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16. 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 construction, transportation, and structural disciplines to define the required weighted success criteria. The interviews will also support evaluating those success indicators by providing success prioritization data, which will be statistically analyzed to develop a corresponding weighted score sheet, i.e., "ABC Success Index".			
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DEVELOPING ABC SUCCESS INDEX TO SUPPORT CONTRACTORS DURING PRE-PROJECT PLANNING

Final Report

September 2023

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CHAPTER 1: INTRODUCTION

1. 1. Project Motivation

ABC projects utilize off-site construction, alignment, material coordination, innovative design, and construction methods safely and cost-effectively to significantly reduce the onsite construction time and improve safety compared to the traditional bridge construction method. To this end, different decision-making tools have been developed to guide transportation specialists in determining the applicability of the ABC technique for a given bridge project. Two of the most common methods used for decision-making are the qualitative approach (i.e., yes/no questionnaire survey) and the quantitative approach (i.e., analytical hierarchical process), which helps to decide whether a project needs acceleration in schedules or can be constructed with conventional practices. Although these frameworks and tools provide an opportunity to make an efficient decision on construction method selection, those tools do not support in the advanced planning stage, i.e., Front End Planning through highlighting the successes and expected challenges when planning for ABC projects. As such, there is a growing concern for elevated costs incurred by the ABC method. Many contractors and manufacturers face technical problems due to a lack of appropriate knowledge and tool to assess the successes and potential challenges in integrating the ABC technique. Several different factors impact the successes of ABC projects, particularly during the planning phase, which is yet to be investigated. ABC contractors not only need a framework to support in helping make a decision to pursue an ABC project but also can strongly benefit from a tool that supports their advanced planning in ABC as well as learn and leverages from previous successes of ABC projects. The demand to successfully support contractors in pursuing ABC projects is not only inaugurated by contractors but also from other stakeholders, including AASHTO and DOTs personnel. Unfortunately, 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, leveraging our existing ABC database inventory of ABC Projects with tight construction schedules is critical to inform and guide future ABC projects about success indicators as well as safety risks, schedule overruns, quality issues, and additional costs. To this end, the index support, educate and direct ABC contractors to realize/value the significance and consequences of such changes. 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, more importantly, supports contractors during the advanced planning stage of an ABC project.

1.2. Research, Objectives, and Tasks

The research team set forth the objective of producing a user-friendly tool for identifying ABC success indicators with the following characteristics and functions: (1) identify the success indicators based upon the literature and industry expertise; and (2) conduct ABC industry interviews-workshops for professionals from construction, transportation, and the structural disciplines to define the required weighted success criteria, i.e., ABC Success matrix. The developed index will support ABC stakeholders, and contractors using the tool to anticipate successes and risks, thus managing safety and the quality, schedule, and cost of ABC projects.

Given the need to involve and learn from different ABC expects in construction, transportation, and structural, the research team will develop a Research Advisory Panel to represent all stakeholders to support, guide research, and ensure the research is satisfactory by different experts. The study utilizes a structured approach to identify success indicators through a Systematic literature review (SLR) of relevant literature. Then, the research team developed an interactive ABC-Success Index, which provides a success score associated with the successful performance index for ABC projects. This approach will not only be beneficial for contractors to make an efficient decision on advanced planning in ABC projects but also provide co-benefits such as an increase in bidding competition for ABC projects since contractors will be able to identify success indicators and risks during the pre-project planning phase and thus have better confidence, risk assessment, the realization of succusses benchmarks and primary knowledge about ABC projects. Despite that a comprehensive educational strategy to support ABC contractors remains needed, the development of the proposed ABC Success Index is a necessary foundation step to educate, guide, and support contractors when pursuing ABC projects.

1.3. Report Overview

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 study conducted 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.

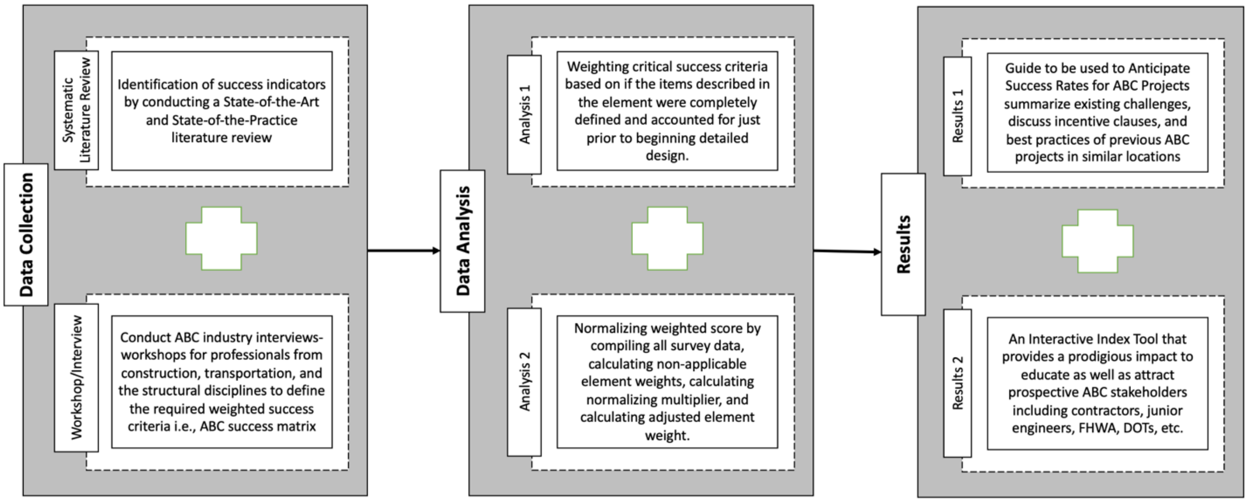

Figure 1. Overview of Project Activities and their Sequence

CHAPTER 2. LITERATURE REVIEW

The objective of the first task is to understand the current status of infrastructure projects with a focus on accelerated bridge construction projects and the importance of Front-end Planning in infrastructure projects. The succeeding section highlights the current state of infrastructure projects, ABC technology, and Front-end planning techniques and tools.

