using the FHWA AHP tool to have a deeper understanding of the response (Colorado DOT, 2012). The pre-scoping contains eight criteria, each one with its weight and score, that are considered the most relevant by the DOT, as shown in Table 2.6. The score goes from 0-5, and the weights have fixed values ranging from 3-10, depending on the criteria. The maximum possible adjusted score is 284, while the lowest possible score is zero. Such a score is normalized to obtain the ABC rating from 0-100%. Once the adjusted score is normalized, the user enters the flowchart shown and, depending on the rating, goes from top to bottom using one of the three possible inputs. Scores lower than 20 require the program director to decide whether to consider using ABC, while scores between 20-50 require a series of criteria or questions related to project delivery time, environmental impact, site conditions, and cost. If the ABC option does not provide the lowest total cost (direct and indirect), then the project is built using traditional construction, as the cost does not justify ABC.

Table 2.6 Pre-scoping ABC rating used in the Colorado DOT decision-making procedure. Adapted from Colorado DOT (2012)

Criteria	Score	Weight Factor	Adjusted Score	Maximum Score	Adjusted Score
Average Daily Traffic	0	10	0	5	50
Delay/Detour Time	0	10	0	5	50
Bridge Importance	0	5	0	5	25
User Costs	0	10	0	5	50
Economy of Scale	0	3	0	3	9
Safety	0	10	0	5	50
Railroad Impacts	0	5	0	5	25
Site Conditions	0	5	0	5	25

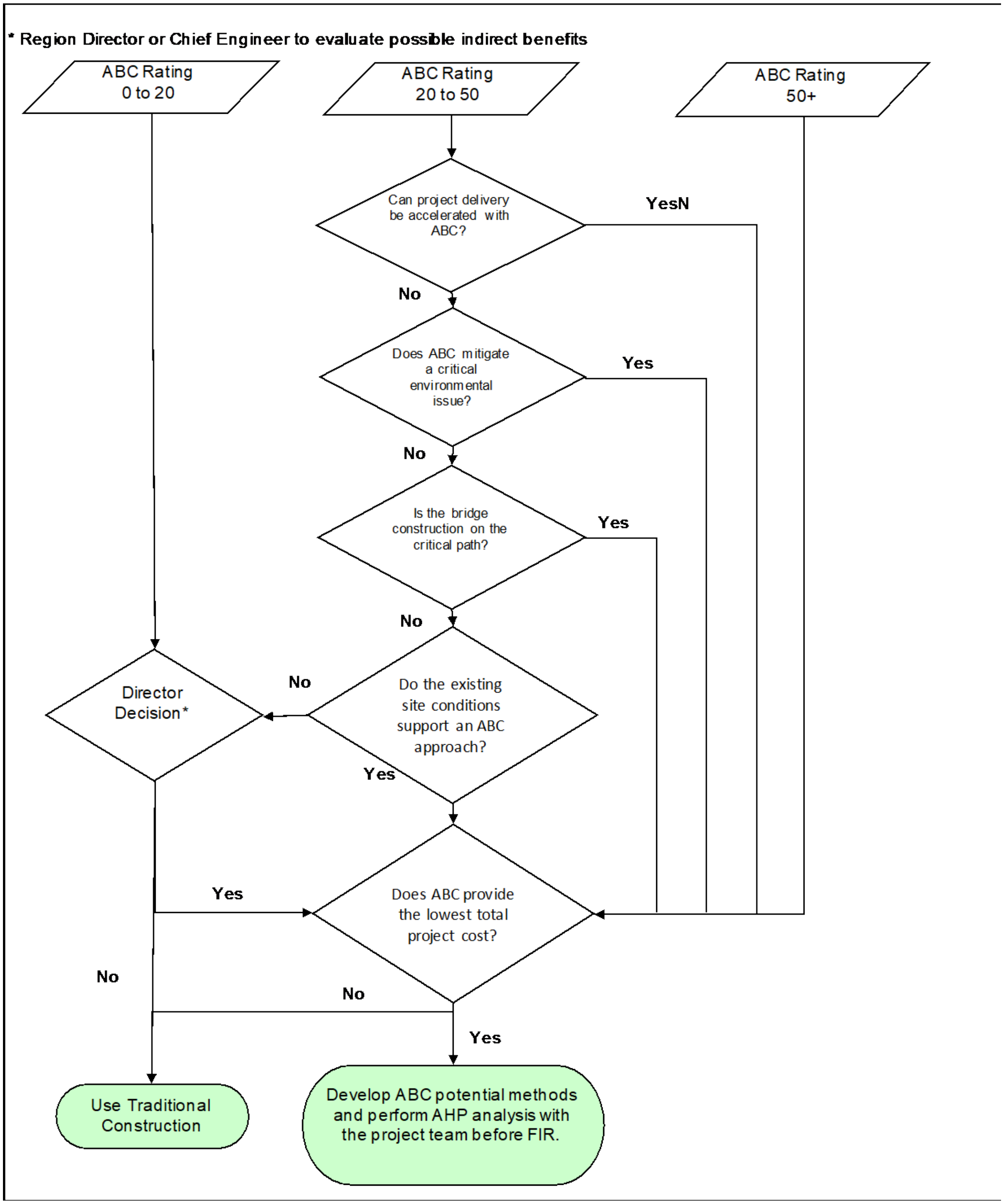


Figure 2.7 Colorado DOT ABC decision flowchart (Colorado DOT, 2012)

2.4.3.4 Connecticut DOT

Connecticut (CT) DOT has taken a single-phase ABC selection process in selecting whether to build with ABC (Connecticut DOT, 2019). CT DOT uses the ten criteria shown in the first column of Table 2.7 to judge the project's feasibility. Each criterion is judged with scores from 0 to 5, while the weights of each criterion are fixed by CT DOT. The two most important factors are the user impact reduction and the cost analysis, which have a weight of 30 each. The maximum final adjusted score is 540, which gives a rating of 100. Three possible outcomes are possible out of this analysis:

- If the rating is 60-100%, then use ABC.
- If the rating ranges between 50-60%, then consider ABC.
- If the rating goes from 0-50%, do not consider ABC.

Table 2.7 CTDOT ABC Decision matrix. Adapted from Connecticut DOT (2019).

Criteria	Score	Weight Factor	Adjusted Score	Maximum Score	Adjusted Score
Average Daily Traffic	0	10	0	5	50
User Impact Reduction	0	30	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. Mater Handling	0	5	0	0	0
Waterway Limitations	0	5	0	0	0

2.4.3.5 Iowa DOT

Iowa DOT has adopted a two-step decision-making tool based on a simple framework with scores and weights and the FHWA AHP to aid in selecting bridge types (Iowa DOT, 2024). The first step consists of using the “ABC worksheet” to obtain a score, deciding whether to use ABC, and then using the AHP to gain additional information. The tool uses the average annual daily traffic (AADT), the out-of-distance travel (OODT), the daily road user cost (DRUC), and the economy of scale (EOS) to determine the first-phase score, which has a maximum score of 100.

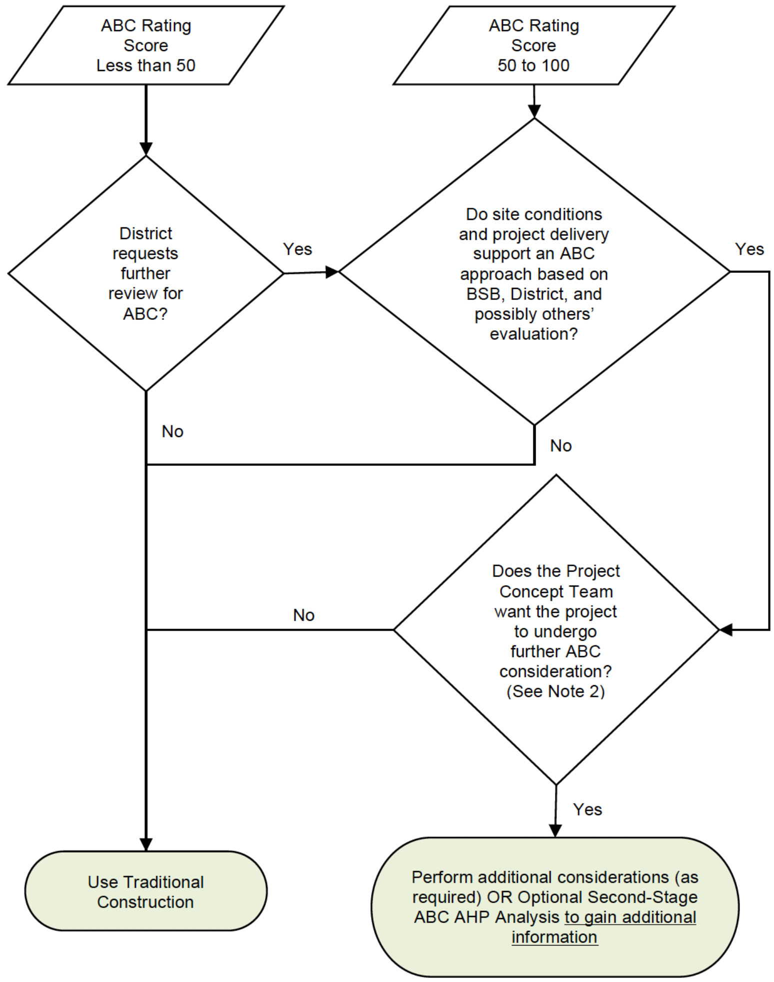


Figure 2.8 Iowa DOT decision flowchart (Iowa DOT, 2024)

