ABC-UTC GUIDE FOR:

DEVELOPING ABC SUCCESS INDEX TO SUPPORT CONTRACTORS DURING PRE-PROJECT PLANNING

ACCELERATED BRIDGE CONSTRUCTION
UNIVERSITY TRANSPORTATION CENTER

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ABSTRACT

Accelerated bridge construction (ABC) is known to reduce on-site construction time, safety hazards, and public nuisance drastically, yet contractors struggle to identify success indicators while planning for ABC projects. The goal of this research is primarily geared toward supporting ABC contractors through twofold attracting contractors to adopt ABC projects and informing project stakeholders about ABC success indicators during the pre-project planning phase. Given that some contractors are new to the ABC method providing knowledge of ABC success indicators during the pre-project planning phase will significantly impact ABC project success. This is particularly true since planning efforts conducted during the early stages of a construction project, known as pre-project planning, which encompasses all the tasks from project initiation to the beginning of detailed design, have a significant effect on project success than efforts undertaken after project kickoff. Therefore, it is fundamental to reinforce the success of ABC projects during the early planning phase by pre-informing contractors about the success indicators, which can be developed into a tool elicited from analyzing the successes of previous ABC projects. To achieve this goal, the first step will be to conduct a State-of-the-Art and State-of-the-Practice literature review. The data collected through a systematic literature review (SLR) will support the objective of identifying and classifying the success indicators and criteria in ABC projects as well as finding potential case studies to interview and analyze. The research plans to facilitate separate ABC industry interviews-workshops including professionals from the Department of Transportation (DOT) to define the required weighted success criteria. The findings of the study foster the development of a streamlined procedure for effective adoption of ABC, which support (1) educating contractors to adopt ABC projects successfully; and (2) encouraging ABC stakeholders to understand and realize the required steps to achieve success in ABC projects during the pre-project planning phase. This report summarizes the work activities undertaken in the study and presents the results of those activities toward developing this ABC-UTC Guide for the development of an interactive ABC success index tool for pre-project planning and effective execution of ABC projects.

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1. INTRODUCTION

This section highlights the current state of infrastructure projects, ABC technology, and Front-end planning techniques and tools. Additionally, the scope of the guide and its intended users are also explained in brief.

1.1. BACKGROUND

The American Society of Civil Engineers (ASCE) rates the U.S. infrastructure every four years, and in 2021 ASCE reported a score of C- for infrastructures. In the report, the bridges in all 50 states were graded C, which in comparison to the C+ of the ASCE 2017 report card, reflects a significant backlog of needs facing our nation's bridges. One of the primary causes for a low score may be due to the fact that out of 617,000 bridges in the United States, approximately 42% of the bridges are more than 50 years or older and are either structurally deficient or approaching the end of their design life (ASCE, 2021). Although 46,154 bridges in the U.S. are in poor condition in 2021, more than 178 million trips have been made across such bridges every day. Additionally, in the last two years, the annual reduction rate of structurally deficient bridges has considerably decelerated to 0.1% annually. Furthermore, several bridges' quality has deteriorated from good to fair condition every year. ASCE (2021) report also estimated that the investment in bridge replacement and rehabilitation needs to increase from approximately $14 billion to $22.7 billion annually or by 58% to improve the current condition of bridges throughout the U.S. Although the current plan of investment from the government promises repairment of at least 10,000 critically damaged bridges and an investment of at least $20 billion (USDOT, 2021), it might take until 2071 to make all of the repairs that are critically needed, with the current rate of investment. Moreover, there might be an additional deterioration over the next 50 years, making it overwhelming for the construction stakeholders to progress. Since the critical load-carrying elements in structurally deficient bridges can be in poor condition due to deterioration or damage, it is critical to adopt innovative solutions for effective replacement or renovation of these structures. Therefore, efforts are required to ensure the safety of traveling vehicles through incessant research and innovation.

Accelerated bridge construction (ABC) is one of the recent technologies that have been adopted in several bridge projects to address the issue. ABC method accelerates the construction schedule through the construction of prefabricated elements such as bridge decks, girders, pier caps, or deck panels in a controlled environment. Besides reduction in construction time, this method incorporates the use of high-performance materials, safe designs, and innovative technologies such as self-propelled modular transporter (SPMT), among others which improves the quality and constructability of the bridge (Jia et al., 2018). In the last few decades, studies in ABC projects have indicated that prefabrication of bridges in a controlled setting provides higher durability properties than the traditional cast-in-place concrete bridge because it ensures that there are appropriate curing and formation of concrete (Ofili, 2015). Thus, ABC bridges have the potential to have a significantly longer life cycle than a traditionally cast-in-place concrete bridge. Considering all these factors, the decision could be made regarding whether the accelerated bridge construction technique can be adopted. In the last few decades, studies in ABC projects have indicated that prefabrication of bridges in a controlled setting provides higher durability properties than the traditional cast-in-place concrete bridge because it ensures that there are appropriate curing and formation of concrete (Klaiber et al., 2009). Thus, ABC bridges have the potential to have a significantly longer life cycle than a traditionally cast-in-place concrete bridge; however, the lack of pre-project planning tool for ABC projects have resulted in several issues during the construction phase. Although the adoption of ABC has several benefits that foster resilient and sustainable infrastructures, there are challenges in its widespread adoption due to lack of standardization, inexperienced contractors, and lack of an advanced tool to ensure the success of ABC projects (Saeedi et al., 2013). To improve opportunities for replacing many deteriorating bridges with minimum traffic disruption, high quality, and improved worker safety in less time as possible, a flexible success indicator tool is required to support contractors during an ABC project's advanced planning stage. Such a tool can play a role in attracting contractors to adopt ABC projects and inform project stakeholders to assess success indicators during the pre-project planning phase.