2.1. Current State of U.S. Infrastructure

An infrastructure project is defined as a project that provides distribution, transmission, transportation, collection, or other capabilities supporting the interaction of goods, services, or people. Infrastructure projects play a critical role in the built environment. Infrastructures provide the basis for personal security and public health, influence communities' economic growth and competitiveness, provide drinking water and handle waste, and, most importantly, allow building and industrial projects to connect with all main utilities. In comparison to building projects (vertical construction), infrastructure projects are "horizontal" and act as vectors that connect residential and industrial nodes and provide services and goods within the built environment. Thus, due to such nature of infrastructure systems, these are commonly overlooked and underfunded until the service is interrupted or deteriorated. According to ISI (2018a), massive investments in infrastructure are now needed due to decades of negligence and outdated infrastructure around the world. Moreover, infrastructure projects require significant investments and result in high impacts on the built environment and the served communities. Thus, these kinds of projects pose many environmental and social repercussions over the sustainability of the built environment. Since most of the natural resources are finite and community development has consequences that affect the TBL, the construction of infrastructures should be cost-effective and sustainable (ISI 2015). The concept of sustainability originated in the late 1980s after the United Nations' Brundtland Commission Report identified it as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (Keeble 1988). Nowadays, sustainability concepts have become more vital among the architecture, engineering, and construction (AEC) industries.

Climate change and waste management are two environmental issues that pose a growing challenge to the construction industry and threaten the well-being of life on earth (Pradhananga and ElZomor 2020). To this end, infrastructure projects tend to reduce the ability of the natural environment (i.e., permeable soils), its habitats, and species to adapt to climate change. Despite such an impact on infrastructure projects, sustainability principles are seldom integrated during the initial phases of these projects (ASCE 2007). Additionally, these projects face unique planning challenges such as right-of-way (ROW) acquisitions or adjustments, underground works, and more interfaces with the public and the environment. Low awareness of a project's societal and environmental impacts, as well as a lack of standardized procedures to quantify these impacts, are often roadblocks to achieving sustainability (Weerasinghe et al. 2007). The sustainable design aims to improve the built environment's performance through a suite of economic, social, and environmental aspects, also known as the "Triple Bottom Line (TBL)" (Elkington 1998). Some of the current sustainable management methods in construction projects are the Leadership in Energy and Environmental Design (LEED) and the Envision Rating System. While LEED mainly focuses on building (i.e., vertical) projects, Envision is a practical framework applicable to all infrastructure (horizontal) projects. Since most of the natural resources are finite and community development has consequences that affect the TBL, the construction of infrastructures should be robust and sustainable (ISI 2015). However, due to the additional challenges of infrastructure projects, i.e., more complex technologies and dynamic societal and political conditions (Wegrich et al. 2017), these projects are often left out of sustainable design and construction efforts.

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 as shown in Figure 2 (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.

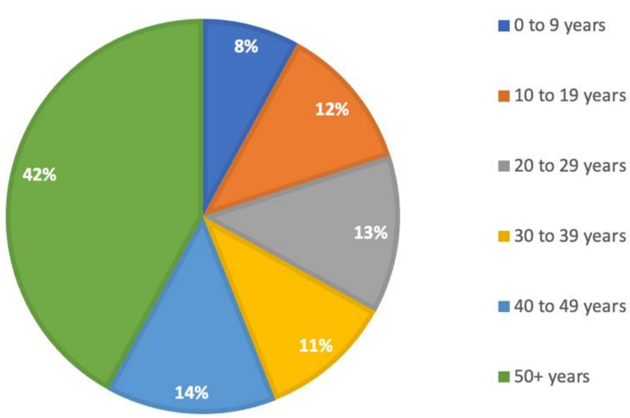

Figure 2. Age of bridges across America based on ASCE (2021) report

2.2. Current State of Accelerated Bridge Construction (ABC) Projects

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. A comprehensive flowchart can be used to make such a decision, as shown in Figure 3. The successful construction and operation of the ABC project are influenced by various factors which can be identified from several past projects. One of the most important factors that impact the construction duration of the project is the constructability of the bridge. Since construction stakeholders are relatively new to the ABC techniques, especially local contractors who are more experienced in small bridges, there are challenges in designing the bridge with constructability in mind. For instance, the Black Hawk County Bridge installation in Iowa was challenging and complex in terms of adding reinforcing steel to the longitudinal joints (Klaiber et al. 2009). Likewise, 24th Street Bridge in Council Bluffs and Boone County Bridges had highly congested longitudinal joints and were difficult to install, which increased the actual time required to complete the bridge installation process (Cheng et al. 2020). Attanayake et al. (2014) also highlighted challenges in constructability faced during the integration of the ABC technique. In particular, contractors faced issues during bridge construction due to the misalignment of longitudinal post-tensioning ducts caused by design errors during the prefabrication process. Consequently, there were delays in the schedule, and the contractor adopted the conventional cast-in-place method to complete the construction process. Secondly, traffic disruption is another important factor that impacts the construction duration and the travel distance of vehicles utilizing the bridge to reduce the time taken to reach the destination. Since the ABC project reduces traffic disruption through fewer on-site construction activities, traffic will be disrupted only during installation, and during that period, commuters need to follow alternate routes (Hällmark et al. 2012). However, bridges have to be built alongside an existing bridge in areas with a high volume of traffic where longer detour routes are not possible. For instance, the 24th Street Bridge in Council Bluffs had no traffic disruption at any time during the construction period. It maintained three lanes of traffic at all times, thereby eliminating the requirement of the use of detours (Becker 2009). The third factor influencing the use of the ABC technique in bridge construction projects is the total cost of all preliminary work, materials, and construction. Lessons learned from ABC projects have indicated that the projects utilizing ABC technology have mostly higher costs than the projects that depend on conventional construction methods. For example, the 24th Street Bridge in Council Bluffs was built at the cost of $185 per square foot of bridge deck which is slightly higher than the non-ABC cost of $155 per square foot of bridge deck (Cheng et al. 2020). This cost difference is primarily due to the use of high-cost, innovative materials and the cost incurred by the maintenance of traffic in high-traffic volume areas throughout the construction phase. Lastly, the durability of the bridge is one of the significant factors that can be achieved by using high-quality materials and innovative construction methods.