2.4.3.6 MN DOT

Minnesota DOT conducts its ABC bridge selection in three stages that comprise an initial screening or ABC rating, project manager evaluation, and the identification of a final construction method (or contract administration method, or a combination of them) (Daubenberger & Barnes, 2017). The first stage of the process involves using the "stage 1 criteria matrix," which consists of implementing a list of criteria and weights that will ultimately yield a weighted score normalized to a maximum of 100%. Any bridge with a score greater or equal to 60% goes to stage 2. The main criteria have scores from 0 to 5 and weights as shown in the following list:

- Daily vehicle operating costs: 30% weight
- Average annual daily traffic: 20% weight
- Heavy commercial average annual daily traffic: 10% weight
- Detour length: 30% weight
- Traffic density: 10% weight

The second stage of the ABC decision process allows the DOT project manager to coordinate closely with the district traffic engineer, construction resident engineer, and the district bridge engineer to consider issues outside of the previously mentioned matrix, which is more subjective and site-specific. Additionally, ABC involves different detours, road closures, and work hours than those found in traditional construction; thus, the project manager considers these trade-offs of the method. The final stage (3) involves the selection of the ABC technique and contract administration method to be implemented in the project. This task is performed in collaboration with the project manager, the bridge office of preliminary plans, the final bridge design unit, the regional bridge construction engineer, and other disciplines.

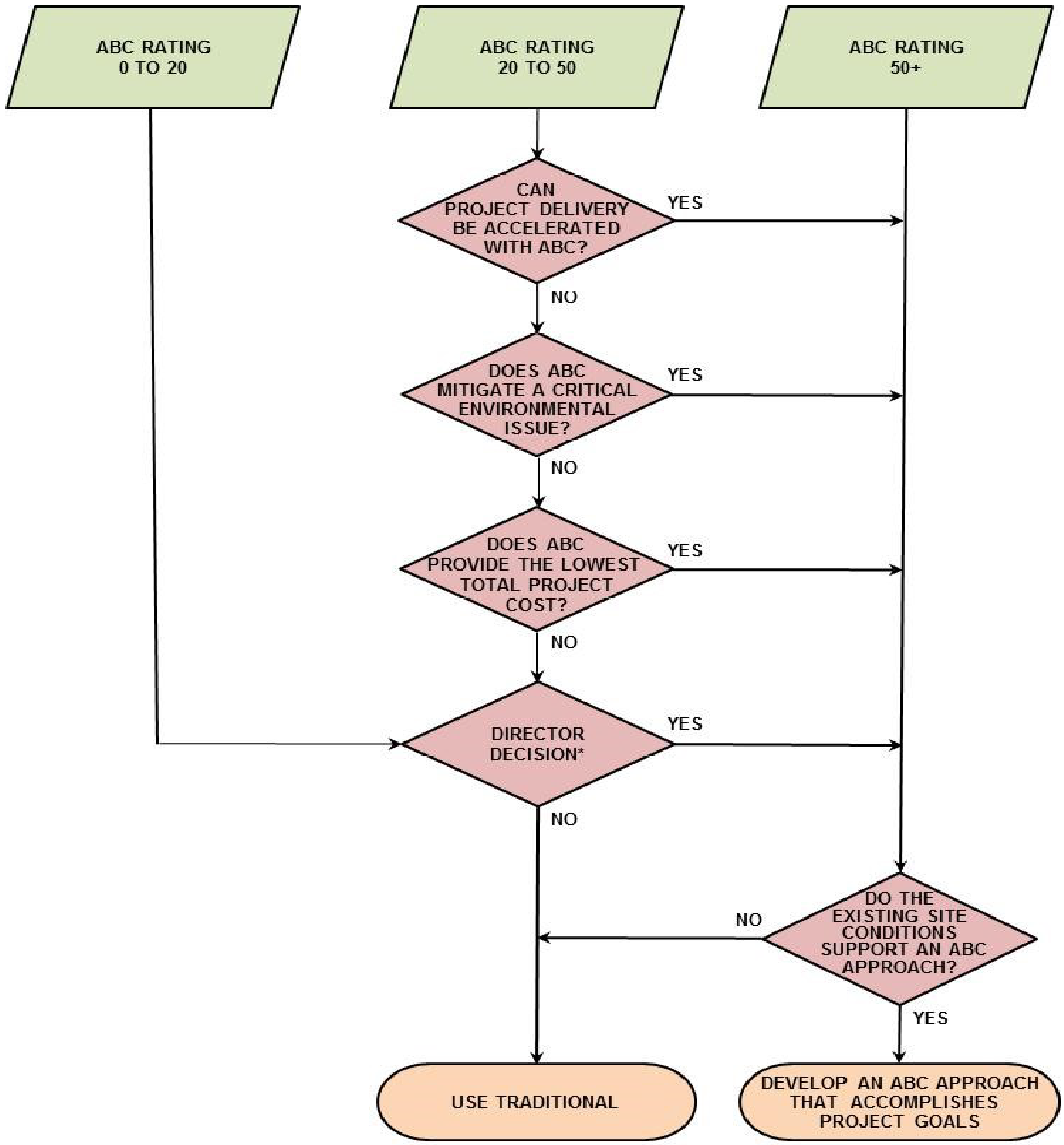
2.4.3.7 UDOT

The Utah DOT approaches the bridge selection problem using a decision matrix and a flowchart (UDOT, 2010), like the one seen above in the Colorado DOT subsection. The UDOT decision matrix uses eight criteria, each one with a maximum score of 5 and a minimum of 0, and weights that go from 3 to 10, depending on the criteria (see Table 2.8). The maximum adjusted score in this tool is 274 points, which are then represented as a percentage to obtain the rating, like the other tools mentioned above. After obtaining the score, the user compares it to the flowchart shown in Figure 2.9. There are three possible outcomes:

- 0-20%: The Director decides whether ABC is feasible.
- 20-50% The project needs more justification, including economics, to be considered for ABC.
- 50% and above: If the decision is supported by site conditions, then build.

Table 2.8 UDOT ABC decision tool (UDOT, 2010)

Criteria	Score	Weight Factor	Adjusted Score	Maximum Score	Adjusted Score
Average Daily Traffic	0	10	0	5	50
Delay/Detour Time	0	10	0	5	50
Bridge Classification	0	5	0	5	25
User Costs	0	10	0	5	50
Economy of Scale	0	3	0	3	9
Use of Typical Details	0	3	0	5	15
Safety	0	10	0	5	50
Railroad Impacts	0	5	0	5	25



* **Region Director or Project Development Director to evaluate possible indirect benefits.**

Figure 2.9 UDOT ABC decision flowchart

2.4.3.8 Wisconsin DOT

Wisconsin DOT (WisDOT) provides a decision matrix and a flowchart to determine how applicable an ABC method is for a given project within their jurisdiction (WisDOT, 2019). A screenshot of the WisDOT decision matrix is presented in Figure 2.10. The main criteria are disruptions on or under the bridge, user cost delays, construction time, environment, cost, risk management, and other sub-criteria, such as economy of scale, weather, and the use of standard details. Unlike other tools, the WisDOT decision matrix does not have scores from 0 to 5 but is variable depending on the criterion examined. One sub-criterion could go from 0-2, such as weather limitations, or from 0-8, like the restricted construction time. This tool also weighs the user cost and delays with the highest percentage, while the comprehensive construction cost has the lowest weight and score. Therefore, the indirect cost dominates the decision-making process when selecting a bridge construction method using the WisDOT tool.

After a score is computed, the user compares it to the flowchart shown in Figure 2.11 to decide which approach should be taken to develop the project. When the rating is above 50%, the project goes directly to the site condition assessment, while a rating between 21 and 49% requires examining whether the project can be accelerated using ABC and the cost can be reduced. When the ABC rating is lower than 21%, the use of ABC is not supported by the tool, but the DOT may have the initiative to perform the project if the existing conditions support the use of ABC. In addition to deciding on the bridge typology, the flowchart also provides multiple construction options based on reducing the bridge's out-of-service time or construction time.