Front-end planning (FEP) is a frequently used pre-project planning tool in infrastructure projects for developing an appropriate scope definition and strategic information with which owners can uncover any project unknown and risks to maximize the chance for a successful project (Bingham & Gibson, 2017). Gibson et al. (2006) demonstrated that the FEP tools play a significant role in capital projects and directly correlate with a project’s success. Hansen et al. (2018) conducted a literature review to understand the general FEP process and its differences from traditional project planning. The research highlighted that there is a strong need for implementation of FEP in infrastructure projects due to several benefits, which include: ease in financial management, reduction in contractual disputes, lower design changes, improved operational performance, increased predictability of cost and schedule, and better risk management. The CII (2006) indicated that despite the requirement for initial investment for FEP, even higher savings could be achieved on a project. Typically, FEP costs around 2.5% of total project cost but will return on average 10% cost savings, 5% fewer changes, and 7% shorter schedule delivery. According to Bingham and Gibson (2017), the FEP process in infrastructure projects can identify and mitigate risks stemming from environmental hazards, permits, right-of-way concerns, utility adjustments, and logistic problems. CII (2006) also highlighted that proper FEP could help achieve project objectives such as improved scheduling, cost, operating characteristics, and social and environmental goals.

1.2. SCOPE OF THE GUIDE

The main objective of this guide is to provide information about the critical success factors and their categorization, weighted scores elicited from analyzing successes of previous ABC projects, and a systematic color-coded interactive tool for pre-project planning and better execution of ABC projects.

1.3. INTENDED USERS

The information will be of interest to highway officials, bridge construction, safety, design, research engineers, and others concerned with the ABC projects.

2. CRITICAL SUCCESS FACTORS FOR THE SUCCESS OF ABC PROJECTS

This study conducted a systematic literature review (SLR) of successful ABC projects in a web-based repository developed by the Federal Highway Administration (FHWA) and Accelerated Bridge Construction – University Transportation Center (ABC-UTC) website to identify critical success factors. The SLR method involves a structured review of literature by defining keywords, searching relevant literature, and identifying research gaps that strengthen the field of interest (Kamble et al., 2018). SLR in this study will be conducted on three levels. The first level deals with the identification of critical success factors through the investigation of articles in different databases such as google scholar and ABC-UTC. To identify the maximum number of relevant articles, different keywords, as shown in Figure 5, are utilized, and any duplicate articles will be eliminated before the second level. In level 2, screening parameters such as feasible and measurable factors and factors that align with the front-end planning (FEP) elements will be used to narrow down the factors. Then, each identified factor will be compared with the elements in each category of FEP and distributed in the relevant categories. Finally, in level 3, the obtained critical success factors and corresponding categories will be used to design a semi-structured survey such that it can be validated by experts in the construction industry.

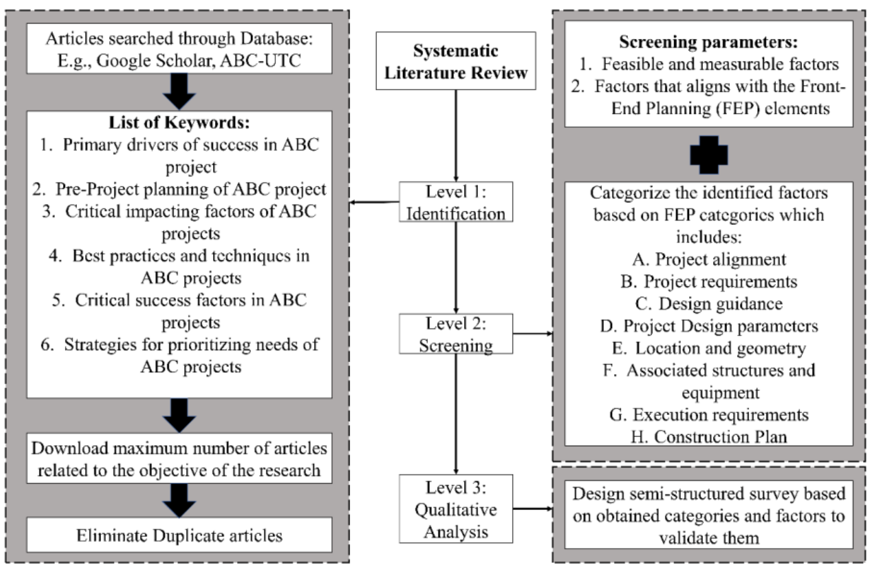

Figure 1. Systematic literature review framework for identification of critical success factors in ABC projects

Several studies have been conducted to investigate the impact of different factors on accelerated bridge construction. However, these factors are mostly focused on social, economic, environmental, and technological factors without a clear distinction of success indicators that influence better ABC project performance. Considering this gap in the literature, this study identified 14 critical success factors that need to be assessed during the pre-project planning stages of the ABC project as well as those factors that impact the project performance. To identify these factors, the authors initially downloaded 84 research articles, of which only 58 research articles aligned with the objective of the research. Among the relevant research articles, most of them have been published in Federal Highway Administration, Accelerated Bridge Construction – University Transportation Center (ABC – UTC), Journal of the Transportation Research Board, PCI Journal, and Journal of Construction Engineering and Management, among others. These research articles were then manually reviewed to identify the critical success factors based on their impact on pre-project planning and the overall success of the ABC project. Finally, as shown in Table 1, only those related to the objective were listed with their relevant references.