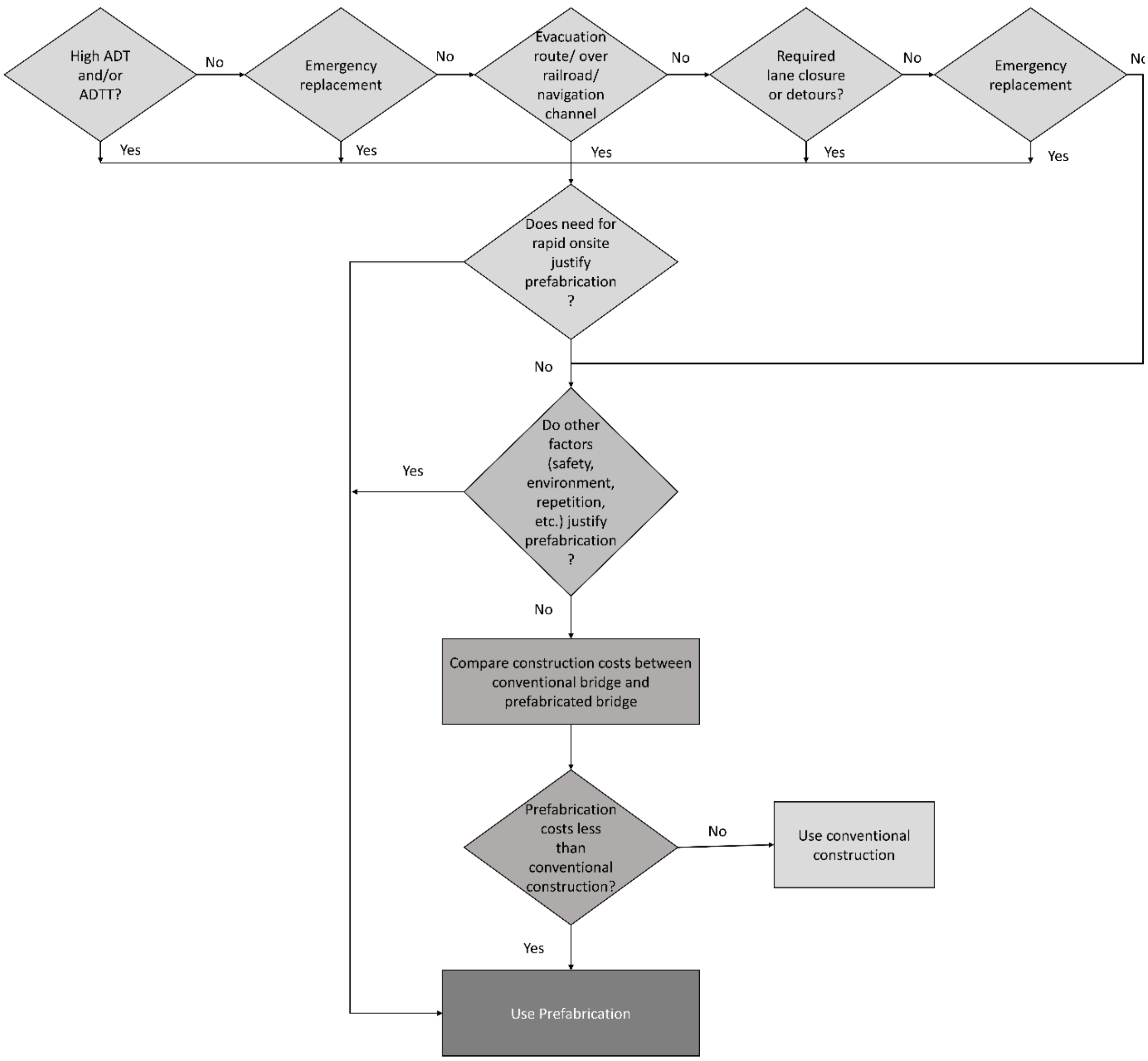

Figure 3. Flowchart for decision-making on the use of the prefabricated bridge (adopted from Federal Highway Administration (FWHA) 2017)

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.

To this end, many bridges constructed with the Accelerated Bridge Construction (ABC) technique have significantly reduced construction schedule, environmental impact, and traffic disruption. Yet, contractors are reluctant to use ABC techniques, especially due to perceived risks during construction (Ofili 2015). To assure proper use of this technique, different departments of transportation (DOTs) have formulated decision-making guidelines such that those projects which do not require acceleration in schedules and can be constructed with conventional practices utilize those methods instead of ABC (Freeseman et al. 2020). Based on the decision-making framework developed by Federal Highway Administration (FHWA), the owner/user may efficiently decide on the applicability of the ABC method in a bridge construction project with the help of either qualitative or quantitative decision-making tools. For instance, the Utah Department of Transportation (UDOT) has developed an ABC decision flowchart to determine if an ABC approach is required yet does not anticipate ABC project success indicators (West et al. 2012). Similarly, a report was also prepared for the Michigan Department of Transportation (MDOT) as a decision-making process, which included site-specific, traffic, and cost alternatives, yet not an interactive tool supporting the ABC project’s anticipated success (MDOT 2015). Hence, merely deciding on the adoption of a specific construction method may not be sufficient for thriving in an infrastructure project. Considering the growing complexity of bridge construction projects, advanced planning strategies are necessary that ensure constructability, safety, and quality in bridge projects. Several studies have developed different tools to make well-informed decisions and facilitate pre-project planning. The Construction Industry Institute (CII) has developed pre-project planning tools that support project stakeholders to anticipate success rates and attract contractors in adopting ABC projects (Gibson et al. 2010); however, such tools do not align with ABC projects nor anticipated their success indicators. Each ABC project has different environmental, traffic, and geometric conditions that influence the type of design, material, and project delivery method to be used for the construction. Therefore, there is an urgent need for a unique pre-project planning tool similar to those prepared by the CII to determine particularly associated risks with ABC.

The accelerated bridge construction method may not be applicable for all types of bridge construction projects (Abu-Hawash et al. 2009). For instance, a large bridge construction project may require a huge initial investment, and the acquisition of a huge amount of funding within a limited duration of a few months may not be viable. Consequently, the rapid construction of bridges may be delayed due to funding constraints (Yavuz et al. 2017). Without adequate funding, contractors may need to distribute labor based on reduced demand, construction materials arrival may be delayed, and work may have to be done in different phases over a longer time. Therefore, there cannot be a uniform construction duration for all bridge projects since different projects require a different amount of investment. According to Khan (2015), bridge projects can be categorized into four different groups based on the funding allocated by these projects: Bridge projects with funding of 5 million dollars are considered small projects, projects that do not exceed 50 million are medium-sized projects, projects not exceeding 250 million dollars are large projects and those projects exceeding 250 million dollars are considered very large projects. Thus, based on the size of the bridge project, all the construction activities such as technical, administrative, coordination, non-technical, and accounting, among others, will increase in number and intensity (Orabi et al. 2016). Considering that funding and resource allocation may take some time, rapid construction would suit for only small project delivery. However, if accelerated construction methods are required to be integrated into large or very large projects, proper pre-project planning for design and construction should be conducted. To this end, research studies have seldom investigated the integration of front-end planning of accelerated bridge construction projects, and this study is an initiative to address the gap.