% 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 2.10 Snapshot of Wisconsin DOT ABC decision-making tool (WisDOT, 2019)

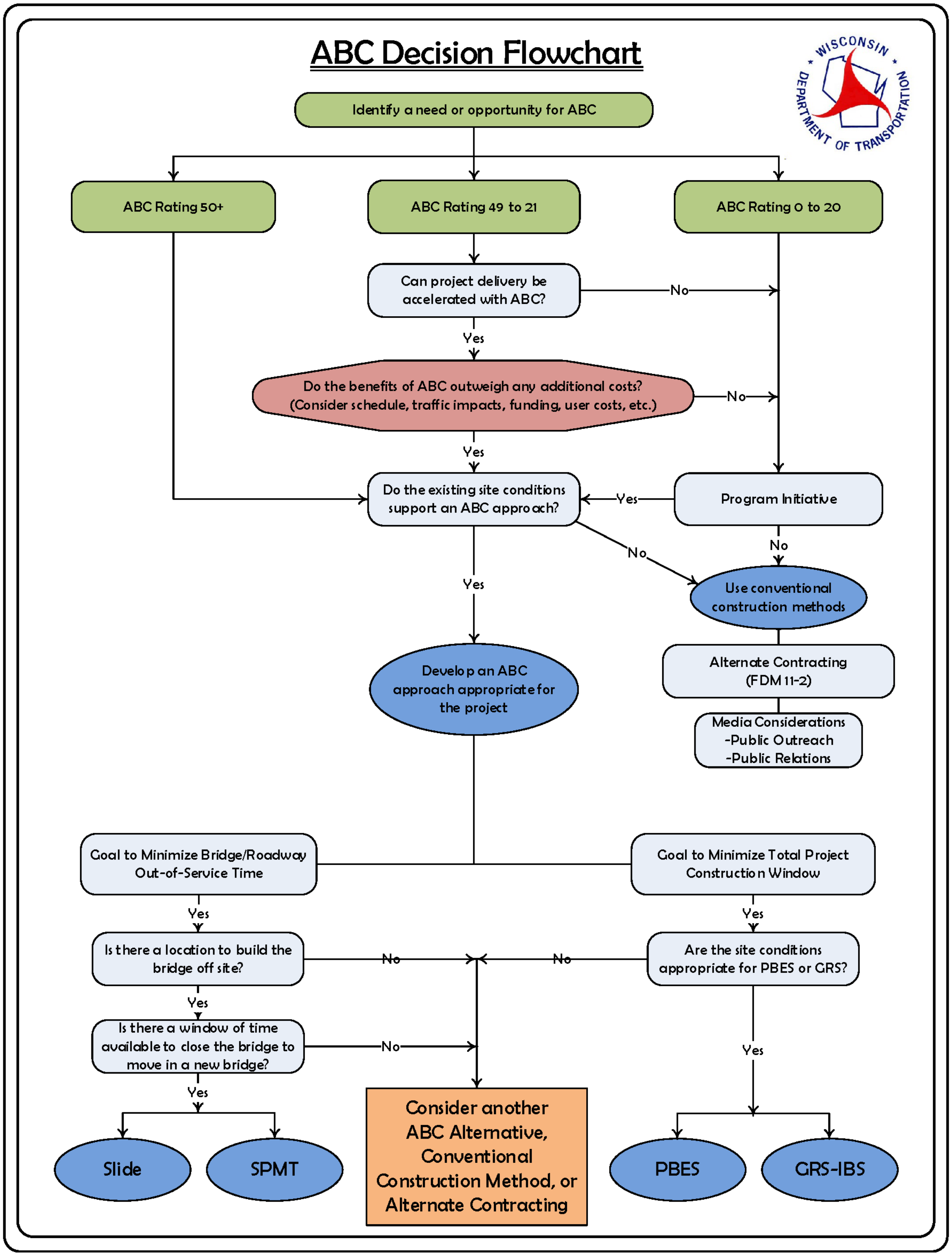


Figure 2.11 Wisconsin DOT ABC Decision Flowchart (WisDOT, 2019)

2.5 Summary

In this chapter, the authors discussed accelerated bridge construction (ABC) methods and how decision-making tools can be developed for the purpose of implementing ABC in new construction or bridge replacements. Departments of Transportation (DOTs) use various tools to decide whether to implement ABC. The main method used by DOTs in developing such decision-making tools is the analytical hierarchical process (AHP). This method involves identifying a set of criteria that are most relevant in the decision-making process, assigning scores and weights to each criterion, and then normalizing the final score to obtain a rating. Table 2.9 shows a list of criteria commonly used in developing decision-making tools by the analyzed DOTs in Section 2.4.1. Some criteria are highly relevant (with high weights assigned to them), while others have medium and low priority based on the weights the tools give to them. The main reason for applying weights is to skew the decision process towards the most relevant aspects of ABC that drive the cost down when compared to traditionally constructed bridges. In the context of bridge construction, factors such as average daily traffic (ADT), detour lengths, traffic delays, and related user costs contribute to the indirect expenses. Advanced bridge construction (ABC) serves to mitigate these expenses by transferring a portion of the user costs to the Department of Transportation (DOT) during the initial construction and planning phases. While certain criteria are given diminished priority based on their relative weights or are omitted during the selection of ABC, they are inherently encompassed within ABC, including enhanced safety measures, economies of scale, and adherence to standard details. Instances exist where DOTs may opt for ABC based solely on economic considerations, even if the minimum target ABC rating (in percentage) is not met. Furthermore, in exceptional cases, the site conditions may not align with the predetermined conditions set by the DOT. It is also plausible for DOTs to select ABC despite the inadequacy of decision tools alone to justify its implementation; however, in such scenarios, site conditions and economies of scale validate the decision.

Table 2.9 Summary of common criteria used in the decision-making process

Criteria	Times	Priority given based on the weight
Average daily traffic (ADT)	8	High
Out of distance travel/detour length	5	High
Delay/detour time	4	High
Bridge classification	6	Medium
User costs	8	High
Economy of scale	2	Low
Use of typical details	3	Low
Safety	5	Low
Railroad impacts	3	Low
Accessibility of navigation channels	4	Low
Weather-related impacts	3	Low
Environmental impacts	3	Low
Preference of the districts	3	Low
Traffic and maintenance	2	Low
Utility impacts	2	Low
Traffic density	5	Medium
Construction cost	3	High
Right of way	1	Low
Toll revenue	1	Low
Revenue loss	2	Medium
Construction personnel safety	1	Low
Physical constraints	3	Low
Emergency replacement	2	Low
Impact to economy	4	Medium

Chapter 3 Tool Development

3.1 Introduction

This chapter presents the development of the ABC decision-making tool, including the step-by-step process, selection of criteria and factors, selection of weights, a sensitivity analysis of the tool to assess its performance, and a brief overview of the performance of other DOT tools when implemented across a bridge dataset provided by the Nebraska Department of Transportation (NDOT). The dataset is explained briefly in this chapter, and histograms are plotted to explain the distribution of bridges across the dataset in terms of the ADT, ADTT, number of spans, maximum span length, and detour lengths in case they were to be replaced.

3.2 Tool Development Process

3.2.1 Selection of Decision-making Technique

The most common decision-making technique implemented in the different frameworks found in other DOTs' tools is the analytical hierarchical process (AHP), which consists of assigning scores and weights to multiple criteria and then normalizing them to obtain what many of them call "ABC Rating." The ABC Rating measures how beneficial it might be to implement the ABC method to construct a new bridge or replace an old one. The AHP was also selected in this study due to its user-friendliness, simplicity, and popularity across DOTs. The AHP has also been heavily studied in the literature, as mentioned in the previous chapter, and there are hundreds of applications in and outside of bridge engineering, making it more accessible for other engineers in terms of general knowledge. Finally, the AHP is also easy to modify, which helps DOTs change the criteria, scores, and weights based on their experience and knowledge of other DOT's practices.

3.2.2 Selection of Criteria and Scale

The AHP criteria used in this section were selected based on meetings with NDOT and the PI, the frequency of using the criteria in the literature, and the authors' experience with ABC. The selected criteria are the ones listed below, and their scale ranges from 0 to 5:

- Average daily traffic (ADT) in vehicles per day
    - Scale 0: No traffic impact
    - Scale 1: Less than 4,000
    - Scale 2: 4,001 to 8,000
    - Scale 3: 8,001 to 12,000
    - Scale 4: 12,001 to 16,000
    - Scale 5: More than 16,000
- Average daily truck traffic (ADTT) in vehicles per day
    - Scale 0: 0 to 300
    - Scale 1: 301 to 900
    - Scale 2: 901 to 1,500
    - Scale 3: 1501 to 2,100
    - Scale 4: 21,001 to 2,700
    - Scale 5: More than 2700
- Detour time (DT) in miles
    - Scale 0: Less than 5
    - Scale 1: 5 to 8
    - Scale 2: 9 to 12
    - Scale 3: 13 to 16

- Scale 4: 17 to 20
- Scale 5: More than 20

- Economy of scale (EOS) in bridges or spans replaced per project
  - Scale 0: Only one single-span bridge is being replaced
  - Scale 1: 2 bridges/spans bridge
  - Scale 3: 3 bridges/spans are being replaced
  - Scale 5: More than 3 bridges/spans are being replaced
- Railroad Impact (RI)
  - Scale 0: No railroad or minor railroad impact
  - Scale 5: Multiple mainline railroad tracks
- Use of typical details (TD)
  - Scale 0: No use due to complex geometry
  - Scale 1: Curved and skewed bridges
  - Scale 2: Curved bridges
  - Scale 3: Skewed bridges
  - Scale 4: Simple geometry with some typical details
  - Scale 5: Simple geometry, with favorable use of typical details

3.2.3 Selection of Weights

The value of the weights is dictated by the importance of a criterion in the decision-making process. This importance is normally decided by the jurisdiction using the tool and may be subject to variation over time due to a change in priorities within the state or country. As observed from the literature review, the values assigned the highest weight among DOTs are the ADT, the detour length and time, user costs, and the cost analysis. The initial selected weights are presented in Table 3.1, where the most relevant criteria are the ADT, the ADTT, the detour time, and the disruption on and under the bridge. Once the weights are multiplied by the score, they are normalized by the maximum possible score of 400, which is the sum of the product of the maximum score times the weight of each criterion, to obtain the ABC rating of the bridge expressed as a percentage.