Table 1. Categorization of critical success factors identified from SLR

Section	Critical Success Factors	References
Basis of Project Decision	A1. Project Type	(Gransberg, 2013); (D'Andrea et al., 2016); (Galvis & Correal, 2017);
	A2. Prefabrication methods	(El-sayegh, 2008); (Ptschelinzew et al., 2013); (Culmo et al., 2013); (Jones, 2014); (Freeseman et al., 2020);
	A3. Competency of key project stakeholders	(Khaleghi et al., 2012); (Khan, 2015); (Muhaimin et al., 2021);
	A4. Training and workshops	(Hällmark et al., 2012); (H Aktan & Attanayake, 2013); (Culmo et al., 2013); (Head et al., 2015);
	A5. Preliminary Project Schedule	(Becker, 2009); (Gransberg, 2013); (Ardani et al., 2013);
Basis of Design	B1. Codes and Policies	(Khaleghi et al., 2012); (H Aktan & Attanayake, 2013); (Becker, 2009); (Shivakumar et al., 2014); (Dean et al., 2019); (Muhaimin et al., 2021)
	B2. Location setting	(Abu-Hawash et al., 2009); (Khaleghi et al., 2012); (H Aktan & Attanayake, 2013); (Jia et al., 2018)
	B3. Civil and Structural Design	(Krumwiede, 1998); (Abu-Hawash et al., 2009); (Akinola, 2015); (Orabi et al., 2016); (Jia et al., 2018); (Chang, 2021)
	B4. Research and development of the innovative construction method	(Sutaria, 2012); (Khaleghi et al., 2012); (Mallela et al., 2014); (Volk, 2020); (Freeseman et al., 2020)

	B5. Life cycle cost analysis	(Littleton & Mallela, 2013); (DeJong, 2019); (Farhangdoust & Mehrabi, 2020);
	B6. Design for Safety and Hazards	(Ormijana & Rubio, 2013); (Tazarv & Saiidi, 2015); (Reid et al., 2018); (Carfagno & Dickerson, 2018); (Garber et al., 2020)
	B7. Monitoring and maintenance	(Roddenberry & Servos, 2012); (Haluk Aktan et al., 2014); (Yen et al., 2015); (Phares & Cronin, 2015); (Mendez, 2011)
Execution Approach	C1. Project Delivery Method	(George et al., 2008); (Gibson et al., 2010); (Elzomor et al., 2017)
	C2. Project Quality Assurance and Control	(Lotfy, 2015); (Gad et al., 2015); (Muhaimin et al., 2021);
	C3. Project Cost Estimate and Cost Control	(Akinola, 2015); (Orabi et al., 2016); (Bingham & Gibson, 2017); (Muhaimin et al., 2021)
	C4. Project Schedule and Schedule Control	(Abu-Hawash et al., 2009); (Khan, 2015); (Jia et al., 2018); (Muhaimin et al., 2021)

3. ANALYSIS OF SURVEY DATA

This section presents the results of the survey including the weighting of critical success criteria, normalization of the weighted score, and analysis of the final score sheet. The study will focus on the assessment of completed ABC project data to test the hypothesis that scores are derived by assessing successful ABC projects and correlating the levels of project performance.

3.1. WEIGHTING OF CRITICAL SUCCESS CRITERIA

The survey participants were asked to consider all pertinent factors that could affect project success related to each element, including cost, scope changes, or project schedule. Then, the participants were assigned two weights to each element based on their sample project. The first weight was to be based on if the items described in the element were completely defined and accounted for just prior to beginning the detailed design. On the other hand, the second weight was to be based on if the items described in the element were not defined or accounted for at all just prior to the detailed design. The weights correspond to level 1 and level 5 scope definitions respectively. The participants were encouraged to think of the weights as a contingency for each element i.e., what contingency would assign to this element if it were completely defined or incomplete or poorly defined, at a point just prior to detailed design. Since the participants involved in the weighting workshops tended to provide linear interpolation of their contingency responses for definition levels 2, 3, and 4, contingency amounts for these definition levels were not collected. To calculate the contingency amounts for those definition levels, an interpolation calculation method was utilized by the author. Therefore, the survey participants provided two weights as contingency amounts on black weighting factor evaluation sheets. In this study, the authors defined contingency as the elements' individual impact on total installed cost, stated as a percentage of the overall estimate at the point before the commencement of detailed project design. The contingency values were to be given as integers. An example of how a workshop participant would record the contingency amount is as shown in table 2.

Table 2. Sample of workshop weighting for Section I

Section I- Basis of Project Decision							
Element	NA	1	2	3	4	5	Comments
A1. Project Type		61%				77%	
A2. Prefabrication methods		56%				65%	
A3. Competency of key project stakeholders		56%				72%	
A4. Training and workshops		68%				34%	
A5. Preliminary Project Schedule		64%				75%	

Where definition levels,

0= Not Application, 1=Complete Definition, 2=Minor Deficiencies, 3= Some Deficiencies, 4= Major Deficiencies, and 5= Incomplete or Poor Definition

If an element in the worksheet were completely defined just before the detailed design, it would logically have a lower contingency than if the element was not defined at all. Additionally, any contingency amount could be given as a value as far as relative consistency of element importance was kept for all responses. Since some of the elements or in some cases entire categories might not be applicable to the projects being referenced by the participants, those non-applicable elements would not be considered during front-end planning. Hence, participants checked the N/A column, if the element was not applicable and the contingency amount for either level 1 or level 5 definition was not listed.

3.2. NORMALIZING WEIGHTED SCORE

The questionnaire survey did not include any contingency range and the participants were instructed to provide contingency amounts based on the relative importance of each element as compared to the balance of elements in the tool. For instance, if the participants provided a Level 5 contingency amount of 30 percent, this element would be twice as critical to project success as an element that received a level 5 contingency amount of 15 percent. This same consistency could be used by a separate survey participant, but with different contingency amounts. For instance, instead of using 30 and 15 percent, another participant may use 60 percent and 30 percent. In relative terms, both participants weighted the elements equally, with one element being twice as important to project success as the other. Since both participants in the above example assigned equal relative importance to the two elements, normalizing or adjusting values to match a standard scale is essential to compare such responses. The normalizing process consisted of four steps: (1) compilation of all survey participant data; (2) calculation of non-applicable element weights; (3) calculation of normalizing multipliers; and (4) calculation of adjusted element weights as shown in Table 3. To calculate the normalizing multiplier for level 1, equation 1 was used:

$$Normalizing\ multiplier = \frac{70 - Total\ level\ 1\ non-applicable\ weights}{Total\ level\ 1\ element\ weights} \quad \text{Equation (1)}$$

Equation 2 shows the calculation for the level 5 normalizing multiplier, used to normalize the level 5 responses to a total score of 1000.

$$Normalizing\ multiplier = \frac{1000 - Total\ level\ 5\ non-applicable\ weights}{Total\ level\ 5\ element\ weights} \quad \text{Equation (2)}$$