Infrastructure projects such as Accelerated Bridge Construction (ABC) are often complex, and contractors need to have substantial experience to thrive in ABC projects (Ofili 2015). Without proper knowledge of potential challenges in advanced planning, there may be schedule overruns, liquidated damages, and legal and contractual issues. These projects play a critical role in the built environment, and some of the projects face unique planning challenges such as right-of-way (ROW) acquisitions or adjustments, underground, and more interface with the public and the environment. Low awareness of a project’s societal and environmental impacts, as well as a lack of standardized procedures to quantify these impacts, are often roadblocks to achieving sustainability (Weerasinghe et al. 2007). Therefore, there is a growing need for a success index that can be utilized for pre-project planning of infrastructure projects like ABC to support contractors in achieving sustainability goals and improving performance. Risk mitigation in infrastructure projects can be achieved by integrating one of the most powerful tools referred to as Front-end planning (FEP) which facilitates infrastructure projects to improve early understanding of scope definition elements to accomplish improved project outcomes (Gibson et al. 2010). However, such tools have seldom been explored in ABC projects, and an investigation is necessary to assess their efficacy.

Lu et al. (2020) investigated the trends of critical factors that impact the design, construction, and maintenance of ABC bridges. The study highlighted that adoption of new construction materials or structures and new construction techniques, changes in the cost of construction, and advanced health monitoring technology, among others, are the impactful factors that are trending in the ABC method. In another study, Barutha et al. (2017) developed a metric based on social return on investment (SROI) that measured the value of an investment in ABC methods to reduce economic, environmental, and social impacts on road network users. The authors highlighted that the SROI metric gives a holistic measure to prioritize socio-economic aspects in the ABC techniques. On the other hand, Prajapati and Ouk Choi (2019) developed a preliminary list of execution plan differences in ABC projects in comparison to conventional bridge projects to extend the scope of its implementation. Considering the subjective nature of the 61-execution plan identified in the study, a comprehensive investigation is necessary to validate the execution plan in the pre-project planning stages. Although identification of these factors is useful for transportation decision-makers and policymakers, there remains a literature gap on how environmental, social, economic, and technological factors can be utilized in the pre-project planning to assist contractors in ensuring the success of ABC projects.

2.3. Front-End Planning of Infrastructure Projects

Front-end planning (FEP) is a process 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, as shown in Figure 4 (Bingham and 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.

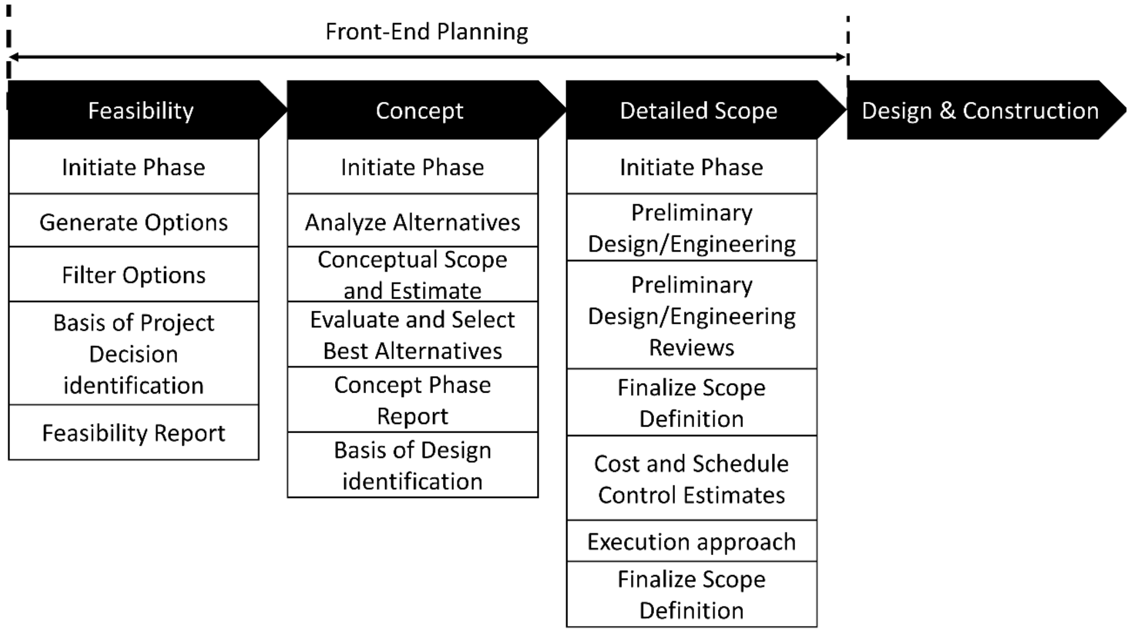

Figure 4. Front-end planning process for infrastructure project

Poor scope definition in an infrastructure project has severe consequences on the project's schedule, cost, and operational performance. As shown in Figure 5, decisions made during earlier phases of a project's lifecycle have a significant influence on a project's outcome than those made during the later stages. According to Gibson et al. (2010), one of the critical tasks in FEP is the development of proper strategic information for creating a stronger link between the project goals and scope throughout the entire infrastructure project's life cycle. However, many owners, agencies, and contractors often neglect the criticality of FEP due to which infrastructure projects are plagued by poor project performance that leads to a deficient design basis (Bingham and Gibson 2017). In an effort to overcome such challenges, the Project Definition Rating Index (PDRI) tools have been developed. PDRI is a weighted matrix with scope definition elements that allows stakeholders to assess, quantify, and rate the level of scope definition and readiness for project execution before detailed design and construction (CII 1997, 2001, 2006). The Construction Industry Institute (CII), together with Bingham and Gibson Jr. (2010), Elzomor and Parrish (2017), Collins et al. (2017), among others, created the different PDRI tools: PDRI-General Buildings Projects, PDRI-Infrastructure Projects, PDRI-Small Infrastructure Projects, and PDRI-Small Industrial Projects, respectively.