Table 3.1 Suggested weights for the criteria used in the decision-making tool.

Criteria	Weight (%)
Average daily traffic (ADT), in vehicles per day	25
Average daily truck traffic (ADTT), in vehicles per day	15
Detour time (DT), in minutes	15
Economy of scale (EOS), bridges/spans per project	10
Railroad Impact (RI)	5
Use of typical details (TD)	10

3.2.4 Passing Criteria

Once the scores are computed, the passing criteria are applied. For this project, three possible outcomes are presented: 1) if the computed ABC rating is greater or equal to 50%, then apply ABC; 2) if the computed ABC rating is between 31 and 49%, then examine whether the bridge needs emergency replacement, the cost of using ABC is smaller than traditional construction, or the project can be accelerated using ABC without exceeding percentage of the cost of a traditionally constructed bridge, determined by the DOT; and 3) if the score is lower or equal than 30%, then the ABC method may not be feasible. The corresponding flowchart is displayed in Figure 3.1.

3.3 Characteristics of Nebraska Bridges Needing Replacement

A dataset comprised of 123 bridges that potentially need replacement across the state of Nebraska was provided by NDOT to conduct a study on potential ABC candidates. Figure 3.2 shows the histograms of the ADT and the ADTT for the entire dataset. It can be observed from these figures that the majority of candidate locations (60) have low traffic with ADTs below or equal to 2,000 vehicles per day. Similarly, the ADTT is very low for 74 locations at 300 vehicles per day or less, indicating the candidate bridges are mostly low-traffic bridges. However, nearly 10% of the bridges have ADTs over 10,000 vehicles, indicating ideal situations for replacement using ABC when checking the score assigned similar ADT using peer state decision-making tools. Figure 3.3 shows the histograms of the number of spans (a), span length (b), and the total length (c) of the bridges in the database. More than 70% of the bridges in the database have 3 or more spans, with spans in the range of 35 to 225 ft. However, the majority of the bridges are shorter than 165 ft in length, meaning that they might be easy to replace depending on the local conditions.

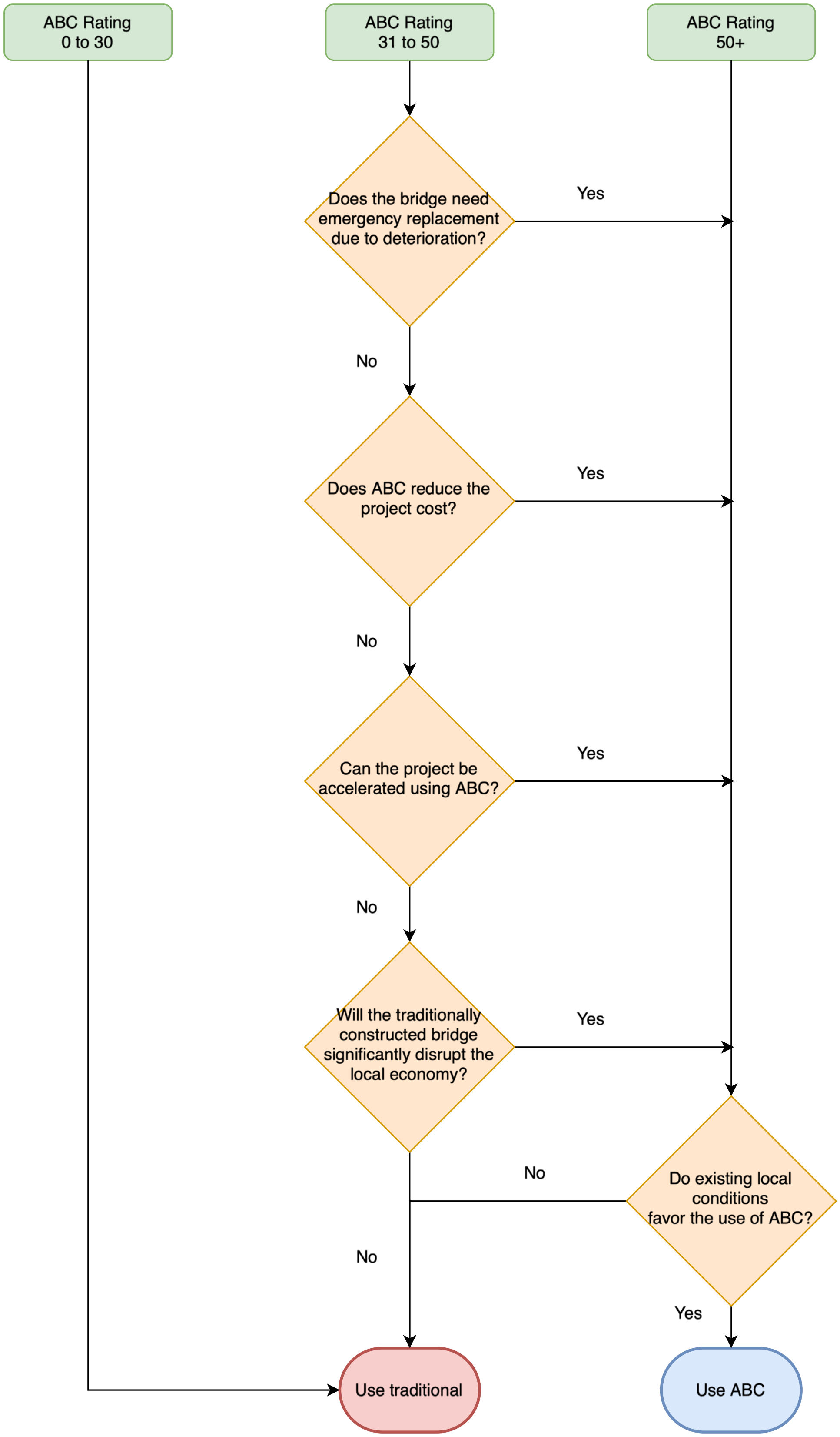


Figure 3.1 Flowchart illustrating the possible outcomes of the decision-making tool

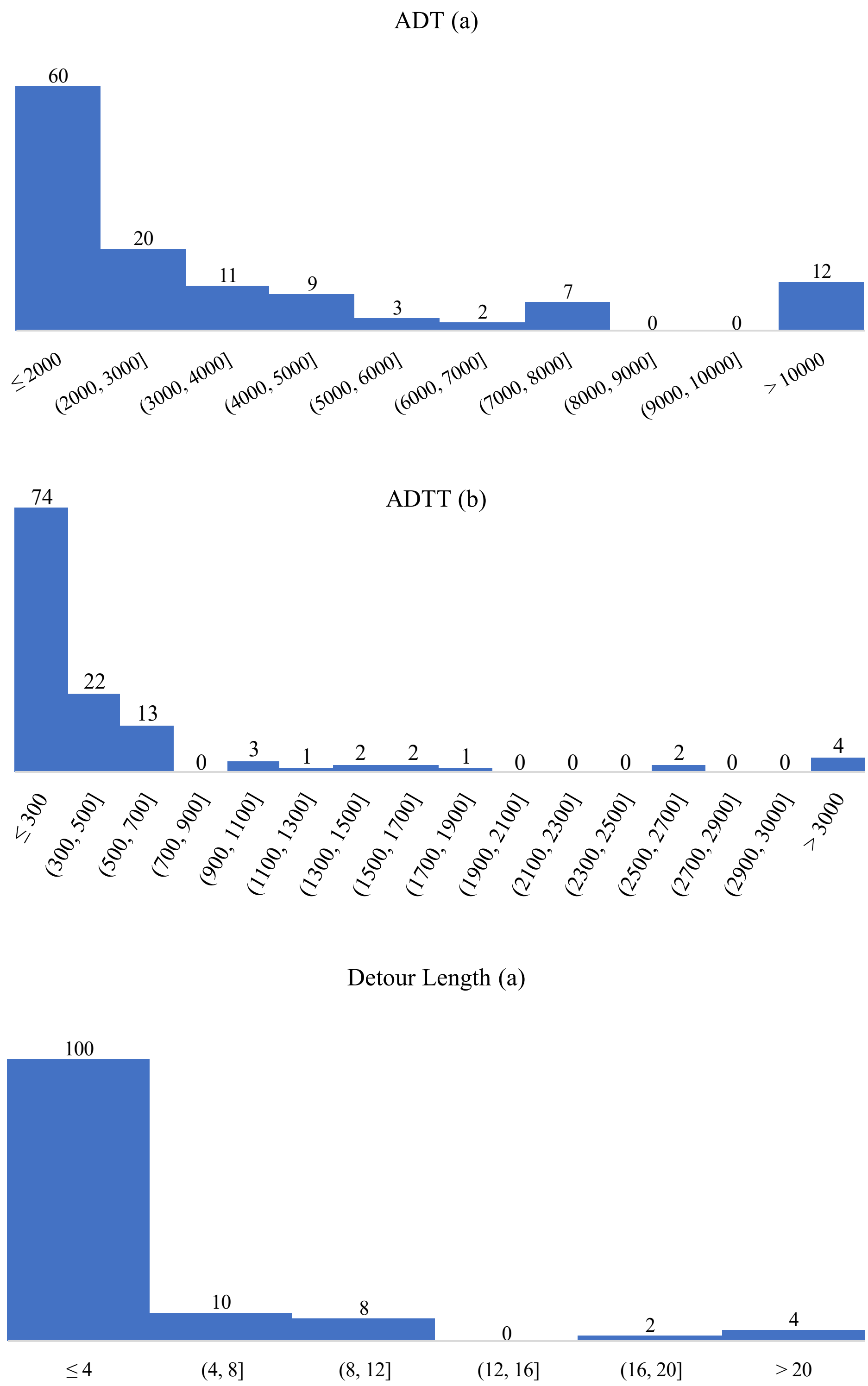


Figure 3.2 Histograms of the ADT (a), the ADTT (b), and the detour length (c) for the selected bridges