Table 3. Excerpt of Data used for Normalizing Level 1 and Level 5 weights for WA-220121

	Contingency Weight		Non-Applicable Elements		Normalizing multiplier		Normalized weight	
Element	Level 1	Level 5	Added weight for 1’s	Added weight for 5’s	Level 1 multiplier	Level 5 multiplier	Level 1	Level 5
A.1.	70	10	0	0	0.068	3.1	4.78	30.77
A.2.	60	30	0	0	0.068	3.1	4.10	92.31
A.3.	50	50	0	0	0.068	3.1	3.41	153.85
A.4.	50	50	0	0	0.068	3.1	3.41	153.85
A.5.	70	10	0	0	0.068	3.1	4.78	30.77
B.1	70	10	0	0	0.068	3.1	4.78	30.77
B.2.	80	5	0	0	0.068	3.1	5.46	15.38
B.3.	70	5	0	0	0.068	3.1	4.78	15.38

B.4.	75	5	0	0	0.068	3.1	5.12	15.38
B.5.	50	30	0	0	0.068	3.1	3.41	92.31
B.6.	50	50	0	0	0.068	3.1	3.41	153.85
B.7.	30	30	0	0	0.068	3.1	2.05	92.31
C.1.	90	5	0	0	0.068	3.1	6.15	15.38
C.2.	60	10	0	0	0.068	3.1	4.10	30.77
C.3.	80	10	0	0	0.068	3.1	5.46	30.77
C.4.	70	15	0	0	0.068	3.1	4.78	46.15
Totals	1025	325	-	-	-	-	70	1000

4. FINAL ABC SUCCESS INDEX SCORE SHEET

The individual scores for Level 1 and Level 5 elements were calculated through data analysis demonstrated in the previous section. The typical 70-1000 scoring range was used during the normalization process. In this section, the scores for Level 2,3, and 4 elements are calculated by linear interpolation between the Level 1 and Level 5 scores already established. The weights are calculated using the following equations:

$$Level\ 2\ Weight = \frac{Level\ 5\ Weight - Level\ 1\ Weight}{4} + Level\ 1\ Weight$$

$$Level\ 3\ Weight = \frac{Level\ 5\ Weight - Level\ 1\ Weight}{4} + Level\ 2\ Weight$$

$$Level\ 4\ Weight = \frac{Level\ 5\ Weight - Level\ 1\ Weight}{4} + Level\ 3\ Weight$$

The interpolation of Levels 2, 3, and 4 based on adjusted weights of Level 1 and Level 2 generated non-integer numbers. Since only integers are used as weights for the score sheet, each number was rounded to complete the score sheet. A standard rounding procedure was used to convert the non-integer numbers. Those numbers with decimals equal to or greater than 0.5 were rounded up while the numbers with decimals less than 0.5 were rounded down. After adjusting the numbers using the standard procedure, the sum of all values in the Level 1 added up to a score of 70. On the other hand, the sum of all the values in Level 5 added up to 1000. The author completed a final check of the element weights for definition levels 1-5 and a weighted score sheet was created after the data interpolation is as shown in Table 4 which also includes the total, average, and percentage of 1000 weights.

Table 4. Project score and weighted datasheet

SECTION I - BASIS OF PROJECT DECISION								
		Definition Level						
CATEGORY / Element		**n/a**	**1**	**2**	**3**	**4**	**5**	**Comments**
A.1	Project Type		5	11	18	24	31	
A.2	Prefabrication methods		4	26	48	70	92	
A.3	Competency of key project stakeholders		3	41	79	116	154	
A.4	Training and workshops		3	41	79	116	154	
A.5	Preliminary Project Schedule		5	11	18	24	31	462
SECTION II - BASIS OF DESIGN								
B.1	Codes and Policies		5	11	18	24	31	
B.2	Location setting		5	8	10	13	15	
B.3	Civil and Structural Design		5	7	10	13	15	
B.4.	Research and development of the innovative construction method		5	8	10	13	15	
B.5.	Life cycle cost analysis		3	26	48	70	92	
B.6.	Design for Safety and Hazards		3	41	79	116	154	
B.7.	Monitoring and maintenance		2	25	47	70	92	415

SECTION III - EXECUTION APPROACH								
C.1.	Project Delivery Method		6	8	11	13	15	
C.2.	Project Quality Assurance Control		4	11	17	24	31	
C.3.	Project cost estimate and cost control		5	12	18	24	31	
C.4.	Project Schedule and Schedule Control		5	15	25	36	46	123
	Totals		70	302	535	767	1000	
	% of 1000		7%	30%	53%	77%	100%	
	Average Weight		4	19	33	48	63	

A higher ABC success index score indicates incomplete scope definition during front-end planning, leading to poor project performance. On the other hand, a lower ABC success index score indicates that the project has sufficient scope definition that leads to better project performance.

5. ANALYZING THE WEIGHTED ABC SUCCESS ELEMENTS

Table 5 provides a listing of the top six ABC success index elements based on definition level 5 weight. This indicates that based on the ABC experts these elements are the most critical to project success for ABC projects. The top six elements make up 74% of the total weight of all elements. Three of the six elements are included in Section I while the other three elements are included in Section II. Therefore, if an ABC project team wanted to focus on specific elements that would have the highest impact on project success, concentrating on elements with the highest weights would be prudent.