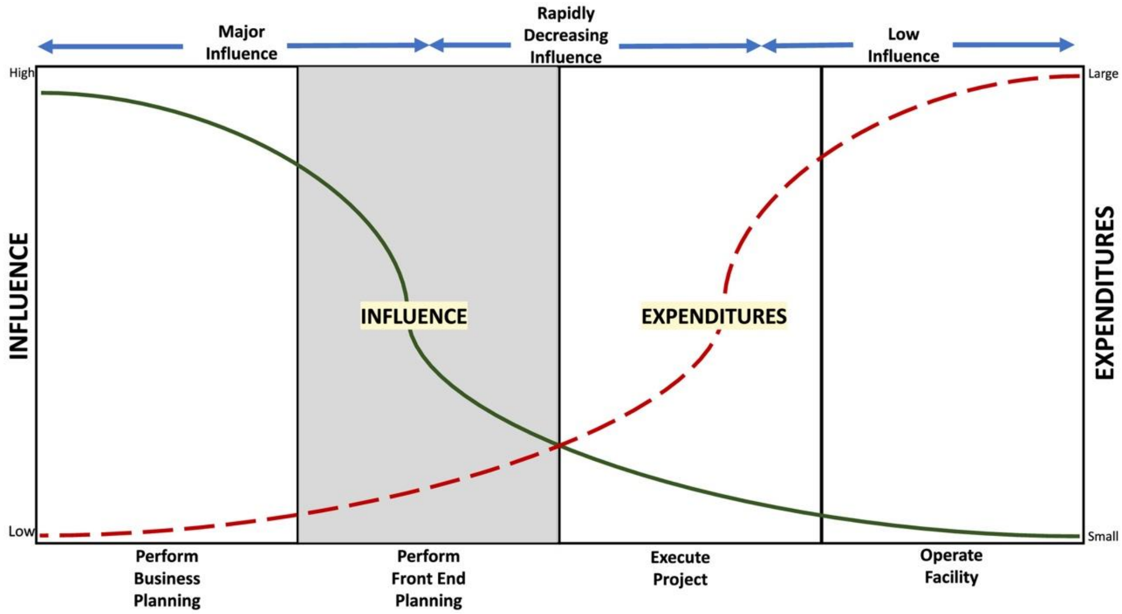

Figure 5. Project lifecycle with influence and expenditure curves (Gibson et al. 1995)

PDRI tools include a structured list of scope definition elements categorized in three separate sections: Section I. Basis of Project Decision, Section II. Basis of Design and Section III. Execution Approach. Then, these sections are broken down into subcategories with their respective elements. PDRI – Small Infrastructure consists of 40 scope definition elements grouped into eight categories, while PDRI – Infrastructure (Large infrastructures) entails 68 elements grouped into 16 categories. Both tools have a maximum score of 1000 points, where a lower score indicates a project with a greater level of scope definition, and a higher score indicates a lesser amount of scope definition (Elzomor et al. 2017). In other words, projects with lower PDRI scores usually maintain more robust cost and schedule performance than those with higher PDRI scores. Although all PDRI tools are divided into the same three categories, each tool has its unique complexities to score each of the respective categories. The first category, Basis of Project Decision, consists of information necessary for understanding the project objectives, which indicates whether the project team is strongly aligned to fulfill the project's business objectives and drivers. Similarly, the second category, Basis of Design, highlights processes and technical information elements that should be evaluated to fully understand the engineering/design requirements necessary for the project. Lastly, the third category, Execution Approach, consists of elements that should be evaluated to understand the owner's strategy fully and the required approach for executing the project construction and closeout (Elzomor et al. 2017). Elzomor et al. (2018) carried out a comparative study between PDRI for small infrastructure and PDRI for large infrastructure in terms of their structure, content, weight, and target score of the elements. The authors determined that the most important section for PDRI-Small Infrastructure was Section II: Basis of Design, with 470 points, while for PDRI-Infrastructure, the highest weighted section was Section I: Basis of Project Decision, with 437 points. This is related to the fact that large infrastructure projects frequently need a more robust decision-making effort to define the project scope, while small infrastructure projects may be less complex and already have the location and scope defined prior to the FEP phase.

Cho and Gibson Jr. (2001), summarized FEP in five major processes: (1) initiation, (2) scope planning, (3) scope definition, (4) scope verification, and (5) scope change control. Gibson and Gebken (2003) recommended the implementation of PDRI in all five steps of FEP. During the initiation, the PDRI tool serves as guidance in defining the project strategy and objectives. In the scope planning and scope definition phases, the PDRI helps in defining a scope management plan and assigning roles to each stakeholder. For the scope verification process, the PDRI specifies the quality and level of completeness of the project and aids in the decision-making process of moving forward to the construction phase. Finally, in the scope change control, the PDRI shows which elements have been poorly defined and need attention, which allows the project team to act and improve those deficiencies. PDRI is an important tool for its efficient use during FEP in terms of evaluating how likely a project is to achieve a specific set of objectives, including social and environmental considerations (Kang et al. 2013). Kivilä et al. (2017) stated the significance of integrating sustainability criteria during the entire project management process, particularly in large infrastructure projects that have long-lasting effects on society.

ElZomor et al. (2018) highlighted that tool such as Project Definition Rating Index (PDRI) had been found to be effective for assisting in front-end planning efforts for small as well as large infrastructure projects thereby, facilitating the assessment of risks and defining of infrastructure projects. However, these tools have not been integrated nor aligned within ABC project planning, due to which it is critical to developing ABC Success Index to integrate the FEP process and support project teams to assess the gaps in a scope definition. The main motivation of this study is to fulfill the literature gap by pre-informing project stakeholders of their success indicators through effective pre-project planning. Therefore, our proposed tool will couple the Framework for Decision-Making that was developed by FHWA with weighted criteria to show success indicators once the project is pursuing an ABC method.

CHAPTER 3. DATA COLLECTION

Data collection in this study will be geared towards developing an interactive index/matrix that would provide an easy-to-use success framework for contractors to identify strengths, challenges, and opportunities to guide ABC project performances. To achieve this, the study will adopt a structured approach which includes: (1) conducting 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; and (2) conduct semi-structured survey with the implementation of purposive and snowball sampling techniques. 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 a 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 through experts in the construction industry.