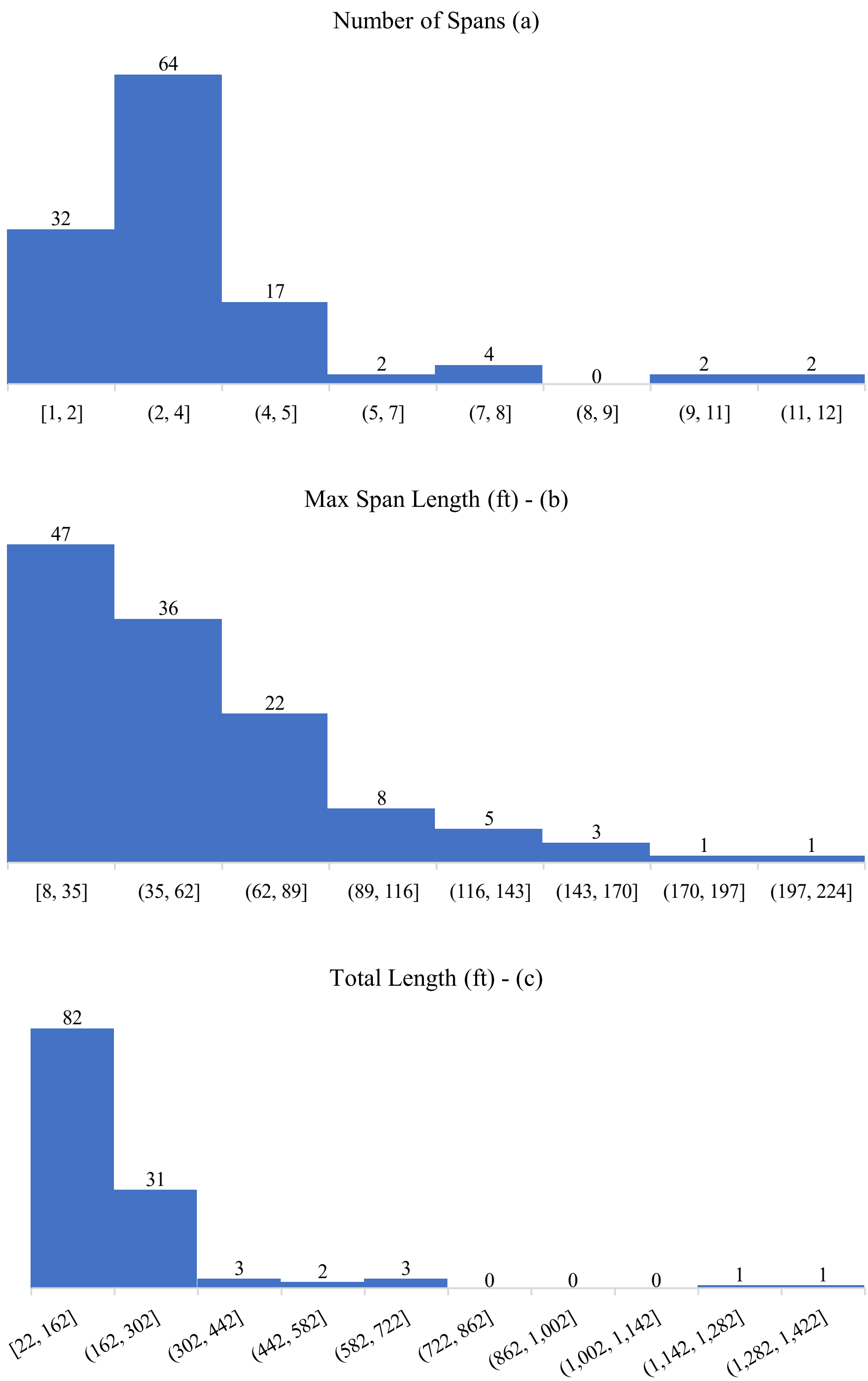


Figure 3.3 Histograms of the detour length in the event a given bridge was reconstructed (a), the number of spans in the bridge (b), and the maximum span length (c) across the entire dataset.

3.4 Sensitivity Analysis

This section deals with two essential aspects of the tool. The first one tackles the sensitivity of the tool to deviations of average and low values in the matrix by performing a parametric study, while the second one tests the performance of the tool on the entire dataset of Nebraska bridges. Parametric studies help users understand the most relevant factors for normal conditions, whereas testing the performance within the database helps the DOT identify which bridges are candidates for ABC.

3.4.1 Parametric Study

The parametric study performed in this investigation consisted of testing the developed tool using average values for all variables and then increasing or decreasing the value of one characteristic to understand the global behavior of the tool. For this study, all the variables but the railroad impact were examined. The railroad impact criterion only has 5% weight in the matrix and has little influence on global performance. The average and median values of the other variables are presented in Table 3.2, which yields an average ABC rating of 31%, meaning that the average replacement falls in the middle of the possible outcomes presented in the flowchart illustrated in Figure 3.1.

Table 3.2 Average values of the criteria used in the decision-making tool

Criteria	Average or mode	Score (0-5)	Weight (%)	Total
Average daily traffic (ADT), in vehicles per day	5,158	2	25	50
Average daily truck traffic (ADTT), in vehicles per day	499	1	15	15
Detour time (DT), in minutes	Less than 5 minutes	0	15	0
Economy of scale (EOS), bridges/spans per project	3 spans	3	10	30
Railroad Impact (RI)	No railroad impact	0	5	0
Use of typical details (TD)	Skewed Bridges	3	10	30

Figure 3.4 shows the variation of the ABC rating as a function of four criteria for an average bridge in the provided dataset. Panel (a) shows the effect of the ADT score on the ABC rating and the "ABC Ready" threshold with a dashed line at 50%. The ADTT, Detour time (DT), and Typical Details (TD) are similarly plotted in panels b-d. In general, the only criteria that drastically affect the ABC rating are the ADT score and the DT score, meaning that projects with high ADTs or long DT will trigger the use of ABC provided average conditions are met.

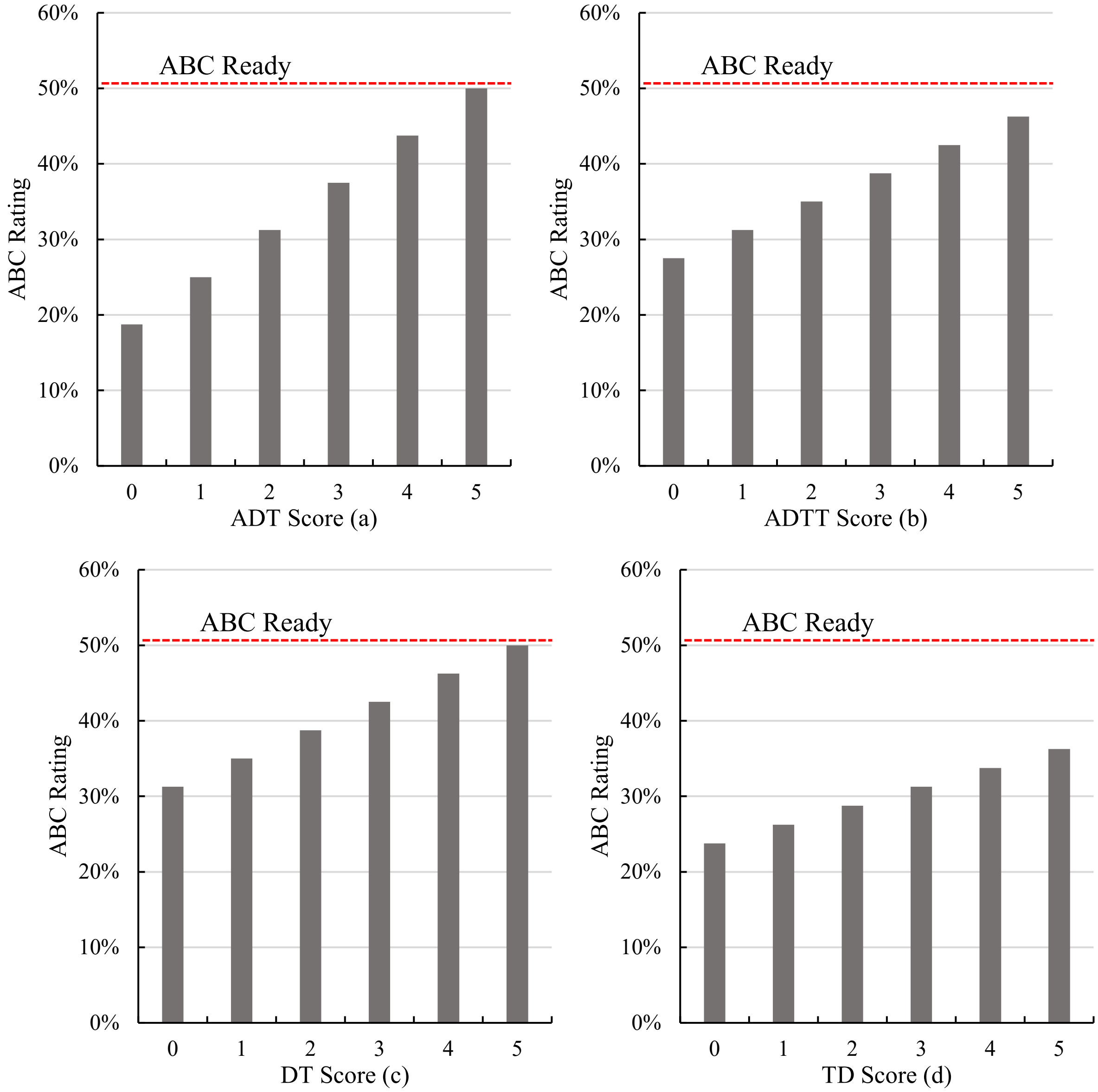


Figure 3.4 Variation of the ABC rating as a function of the ADT score (a), the ADTT score (b), the DT score (c), and the TD score (d).