Table 5. Top six ABC success index elements by weight (Definition Level 5)

Rank	Element	Element Description	Definition level 5 weight	Section
1	A.3	Competency of key project stakeholders	154	I
2	A.4	Training and workshops	154	I
3	B.6.	Design for Safety and Hazards	154	II
4	A.2	Prefabrication methods	92	I
5	B.5.	Life cycle cost analysis	92	II

6	B.7.	Monitoring and maintenance	92	II
Total			738	

Based on the obtained results, the establishment of a positive relationship, synergies, and communication among all the key project stakeholders is critical for the efficiency and success of the project. ABC Stakeholders need to be competent in evaluating various alternative construction strategies through consideration of qualitative and quantitative criteria and create and analyze comparisons of different strategies with consideration of tangible and intangible factors. Additionally, timely coordination with external project stakeholders and transparency to the public for ensuring proper public support and reducing problems during construction is also critical for project success. The second element that has one of the highest impacts on project success is training and workshops which may include training on: (1) optimization of design; (2) effective coordination with a consultant, client, subcontractor, and subconsultant; (3) identification of sensitive activities to be performed promptly using critical path method; (4) logistics of transporting assembled bridges; (5) construction technology tasks such as modern concrete technology; (6) safe and economical design of ABC technology for repair and replacement of bridges; and (7) slide-in bridge construction method as an alternative to incremental launching, among others. Another element with the highest impact on ABC project success is designing the bridge for safety and hazard prevention. It is extremely important to enhance the construction site environment through the inclusion of prevention methods in all designs that impact workers and others on the premises. Similarly, it is also critical to incorporate the design, redesign, and retrofit of new and existing work premises, work processes, substances, products, machinery, equipment, facilities, tools, structures, and the organization of work.

Proper investigation of necessary prefabricated elements of a bridge also plays a critical role in the success of ABC bridge construction since it eliminates possible liquidated damages, delays in schedule, and waste of materials. As such, it is imperative to choose the most adequate location for the prefabrication of elements and systems whether it is in an offsite factory or adjacent to the site. If prefabrication is being done near a site, ample room within the highway right of way should be established for staging areas of manufacture. Similarly, the project team should ensure the area is large enough for the fabrication of elements, overhead wires can be easily relocated, and relocate any utilities above ground and underground. Additionally, it is essential to review shop drawings developed by the manufacturer of prefabrication elements and systems such that there are no liquidated damages. Since life cycle cost analysis is one of the top five ABC success index criteria, it is essential to adopt different strategies to reduce the life cycle cost of ABC bridge projects at the beginning of the project. Different strategies can be adopted to minimize life-cycle costs in ABC projects, which include: (1) to improve the durability of deck concrete, corrosion inhibitor concrete or HPC should be used; (2) to improve deck joints performance, integral abutments should be used; and (3) to improve bearings performance, elastomeric pads and isolation bearings should be used (Orabi et al., 2016). Additionally, the use of software such as Primavera for life cycle cost and schedule risk analytics would also help analyze cost-effective materials and construction techniques. Lastly, with the recent advancement in measuring instrumentation technology, structural health monitoring is becoming a widely accepted solution for ensuring the long-term safety of the structure and reducing the life-cycle costs of the project (Littleton & Mallela, 2013). Some strategies for maintenance and monitoring include: (1) provisions for safe maintenance/operation including out-of-service; (2) remote monitoring/operating capabilities; (3) storage and fabrication facilities for repair parts; and (4) measure rotations, strains, and displacements using the sensors which provide information about peak stress distributions through computer software, among others.

6. SYSTEMATIC COLOR-CODED ABC SUCCESS INDEX TOOL

To determine the potential success of the ABC project, ABC stakeholders can provide weightage on a scale from 1 to 100 to different critical success factors within the interactive tool developed in this study. Moreover, this research developed an ABC success index score which is an interactive index/tool that utilizes a systematic color-coded score to highlight the success of the ABC projects as shown in Figure 2. The dark green color indicates that the project has sufficient scope definition, reduction in cost and schedule, and improve safety and innovation, among others which fostered improved project performance and success of the ABC project. To achieve this, ABC projects should have an ABC success index score of less than or equal to 200. However, as the score increases the color of the ABC success index also changes to a red color indicating that the project has an incomplete scope definition, high cost, and schedule overrun, among others, during pre-project planning that leads to poor project performance. Therefore, the tool can be used in the rehabilitation or total replacement of thousands of bridges that require immediate attention.

Instructions for using the ABC Success index matrix tool are as follows:

1. Weight corresponding to Level 1 and Level 5 scope definitions are contingency weights for each element i.e., what contingency should be assigned to this element if it were completely defined (for Level 1) or incompletely defined just before the detailed design.
2. If an element in the worksheet were completely defined just before the detailed design, it would logically have a lower contingency than if it was not defined at all.
3. Any contingency amount could be given as a value as far as relative consistency of element importance was kept for all responses.
4. Since some of the elements or in some cases entire categories might not be applicable to the projects being referenced by the participants, those non-applicable elements would not be considered during the pre-project planning of the ABC project. Hence, you can check the N/A column, if the element was not applicable and the contingency amount for either level 1 or level 5 definition was not listed.
5. Green indication in the Level 5 weights is good for the project, yellow indication in the Level 5 weights means you may consider lowering the weighted score by lower

number, and red indication in the Level 5 weights means you may reconsider lowering the weighted score by significantly lower number.

6. If the “Please reconsider the weighted score!” message appears in the comment section with a yellow indication to the level 5 contingency weight, reduce the weighted score by at least 30 to ensure the success of the ABC project.
7. If the “Please reconsider a lower weighted score!” message appears in the comment section with a red indication to the Level 5 contingency weight, reduce the weighted score by at least 50 to ensure the success of the ABC project.