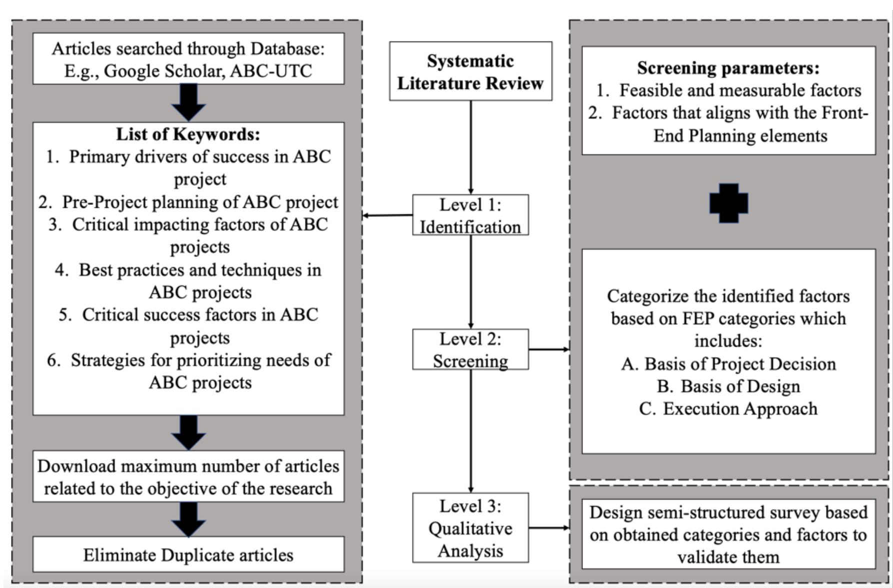

Figure 6. Systematic literature review framework for identification of critical success factors in ABC projects

3.1. Identification of Critical Success Factor for Success of ABC project

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. Critical success factors identified from SLR

S.N.	Critical Success Factors	References
1.	Location setting	(Gransberg 2013); (D'Andrea et al. 2016); (Galvis and Correal 2017);
2.	Project Delivery Method (i.e., CMGC, DBB, DB)	(El-sayegh 2008); (Ptschelinzew et al. 2013); (Culmo et al. 2013); (Jones 2014); (Freeseman et al. 2020);
3.	Project Type	(Khaleghi et al. 2012); (Khan 2015); (Muhaimin et al. 2021);
4.	Prefabrication methods	(Hällmark et al. 2012); (Aktan and Attanayake 2013); (Culmo et al. 2013); (Head et al. 2015);
5.	Competency of key project stakeholders	(Becker 2009); (Gransberg 2013); (Ardani et al. 2013);
6.	Civil and Structural Design	(Khaleghi et al. 2012); (Aktan and Attanayake 2013); (Becker 2009); (Shivakumar et al. 2014); (Dean et al. 2019); (Muhaimin et al. 2021)
7.	Project Quality Assurance and Control	(Abu-Hawash et al. 2009); (Khaleghi et al. 2012); (Aktan and Attanayake 2013); (Jia et al. 2018)
8.	Life cycle cost analysis	(Krumwiede 1998); (Abu-Hawash et al. 2009); (Akinola 2015); (Orabi et al. 2016); (Jia et al. 2018); (Chang 2021)
9.	Design for Safety and Hazards	(Sutaria 2012); (Khaleghi et al. 2012); (Mallela et al. 2014); (Volk 2020); (Freeseman et al. 2020)

10.	Monitoring and maintenance	(Littleton and Mallela 2013); (DeJong 2019); (Farhangdoust and Mehrabi 2020);
11.	Research and development of the innovative construction method	(Ormijana and Rubio 2013); (Tazarv and Saiidi 2015); (Reid et al. 2018); (Carfagno and Dickerson 2018); (Garber et al. 2020)
12.	Training workshops on constructability	(Roddenberry and Servos 2012); (Aktan et al. 2014); (Yen et al. 2015); (Phares and Cronin 2015); (Mendez 2011)
13.	Preliminary project schedules	(George et al. 2008); (Gibson et al. 2010); (Elzomor et al. 2017)
14.	Legislation and policies	(Lotfy 2015); (Gad et al. 2015); (Muhaimin et al. 2021);
15.	Project Cost Estimate and Cost Control	(Akinola 2015); (Orabi et al. 2016); (Bingham and Gibson 2017); (Muhaimin et al. 2021)
16.	Project Schedule and Schedule Control	(Abu-Hawash et al. 2009); (Khan 2015); (Jia et al. 2018); (Muhaimin et al. 2021)

Location Setting: To this end, location setting such as weather conditions, soil conditions, and urban or rural conditions, among others, have a significant impact on the successful construction as well as maintenance of ABC bridges. For instance, scour and erosion has been one of the most common reasons for the trend of bridge failures in the past (Gransberg 2013). Similarly, during the construction phase, there is a higher probability that a traffic detour or temporary bridges may be required, which would impose additional direct or indirect costs. In many cases, such costs can also exceed the actual costs of the primary structure itself (Galvis and Correal 2017). For example, in an urban setting where there is heavy traffic volume, full-lane closures can have a critical impact on industrial and commercial activities in such locations (D'Andrea et al. 2016). Furthermore, in case of partial lane closures, there may be safety concerns if construction activities are conducted adjacent to traffic. Although bridge components in accelerated bridge construction are produced offsite and fully assembled on-site, it is critical to consider location setting as a critical success factor that needs to be considered during the pre-project planning stages of design and construction.

Project Delivery Methods: The determination of a suitable project delivery method for construction projects is a complex decision and may largely depend on project aim, budget, project schedule, associated risks, the expertise of stakeholders, and opportunities (Ptschelinzew et al. 2013). Traditionally, the cost was generally considered as a significant criterion for determining the winning bid, and most of the highways were built with Design-Bid-Build (DBB) contract delivery method. However, there is no collaboration between the designer/architect and general contractor during the design phase, which makes the process slower and consequently increases the project's timeline. In the last few decades, Federal Highway Administration (FHWA) has started to use alternative contracting methods such as Design-Build, and Construction Manager-General Contractor that reduces risks and minimizes unforeseen delays (Jones 2014). Design-

Build is a contract delivery method where the design and construction of a project are under a single contract. One of the key opportunities in DB contract delivery is that the contract allows innovation in resource loading and scheduling by the DB team. Furthermore, designers and contractors can collaborate to optimize means and methods as well as improve innovation (Mattox 2019). On the other hand, the construction Manager-General Contractor project delivery method involves procurement of professional services based on qualifications or best value from a construction manager during the design phase such that cost and schedule savings, innovations, and constructability issues can be offered. Therefore, it can be observed that the adoption of any specific project delivery methods has a significant impact on the success of the ABC projects (Freeseman et al. 2020).