In the case of the TD and economy of scale (EOS) criteria, the ABC rating changes moderately when these scores go from 0 to 5, indicating a mild sensitivity to those parameters for an average bridge in the dataset (see Figure 3.5).

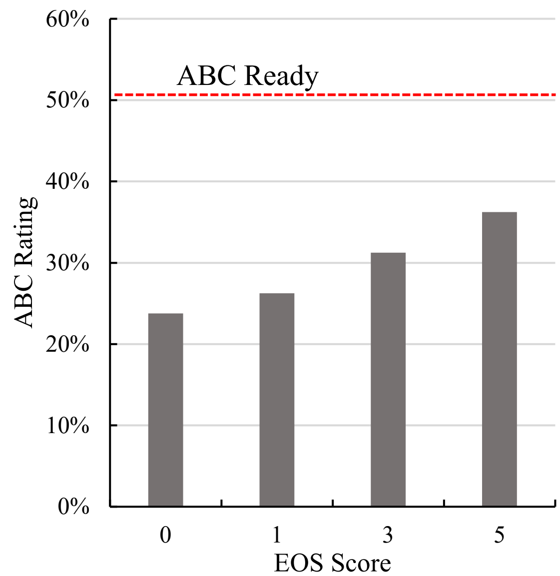


Figure 3.5 Variation of the ABC rating as a function of the EOS score.

3.4.2 Performance of the tool on the provided dataset

Figure 3.6 shows a histogram of the number of bridges in Nebraska categorized by their suitability for traditional construction, need for a second evaluation, or accelerated bridge construction. The x-axis represents the ABC rating score in 10% increments, except for the 50-51 bin, which has been done to show the selected threshold that triggers the "use ABC" condition in the decision-making tool. The left y-axis shows the frequency, while the right y-axis shows the cumulative percentage, represented by the square legend. The histogram is also broken down into three zones, delimitating which bridges belong to traditional construction (ABC Rating < 31), need a second evaluation (ABC Rating in the range of 31-50), or are ABC candidates (ABC Rating ≥50).

As shown in the figure, 38 bridges fall within the 30-50 bin ABC rating range, indicating that many bridges need a second evaluation following the flowchart shown in Figure 3.1. If any of those conditions favor using ABC, then those bridges would likely be constructed using ABC, especially those close to the 50% ABC rating. From the entire dataset, only 10 bridges are candidates for ABC construction, largely due to having long detours and large ADTs and ADTTs. In summary, only 10 bridges are true candidates for ABC, 38 need a second evaluation, and 75 fit the traditional construction criteria.

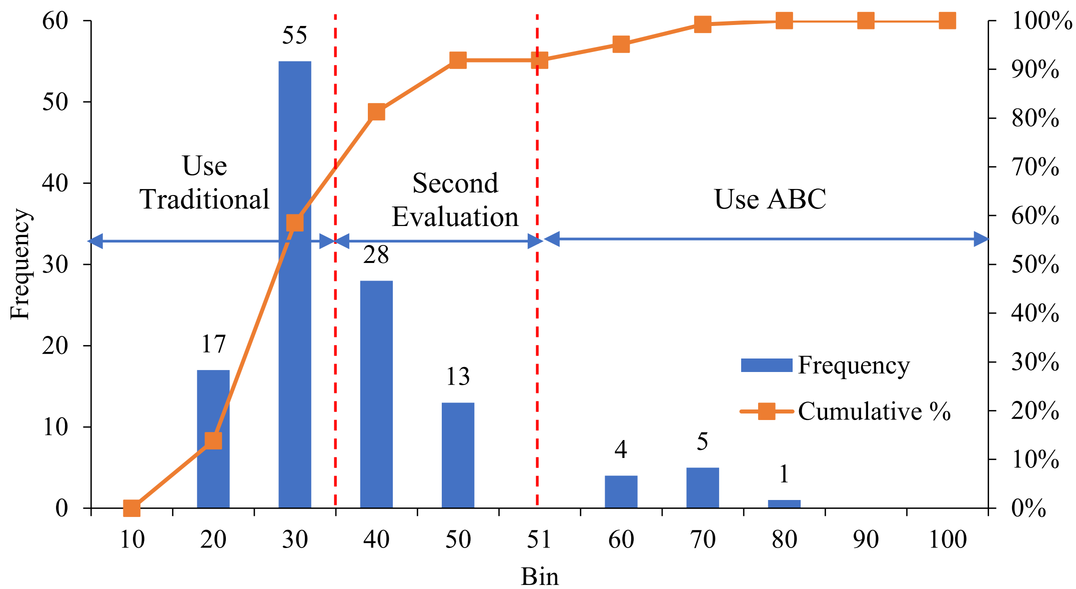


Figure 3.6 Histogram of the ABC rating for the 123 bridges in the database using the developed tool

Chapter 4 Discussion

4.1 Introduction

This chapter deals with the discussion and comparison of the developed tool with two other DOT tools, which can be implemented using data straight out of the National Bridge Inventory (NBI) without performing additional complex analyses of the NBI data. The first tool is the Iowa DOT tool, and the second one is the Minnesota DOT decision-making tool, both explained in Chapter 2. These tools are used during the first phase of the bridge construction planning to determine ABC candidates, which will subsequently be analyzed in economic terms to determine the feasibility of building them using ABC. Therefore, whenever it is mentioned in this chapter that a bridge is ABC-ready, it means that the bridge has successfully passed stage/phase 1.

4.2 Performance of other tools

4.2.1 Iowa DOT tool

4.2.1.1 Sensitivity

Figure 4.1 shows the variation of the ABC rating as a function of the AADT (a) and the daily road user costs (DRUC) (b). As panel (a) shows, the AADT has a significant effect on the average bridge in the dataset when examining the possibility of using ABC to replace it, mainly due to the 30% factor assigned to the criterion. However, the average bridge with a substantial AADT will not qualify for ABC using this tool as the maximum score of five does not trigger the ABC-Ready threshold. In contrast, the DRUC criterion pushes the ABC rating beyond the 50% mark established in the IA DOT tool, making it ABC-Ready when the score is maxed out at 5/5. This is mainly due to the low average score related to the DRUC criterion in the dataset. Figure 4.2 shows the effect of the out-of-distance travel (OODT) and the economy of scale (EOS) on the ABC rating for the average bridge in the dataset, in panels (a) and (b), respectively. Since the EOS does not have a large weight applied to it and the score only goes from zero to three, it has a negligible effect on the ABC rating. The OODT greatly influences the ABC rating for the typical bridge in the dataset, triggering the rating to ABC-Ready when the OODT scores 5/5.

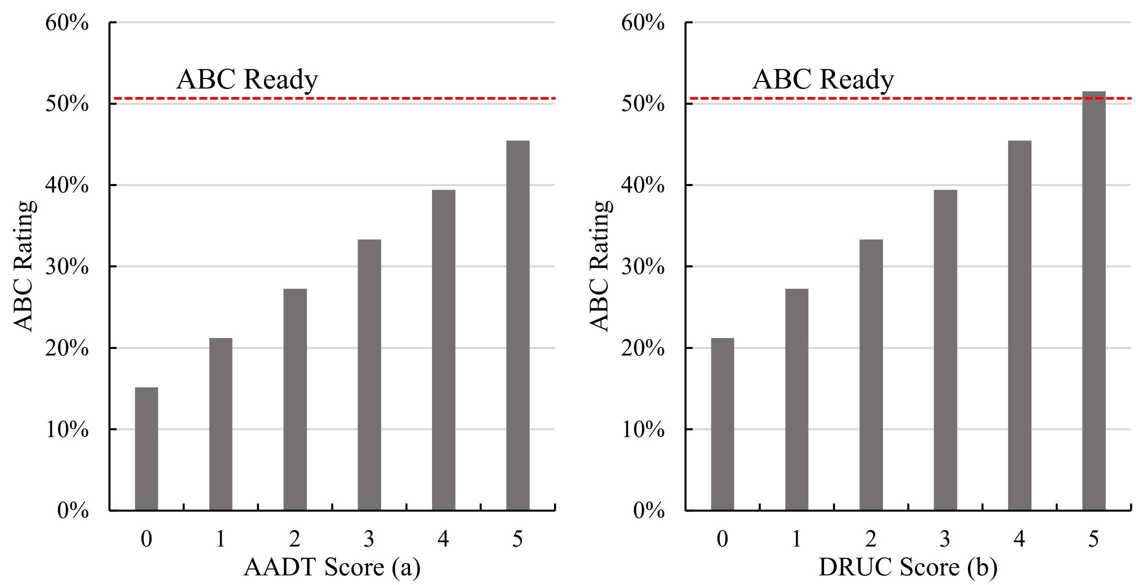


Figure 4.1 Variation of the ABC rating as a function of the AADT score (a) and the DRUC score (b)