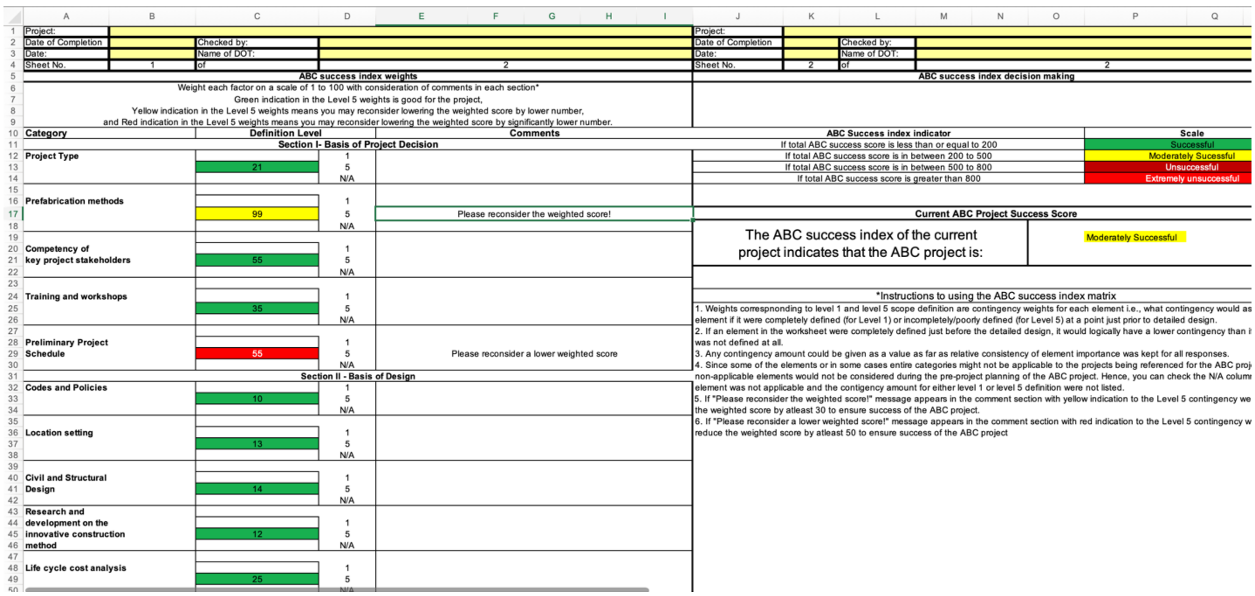

Figure 2. A systematic color-coded interactive tool to highlight the success of the ABC projects

One example of how the index may support ABC contractors’ successes is to prioritize safety by guiding contractors to avoid the traditional requests of compressing schedules and pressuring construction since this may compromise not only safety but quality too. Furthermore, the interactive index will alert ABC contractors about expected challenges and share previous ABC successes around the nation, which would provide more confidence by showcasing quantitative comparative exemplar successes in ABC projects and thus increase bidding competition for ABC projects. It is vital to provide an ABC Success Index, which serves as a success threshold to guide ABC project stakeholders during early project planning. Consequently, the research team plans to embrace marketing strategies, including integrating the ABC Success Index into websites, educational materials, conferences, and webinars to strengthen the useability of the index amongst DOTs personnel and contractors. Finally, this index will potentially support the project’s cost, quality, and schedule, thus ultimately, endorsing higher chances of planned success for ABC projects.

7. RECOMMENDATION

The American Society of Civil Engineers (ASCE) rates the U.S. infrastructure every four years, and in 2021 ASCE reported a score of C- for infrastructures. This constructive criticism can form the basis for modernizing the U.S. bridges with sustainable methods. To reconstruct many old and deteriorating bridges, the ABC stakeholders need to make sure pre-project planning is effective and ensures the success of the project. ABC construction method is becoming popular in the construction industry for highway bridge construction in recent years. The transportation of prefabricated elements of bridges using specialized equipment such as SPMT was not previously readily available. However, with the growing use of this method, such machinery is now available for leasing or renting for the duration of the project. Additionally, growing research in ABC methods has increased opportunities to educate and train ABC stakeholders related to the type of bridge to be built, whether on an entirely new route or a bridge replacement over an existing old bridge. Web-based continuing educational module through seminars, workshops, and conferences provides an opportunity to increase awareness of success factors impacting ABC projects. Therefore, this study identified such different critical success factors based on their impact on pre-project planning and the overall success of the ABC project. Using these critical success criteria, the research team developed a systematic color-coded ABC success index tool that would support ABC stakeholders in decision-making to pursue an ABC project and during advance planning in ABC to ensure the success of the project. ABC stakeholders may use this tool to identify success indicators and risks during the pre-project planning phase and develop better confidence, risk assessment, the realization of success benchmarks, and primary knowledge about ABC projects. Consequently, this would increase in bidding competition for ABC projects and fulfill the gap with the necessary foundation step to educate, guide, and support contractors to achieve success when pursuing ABC projects.

8. CONCLUSION

To put it briefly, ABC is a relatively new subject for many stakeholders, and research on various factors impacting the success of the ABC project is critical. These factors can be taken into consideration during the pre-project planning stages of the ABC project and educate ABC stakeholders to adopt ABC projects successfully. Sometimes projects are asked to rush the delivery of the project to meet a new opening date, which may threaten safety and compromise quality. Therefore, this research fills in the research gaps by providing a user-friendly and flexible success indicator tool that not only encourages the adoption of ABC but also supports contractors during the advanced planning of an ABC project. Bridge designers, developers, and owners have a major role to play in adopting ABC methods, as they can provide incentives and encouragement to contractors to invest in the necessary advanced machinery and equipment to minimize the delays of the bridges. This research identified 16 different critical success factors and each of these factors was sub-divided into three different categories including the basis of project decision, the basis of design, and the execution approach. The basis of the project decision includes all the success criteria that demonstrate whether the project stakeholders are aligned to fulfill the project objectives and drivers such as project type, prefabrication methods, competency of key project stakeholders, training and workshops, and preliminary project schedule. Similarly, the basis of design includes the critical success criteria that define the processes and technical information elements that need to be considered for a full understanding of the engineering or design requirements necessary for the project such as codes and policies, location setting, civil and structural design, research and development on the innovative construction method, life cycle cost analysis, design for safety and hazards, and monitoring and maintenance. Lastly, the execution approach includes critical success criteria that play a critical role in procurement, owner approvals, and coordination among key project stakeholders such as project delivery method, project quality assurance and control, project cost estimate and cost control, and project schedule and schedule control. The results of this study indicated that competency of key project stakeholders, training and workshops, design for safety and hazards, prefabrication methods, life cycle cost analysis, and monitoring and maintenance are some of the most critical ABC success index elements by weight and makeup to 74% of the total weight of all elements. ABC stakeholders can use the ABC success index interactive tool for pre-project planning and to prioritize critical success criteria within the tool based on the needs of the ABC project. A higher ABC success score indicates incomplete scope definition during pre-project planning, leading to poor project performance while a lower ABC success index score indicates that the project has sufficient scope definition that leads to better project performance. Hence, by using ABC success index interactive tool, ABC stakeholders can ensure constructability, prevent future changes in design, reduce the delay of the project, make accurate cost estimations, continue training and education to ABC stakeholders, and ensure better project performance, among others.