Project Type: ABC method is applicable to several different types of bridges with structural variations such as pedestrian bridges, over streams bridges, over wide river bridges, concrete arch bridges, cable-stayed bridges, and steel arch bridges, among others (Khaleghi et al. 2012). Conventional bridges require more time to construct, due to which different parts of the bridges have started to integrate prefabricated components. Overall, different approaches are adopted for the planning of new bridges in comparison to the replacement of bridges or the widening of bridges. During the construction of new bridges in a new location, there are seldom any traffic problems for maintenance and protection of traffic (MPT). On the other hand, the replacement of bridges in an existing location is required to have a detour that increases the travel distance and time taken to reach the destination (Khan 2015). To overcome this issue, bridge engineers practice replacing the bridge in stages or constructing a new bridge adjacent to the existing one such that there is no disruption in traffic. Additionally, some bridges also require widening, which is one of the most difficult constructions. It requires additional foundations, substructure, and new wing walls, due to which maintenance and protection of traffic in such construction takes significant time. Also, there are possibilities of construction hazards due to which labor needs to be protected from accidents, and nightshift should be made safer and more flexible (Muhaimin et al. 2021). Therefore, during the pre-planning stages, it is important to select the appropriate project type with minimum impact on the public, environment, and performance of the structure.

Prefabrication methods: Prefabricated materials and systems are generally utilized to minimize the on-site construction schedule of ABC bridges. The prefabricated construction materials and methods are widely different from conventional methods and require innovative concepts to make the system efficient and sustainable. A prefabricated bridge superstructure consists of prefabricated girders and precast deck panels with or without a cast-in-place concrete deck, modular systems such as segmental box girders, single-tee, double-tee, among others, and any other configuration where a continuous bridge superstructure is formed one the elements are placed and connected through the cast joints (Hällmark et al. 2012). In terms of deck-plan shapes, the use of skewed, normal, or curved decks can make a significant difference in the overall construction schedule. Similarly, cross-sectional types, span types, and the selection of modern materials have an equal impact on the cost, duration, performance, and quality of ABC bridges (Culmo et al.

2013). Therefore, proper investigation of necessary prefabricated elements of a bridge plays a critical role in the success of ABC bridge construction since it eliminates possible liquidated damages, delays in schedule, and waste of materials.

Competency of Key Project Stakeholders: Faster design approvals and coordination with utility companies is highly influenced by effective coordination between the stakeholders. For instance, ABC projects in which contractors play a due role in coordination, planning, and progress management can achieve reasonable rapid progress in the project (Becker 2009). Similarly, during construction, coordination with the utility agencies is required to relocate gas, water, and other pipes supported by cross beams under the bridge. Also, an electrical engineer will need to ensure coordination with the utility agency for long-term deck and overhead lighting (Ardani et al. 2013). To ensure that there are no delays in schedule, it is critical to timely coordinate between stakeholders and utility agencies.

Civil and Structural Design: The design of bridges constructed through ABC technology is constantly advancing. For instance, new materials are being developed and used for construction such as lightweight aggregate (LWA) concrete, FRP concrete, and recyclable plastics, among others to foster sustainability and resilience (Muhaimin et al. 2021). Such advancements are also critical for achieving sustainability certifications such as Envision. Envision is a practical framework applicable to all types of infrastructure (horizontal) projects such as bridges used to improve the built environment’s performance through a suite of economic, social, and environmental aspects, also known as “Triple Bottom Line (TBL)” (Shivakumar et al. 2014). Besides, there are different types of ABC structural elements such as deck elements (e.g., partial depth precast deck panels, full-depth precast deck panels), deck beam elements (e.g., adjacent deck bulb-T beams, adjacent slab beams, adjacent box beams), full-width beam elements (e.g., precast segmental), pier elements (e.g., precast pile cap, precast columns), among others (Roddenberry and Servos 2012). It is critical to determine the most suitable structural elements based on the requirement of the site and owner specifications/standards to ensure the success of the project.

Project Quality Assurance and Control: Quality assurance of accelerated bridge construction projects involves two major components: (1) fabrication of precast bridge elements in a plant or near a jobsite, and (2) assembly of precast elements in the field (Alashari 2016). Projects selected will ideally have lessons learned or unique quality assurance plans and practices in four areas which include design aspects, procurement aspects, construction aspects, and long-term performance of critical members/connections (Head et al. 2015). Citir et al. (2018) indicated that there are eight different types of non-destructive evaluation (NDE) method for inspecting ABC structure for quality control which includes: visual inspection, hammer-sound and chain drag, acoustic emission, impact echo, ultrasonic testing, ground penetrating radar, infrared thermography, and x-ray and gamma-ray. Additionally, recent advancements in robotics and automation technologies have allowed for greater efficiencies in improving project quality assurance and control (Javed et al. 2021; Azizinamini et al. 2021).

Life cycle cost analysis: The life cycle cost analysis is the process of assessing the total economic worth of a usable project through analysis of initial costs and discounted future costs including reconstruction, rehabilitation, maintenance, resurfacing, and reconstruction costs over the life of the project (Valigura et al. 2021). In the case of the ABC project, life cycle costs are relatively lower in long term and the returns are greater due to the avoidance of discomfort and indirect costs to the public during the construction (Khan 2015). Moreover, 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). Since the increase in quality leads to an increase in service life and a reduction in the life cycle cost of the ABC project, it is one of the important critical success factors that should be considered during the pre-project planning of ABC projects.

Design for Safety and Hazards: An ABC project site is vulnerable to different kinds of accidents, including crane collapses, injuries from equipment, or traveling vehicles. To this end, the number of highway and bridge renovation projects is constantly increasing due to the growing number of deteriorating infrastructures (Volk 2020). As such, work zones generate traffic congestion, which can increase the risk of crash occurrence. For instance, according to Federal Highway Administration (FHWA 2020), there were 2000 fatal vehicle crashes in the construction work zones where 44% of bridge construction work injuries involve a vehicle traveling through a construction work zone. Most importantly, two-thirds of these injuries are fatal injuries indicating that there are significant challenges in safety even during construction. Since work zone crashes and injuries impose millions of dollars of cost on the project, it is critical to consider safety measures during and after construction through innovative designs and preventive measures (Mokhtarimousavi et al. 2020). Some of the common challenges to addressing safety issues include increasing fatalities, limited funds, sizable highway systems, long project development cycles, and a limited safety toolbox (Khaleghi et al. 2012). To address these challenges, DOTs and ABC construction stakeholders should adopt the data-driven safety part of the strategic vision, quantitative safety analysis, and analyze the effectiveness of safety improvements (Freeseman et al. 2020). Therefore, the pre-project planning phase of ABC projects needs to ensure safety as a part of the project scope such that it is easier to achieve a successful project.