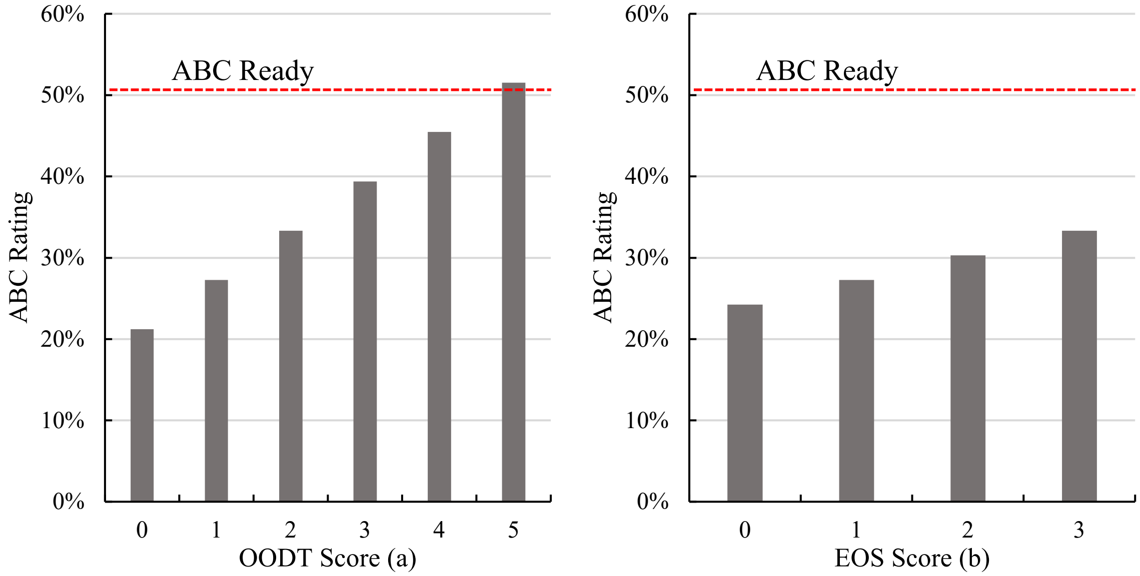


Figure 4.2 Variation of the ABC rating as a function of the OODT score (a) and the EOS score (b)

4.2.1.2 Performance

Figure 4.3 shows a histogram of the number of bridges categorized by their suitability for traditional or accelerated bridge construction in Nebraska. In the graph, the horizontal axis represents the ABC rating score in 10% increments, except for the 50-51 bin range. This range highlights the threshold for triggering the "use ABC" condition in the Iowa DOT decision-making tool. The frequency is shown on the left vertical axis, while the cumulative percentage is shown on the right vertical axis. The histogram is divided into two zones, indicating bridges suitable for traditional construction (ABC rating < 50) and ABC candidates (ABC rating ≥ 50). It's worth noting that due to the lack of information on the AADT, the criterion was assumed to be equal to the ADT. The figure illustrates that out of the entire dataset, only nine bridges are candidates for ABC construction. This is mainly due to long detours and high AADTs and ADTTs. Conversely, 143 bridges are better suited for traditional construction.

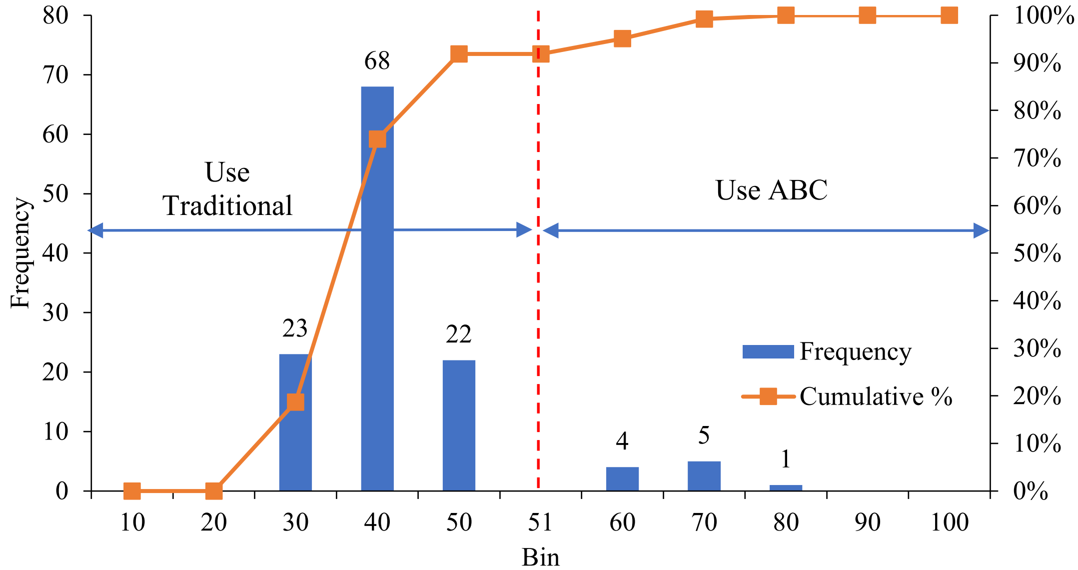


Figure 4.3 Histogram of the ABC rating for the 123 bridges in the database using the first phase of the Iowa DOT tool

4.2.2 Minnesota DOT tool

4.2.2.1 Sensitivity

Figure 4.4 shows the variation of the ABC rating as a function of the Daily Vehicle Operating Cost (DVOC) (a) and the AADT (b). In this tool, the minimum ABC rating is 60% to be considered ABC-ready. As panels (a) and (b) show, both the DVOC and the AADT have a significant effect on the average ABC rating in the dataset when examining the possibility of using ABC to replace it, mainly due to the 30% weight assigned to the former criterion, while 20% to the latter. Both criteria change the ABC rating from traditional to ABC-Ready after having a score of four or greater. Figure 4.5 shows the effect of the heavy commercial annual average daily traffic (HCAADT) and the detour length on the ABC rating for the average bridge in the dataset, in panels (a) and (b), respectively. Since the HCAADT does not have a large weight applied to its score (10%), it has a negligible effect on the ABC rating. The detour length, in contrast, dramatically increases the ABC rating for the typical bridge in the dataset, triggering the rating to ABC-Ready when the detour length scores 5/5.

Finally, Figure 4.6 shows the effect of the traffic density score on the ABC rating. The traffic density is defined as the AADT divided by the road width, yielding results in units of vehicle per foot. In this case, the criterion has a moderate effect on the ABC rating but does not push the rating from traditional to ABC-ready when reaching its maximum value, meaning that even when the maximum score is reached in a typical bridge, it will not automatically turn the bridge into ABC-Ready.

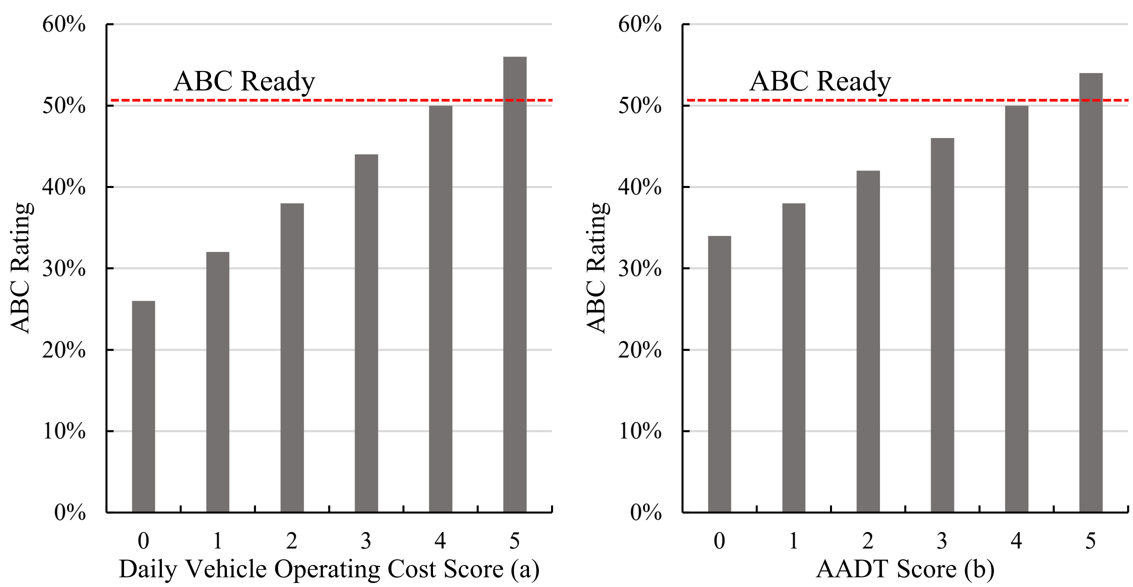


Figure 4.4 Variation of the ABC rating as a function of the Daily Vehicle Operating Cost score (a), the AADT score (b)