9. REFERENCES

Abu-Hawash, A., Nelson, J., & Bierwagen, D. (2009). ABC- achieving the need for speed. In *Iowa Department of Transportation News* (Issue April).

Akinola, A. A. (2015). *Examining the Cost Distinction between the Accelerated Bridge Construction (ABC) and the Conventional Cast-In-Place (CIP) Methods of Bridge Construction* (Issue December).

Aktan, H, & Attanayake, U. (2013). *Improving Bridges with Prefabricated Precast Concrete Systems*.

Aktan, Haluk, Attanayake, U., & Mohammed, A. W. (2014). *Michigan Department of Transportation Bridge Slide Showcase*.

Ardani, A., Mallela, J., & Hoffman, G. (2013). *OREGON DEMONSTRATION PROJECT : ALTERNATE PROJECT DELIVERY AND ACCELERATED BRIDGE CONSTRUCTION ON OR 38 , DRAIN TO ELKTON* (Issue June).

ASCE. (2021). *ASCE Bridges Report Card 2021*.

Becker, M. F. (2009). *Evaluation of accelerated bridge construction methods and designs in the state of Iowa*.

Bingham, E., & Gibson, G. E. (2017). Infrastructure Project Scope Definition Using

Project Definition Rating Index. *Journal of Management in Engineering*, *33*(2), 04016037. https://doi.org/10.1061/(asce)me.1943-5479.0000483

Carfagno, M. G., & Dickerson, K. (2018). Rapid Replacement of Two Washington DOT Stream Crossing Bridges using Prefabricated Arch Bridge Systems. In *ABC-UTC* (Issue 513).

Chang, C. M. (2021). *Life-Cycle Cost Analysis of Ultra High-Performance Concrete (UHPC) in Retrofitting Techniques for ABC projects*.

CII. (2006). *Front End Planning: Break the Rules, Pay the Price. Research Summary 213-1.* Construction Industry Institute.

Culmo, M., Sadasivam, S., Gransberg, D., Boyle, H., Deslis, A., Duguay, W., Rose, D., Mizioch, C., & Mallela, J. (2013). *Contracting and Construction of Accelerated Bridge Construction Projects with Prefabricated Bridge Elements and systems* (Issue June).

D'Andrea, M., Young, W., & Turnbull, A. (2016). Westminster drive underpass - Accelerated bridge construction using GiGo (get in-get out) bridge concept. *Proceedings, Annual Conference - Canadian Society for Civil Engineering*, *3*, 1881–1890.

Dean, N., Stevens, C., & Hastings, J. (2019). *Accelerated Bridge Construction Methods for Bridge 1-438 Replacement*.

DeJong, A. (2019). *Innovations in integral abutment connection details for accelerated bridge construction*.

El-sayegh, S. M. (2008). EVALUATING THE EFFECTIVENESS OF PROJECT DELIVERY METHODS. *Journal of Construction Management and Engineering*, *May*, 457–465.

Elzomor, M. A., Parrish, K., Gibson, Jr., G. E., & El Asmar, M. (2017). *Development of the Project Definition Rating Index (PDRI) for Small Infrastructure Projects*. Arizona State University.

Farhangdoust, S., & Mehrabi, A. (2020). Non-destructive evaluation of closure joints in accelerated bridge construction using a damage etiology approach. *Applied Sciences (Switzerland)*, *10*(4). https://doi.org/10.3390/app10041457

Freeseman, K., Shane, J., & Volk, M. (2020). *Delivery Methods for Accelerated Bridge Construction Projects: Case Studies and Consensus Building*. https://doi.org/10.1016/s0167-2991(04)80926-1

Gad, G. M., Gransberg, D. D., & Loulakis, M. (2015). Policies and procedures for successful implementation of alternative technical concepts. *Transportation Research Record*, *2504*, 78–86. https://doi.org/10.3141/2504-10

Galvis, F., & Correal, J. F. (2017). Characterization of the Seismic Behavior of a Column-Foundation Connection for Accelerated Bridge Construction. *16th World Conference on Earthquake, 16WCEE 2017*, *June*.

Garber, D., Shahrokhinasab, E., & Pineres, C. G. D. (2020). *Development of Non-Proprietary UHPC Mix* (Issue June).

George, R., Bell, L. C., & Edward Back, W. (2008). Critical Activities in the Front-End Planning Process. *Journal of Management in Engineering*, *24*(2), 66–74. https://doi.org/10.1061/(asce)0742-597x(2008)24:2(66)

Gibson, G. E., Bingham, E., & Stogner, C. R. (2010). Front end planning for infrastructure projects. *Construction Research Congress 2010: Innovation for Reshaping Construction Practice - Proceedings of the 2010 Construction Research Congress*, 1125–1135. https://doi.org/10.1061/41109(373)113

Gibson, G. E., Wang, Y.-R., Cho, C.-S., & Pappas, M. P. (2006). What Is Preproject Planning, Anyway? *Journal of Management in Engineering*, *22*(1), 35–42. https://doi.org/10.1061/(asce)0742-597x(2006)22:1(35)

Gransberg, D. D. (2013). Early contractor design involvement to expedite delivery of emergency highway projects. *Transportation Research Record*, *2347*, 19–26. https://doi.org/10.3141/2347-03

Hällmark, R., White, H., & Collin, P. (2012). Prefabricated bridge construction across Europe and America. *Practice Periodical on Structural Design and Construction*, *17*(3), 82–92. https://doi.org/10.1061/(ASCE)SC.1943-5576.0000116

Hansen, S., Too, E., & Le, T. (2018). Retrospective look on front-end planning in the construction industry: A literature review of 30 years of research. *International Journal of Construction Supply Chain Management*, *8*(1), 19–42. https://doi.org/10.14424/ijcscm801018-19-42

Head, M., Efe, S., Grose, S., Drumgoole, J., Lajubutu, O., Wright, R., & Hansboro, T. (2015). *Durability assessment of prefabricated bridge elements and systems* (Issue August).