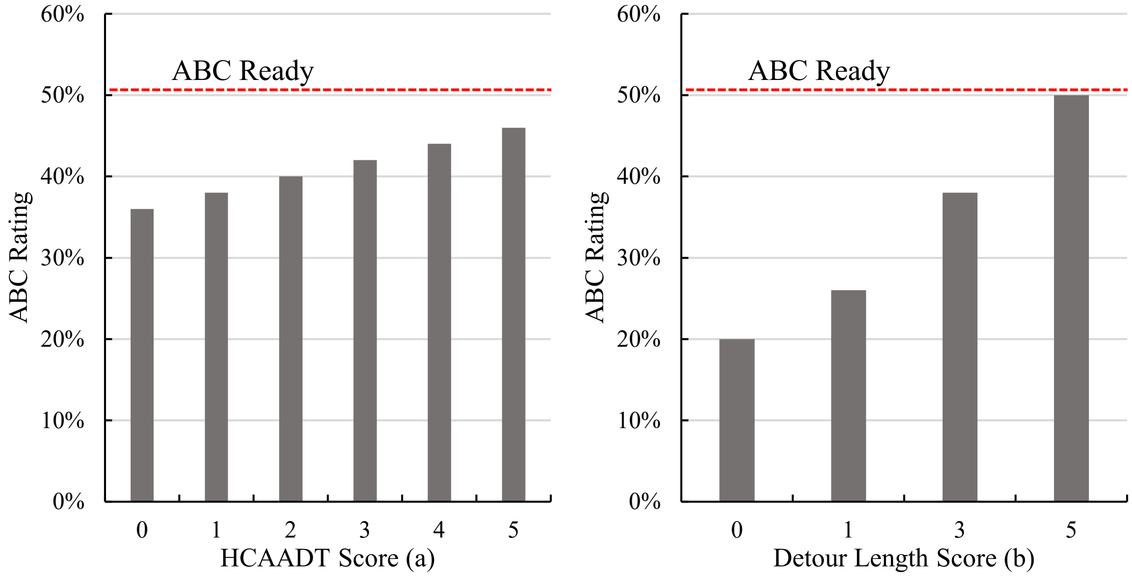


Figure 4.5 Variation of the ABC rating as a function of the HCAADT score (a) and the Detour Length score (b)

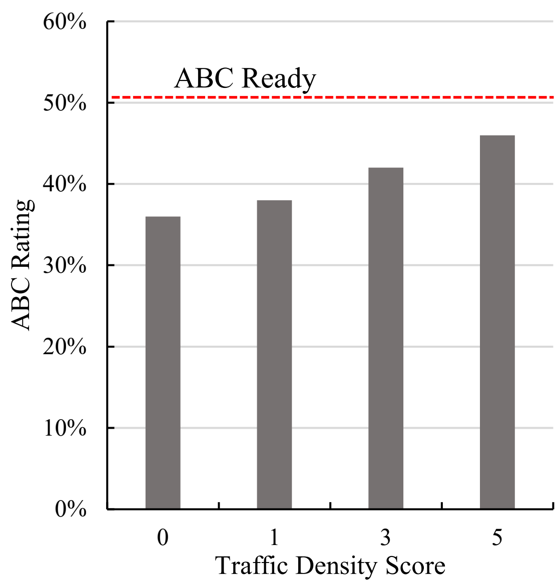


Figure 4.6 Variation of the ABC rating as a function of the Traffic Density Score

4.2.2.2 Performance

Figure 4.7 shows a histogram of the number of bridges categorized by their suitability for traditional or accelerated bridge construction in Nebraska. The chart uses the horizontal axis to show ABC rating scores in 10% increments, except for the 60-61 range, which is the threshold for triggering the "use ABC" condition in the Minnesota DOT decision-making tool. The frequency is displayed on the left vertical axis, while the cumulative percentage is shown on the right vertical axis. The histogram is split into two areas, indicating bridges suitable for traditional construction (ABC rating < 60) and ABC candidates (ABC rating ≥ 60). It is important to note that due to the lack of AADT information, the criterion was assumed to be equal to the ADT. The figure shows that out of the entire dataset, only 10 bridges are candidates for ABC construction, primarily because of long detours and high AADTs. On the other hand, 113 bridges are better suited for traditional construction.

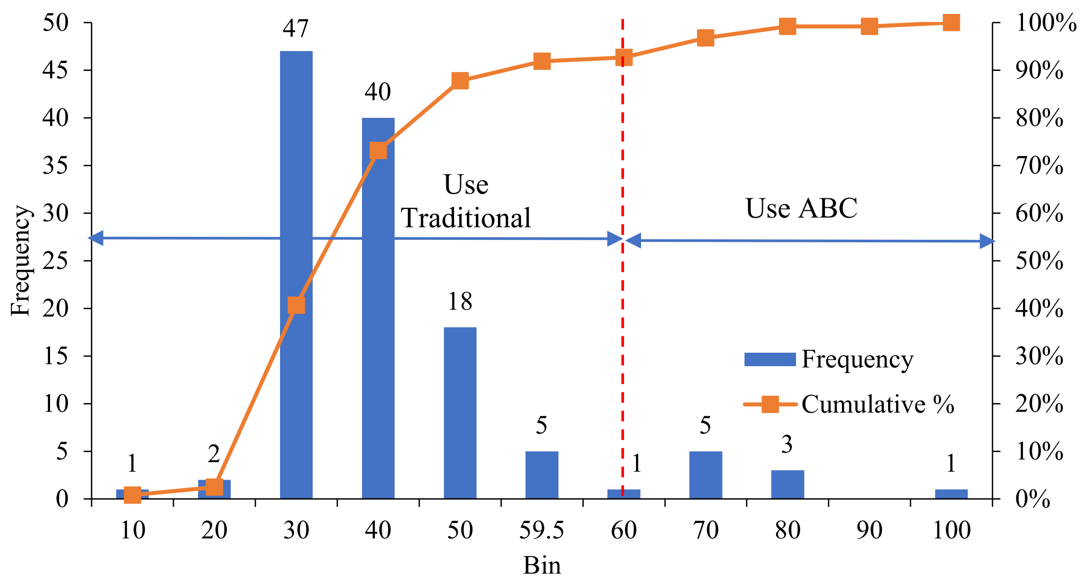


Figure 4.7 Histogram of the ABC rating for the 123 bridges in the database using the first phase of the Minnesota DOT tool

4.3 Comparison of the developed tool's performance with other tools

In general, all decision-making tools performed similarly in terms of bridges that would benefit more from using ABC over traditional construction. In summary, the developed tool yielded 10 ABC bridge candidates, while the IA DOT tool resulted in nine candidates and the MN DOT tool outputted 10 bridge candidates. In general, the three tools matched eight of the bridges in the dataset, as shown below:

1. S015 10547, 3S SCHUYLER at PLATTE RIVER
2. S030 37773L, SJCT US30/US81 .3N at Loup River
3. S075 08730L, IN OMAHA at J ST
4. S075 08730R, IN OMAHA at J ST
5. S080 40105, I80/I180 INTRCHG at I80
6. S080 40106, I80/I180 INTRCHG at I80
7. S275 18809, 36th & L Street Omaha at BNSF RR 074-715-B
8. SL79E00145, 1N MELBETA at NORTH PLATTE RIVER

Chapter 5 Summary and Conclusions

This report investigates the creation and assessment of a decision-making tool developed to aid the Nebraska Department of Transportation (NDOT) in determining the suitability of the Accelerated Bridge Construction (ABC) method for bridge replacement projects. The tool was developed based on the Analytic Hierarchy Process (AHP) to integrate different criteria, including Average Daily Traffic (ADT), Average Daily Truck Traffic (ADTT), detour time, railroad impact, economy of scale, and the use of typical details, which were found to be paramount in the decision-making process across the state. In all cases, the scale varied from 0 to 5, where 0 was considered “no effect” on ABC decision, and 5 was considered a “high effect.” Weights were assigned to each criterion, ranging from 5 to 25%, and applied to the score in consideration.

A sensitivity analysis was conducted to evaluate the tool’s performance and identify the most significant factors influencing the implementation of ABC for average Nebraska bridges. After testing the tool on a dataset of 123 local bridges needing replacement, it identified 10 confirmed candidates for ABC, 38 requiring further evaluation, and 75 more suitable for traditional construction methods. Additionally, the developed tool was compared with two existing decision-making tools from other states, showing similar results in 80% of the bridge replacement cases for a combination of the Iowa and Minnesota DOT tools. In the case of the Iowa DOT decision-making tool, the match was at 90%, while the Minnesota DOT’s tool matched 80%.

Future research could focus on incorporating a cost analysis of the indirect cost and adding variables outside of the National Bridge Inventory, such as the disruption to the local economy, and updating driver costs associated with the detours. Additionally, the tool can be studied outside of the local dataset, over a larger dataset, and with a dataset comprised of already ABC-built bridges to validate its accuracy.

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