Jia, J., Ibrahim, M., Hadi, M., Orabi, W., & Xiao, Y. (2018). Multi-Criteria Evaluation Framework in Selection of Accelerated Bridge Construction (ABC) Method. *Sustainability*. https://doi.org/10.3390/su10114059

Jones, B. (2014). Integrated project delivery (IPD) for maximizing design and construction considerations regarding sustainability. *Procedia Engineering*, *95*(Scescm), 528–538. https://doi.org/10.1016/j.proeng.2014.12.214

Kamble, S. S., Gunasekaran, A., & Gawankar, S. A. (2018). Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives. *Process Safety and Environmental Protection*, *117*, 408–425. https://doi.org/10.1016/j.psep.2018.05.009

Khaleghi, B., Schultz, E., Seguirant, S., Marsh, L., Haraldsson, O., Eberhard, M., & Stanton, J. (2012). Accelerated bridge construction in Washington state: From research to practice. *PCI Journal*, *57*(4), 34–49. https://doi.org/10.15554/pcij.09012012.34.49

Khan, M. (2015). Accelerated bridge construction: Best Practices and Techniques. In

Bridge Engineering Handbook, Second Edition: Construction and Maintenance. https://doi.org/10.1201/b16467

Klaiber, W., Wipf, T., & Wineland, V. (2009). Precast Concrete Elements for Accelerated Bridge Construction: Volume 3. Laboratory Testing, Field Testing, and Evaluation of a Precast Concrete Bridge-Black Hawk County. In *Center for Transportation Research and Education* (Vol. 2).

Krumwiede, K. (1998). The Implementation Stages of Activity-Based Costing and the Impact of Contextual and Organizational Factors. *Journal of Management Accounting Research*, *10*, 239–277.

Littleton, P., & Mallela, J. (2013). *Iowa Demonstration Project: Accelerated Bridge Construction on US 6 over Keg Creek Final Report* (Issue June).

Lotfy, I. (2015). *Structural Performance of High Density Polyethylene Crossties and Use in Accelerated Bridge Construction*.

Mallela, J., Sadasivam, S., & Ullman, J. (2014). *Massachusetts Demonstration Project : Reconstruction of Fourteen Bridges on I-93 in Medford Using Accelerated Bridge Construction Techniques*.

Mendez, V. M. (2011). Accelerating Bridge Replacements in Massachusetts. *FOCUS*, *October*.

Muhaimin, A. M. M., Zhang, L., Dhakal, S., Lv, X., Pradhananga, N., Kalasapudi, V. S., & Azizinamini, A. (2021). Identification and Analysis of Factors Affecting the Future of Bridge Design, Construction, and Operation. *Journal of Management in Engineering*, *37*(5), 04021049. https://doi.org/10.1061/(asce)me.1943-5479.0000943

Ofili, M. (2015). *State of Accelerated Bridge Construction (ABC) in the United States*.

Orabi, W., Mostafavidarani, A., & Ibrahim, M. (2016). *Estimating the Construction Cost of Accelerated Bridge Construction (ABC)* (Issue June).

Ormijana, F. S. de, & Rubio, N. (2013). Innovation Capture through the Alternative Technical Concept Process in PPPs in Texas: A Tool for Financial Viability. *Advances in Public-Private Partnerships*, *2000*, 275–289.

Phares, B., & Cronin, M. (2015). *Synthesis on the Use of Accelerated Bridge Construction Approaches for Bridge Rehabilitation*.

Ptschelinzew, L. R., Edward Minchin, R. J., Migliaccio, G. C., Atkins, K. E., Hostetler, G. A., Warne, T. R., & Nettuno, G. (2013). Best Practices in Design Process Development for Accelerated Construction Project Delivery. *New Developments in Structural Engineering and Construction*, 1–6.

Reid, S., McLeod, C., & McInnis, S. (2018). Slide-in Bridge Construction using the Construction Manager General Contractor , Contract Delivery Model. *Conference of the Transportation Association of Canada*.

Roddenberry, M., & Servos, J. (2012). *Prefabricated/Precast Bridge Elements and*

Systems (PBES) for Off-System Bridges (Issue August 2012).

Saeedi, A., Emami, S., Doolen, T. L., & Tang, B. (2013). A decision tool for accelerated bridge construction. *PCI Journal*, *58*(2), 48–63. https://doi.org/10.15554/pcij.03012013.48.63

Shivakumar, S., Pedersen, T., Wilkins, S., & Schuster, S. (2014). EnvisionTM – A Measure of Infrastructure Sustainability. *Pipelines: From Underground to the Forefront of Innovation and Sustainability*, 2249–2256.

Sutaria, C. P. (2012). *" Safe and Sound " – An Accelerated Bridge Improvement Program in Missouri*.

Tazarv, M., & Saiidi, M. S. (2015). UHPC-filled duct connections for accelerated bridge construction of RC columns in high seismic zones. *Engineering Structures*, *99*, 413–422. https://doi.org/10.1016/j.engstruct.2015.05.018

USDOT. (2021). *INVEST IN AMERICA-COMMIT TO THE FUTURE GROW AMERICA Act : Making Critical Investments in Highway and Bridge Infrastructure*.

Volk, M. (2020). The effect of alternative delivery on accelerated bridge construction projects. In *Iowa State University*.

Yen, W. P., Saiidi, M. S., Keever, M., Kapur, J., Dekelbab, W., Bardow, A. K., Sletten, J. J., & Tobias, D. H. (2015). Performance of Accelerated Bridge Construction Connection in Bridges Subjected to Extreme Events. In *Public Works Research Institute*.