Monitoring and maintenance: 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 and Mallela 2013). In particular, structural health monitoring technology helps to: (1) identify structural deficiencies; (2) measure rotations, strains, and displacements using the sensors which provide information about peak stress distributions through computer software; (3) assess the performance of high-performance concrete, hybrid materials, materials made from thermoplastic or thermosetting resins, high-performance steel, among others; and (4) assess the feasibility of repair, replacement or retrofit of bridges (Khan 2015). Such specialized technology will continue to grow and has significant potential for asset management, and condition monitoring and may eventually replace the visual inspection techniques and life-cycle costs inspections. Most importantly, it would ensure better project performance and maintenance of the bridge.

Research and development on innovative construction methods: Federal Highway Administration (FHWA), along with Department of Transportation (DOT) officials, developed a list of initiatives to encourage innovative construction methods over the past several years (Reid et al. 2018). One of those initiatives included alternative technical concepts to allow states to present innovative ideas that save cost and time of construction. An alternative Technical Concept (ATC) is a proposal made during the bidding or procurement process to gain competitive benefits in terms of modifying the project's scope of work. ATC is one of the methods of early contractor involvement, allowing them to propose modifications to contract requirements before the bidding or proposal process (Mattox 2019). Geospatial data collaboration is another innovative initiative that allows data sharing between ABC project stakeholders to explore a cloud-based geographic information system platform. Similarly, 3D modeling and construction equipment that utilizes global positioning system (GPS) receivers can increase productivity by 50% by identifying accurate grades in the first trial (Khan 2015). Similarly, many research initiatives from ABC-UTC have also led to the research and development of innovative construction methods. For instance, Garber et al. (2020) have conducted an experimental study on non-proprietary UHPC mix made with local materials to lower the costs as well as achieve the important mechanical properties and durability for its utilization in bridge components, connections, and repair. Therefore, encouraging research for innovative solutions during pre-project planning of ABC projects is critical for the overall success of the construction project.

Training and workshops: Training and workshops are critical for the construction and maintenance of ABC projects. For instance, a lack of maintenance of construction equipment and operating training can lead to frequent breakdowns or accidents (Aktan et al. 2014). Several precautionary measures need to be taken to avoid any hazards. Training in ABC beyond the college level education is one of the most effective ways to achieve those objectives (Yen et al. 2015). Specialized training in the form of webinars and workshops offered by DBIA, FHWA, AASHTO, state agencies, and universities like FIU is effective in informing new ABC stakeholders about understanding the methods and processes involved in ABC projects. Overall, it can be concluded that the pre-project planning stages should ensure proper training of all the ABC stakeholders through workshops and webinars for the project's overall success.

Preliminary Project Schedule: Preliminary project schedule deals with applying known, contractual, or tentative dates to the sequence of activities in the ABC project prior to resource scheduling (George et al. 2008). In any infrastructure project, it is critical to developing a standard sequenced task logic network that reflects the major control activities and relationships between procurement, engineering, construction, and startup (Gibson et al. 2010). According to George et al. (2008), there are seven core activities that impact the successful completion of the pre-project planning process that should be considered during preliminary project schedule preparation. The activities include establishing the image and public relations, defining startup requirements, refining public relations, addressing quality and safety issues, developing a preliminary startup plan, compiling project scope, and developing utilities and offsite project scope. Therefore, considering these elements during pre-project planning of accelerated bridge construction (ABC) projects could be advantageous for key project stakeholders.

Codes and policies: Many state DOTs have their own codes and policies regarding ABC construction projects. For instance, some states have codes that mandate the minimization of any traffic disruption during the construction or replacement of bridges (Lotfy 2015). Similarly, if an ABC project integrates alternative technical concepts to exploit its benefits, different codes and policies should be followed. Confidentiality, protest rights, and criteria for consideration and acceptance are some of the legal issues related to ATC identified through procurement documents for a given project (Gransberg and Tapia 2016). It is significant to provide detailed information about the conduction of one-on-one meetings in the procurement documents to ensure confidentiality. Competitors are allowed to have confidential one-on-one meetings to determine potential ATCs and receive an indication response from the department for a given ATC (Gad et al. 2015). Due to such codes or policies, a contractor is able to integrate innovative ideas and designs in the project outside of the original project scope.

Project Cost Estimate and Cost Control: The project cost estimates should address all costs necessary for the completion of the project (Bingham and Gibson 2017). Orabi et al. (2016) developed a parametric cost estimation tool to predict the cost of different ABC bridges based on different bridge characteristics and compare the cost per square foot for both ABC and conventional bridges. The authors utilized historical nationwide data about the final construction costs and characteristics of previously constructed ABC projects. Therefore, such a tool can be used by the decision maker to estimate a range of the predictable cost per square foot for that particular bridge through simple inputs like location, type, number of spans, and AADT. Moreover, the project cost estimates of an ABC project are also impacted by the type of method used for construction i.e., modular, SPMT, and lateral sliding (Akinola 2015). Hence, for the overall success of ABC projects, it is critical to determine the cost estimate and cost control during the pre-project planning phase.

Project Schedule and Schedule Control: In a conventional contract, a contractor should stick to the agreed schedule (Khan 2015). However, unpredictable weather, timely supply of materials, or trained labor are some issues that may delay the project (Jia et al. 2018). Therefore, it is critical to consider these factors during pre-project planning such that there is no prolonged construction duration that would adversely affect public comfort and waste funding (Abu-Hawash et al. 2009). On the other hand, over the acceleration of the construction schedule of bridge projects might have an effect on the quality of construction as well (Muhaimin et al. 2021). As such, it is critical to ensure both quality and timely completion of construction activities for overall project success.

3.2. Categorization of Critical Success Factors

According to Khan (2015), bridge projects can be categorized into four different groups based on the funding allocated by these projects. Bridge projects with funding of 5 million dollars are considered small projects and these bridge projects should not use the ABC method for construction according to FHWA. Only those bridges whose cost exceeds $ 10 million should use the ABC method, as recommended by FHWA. Besides that, the other three categories include: bridge projects that do not exceed 50 million are medium-sized projects, projects not exceeding 250 million dollars are large projects, and those projects exceeding 250 million dollars are considered very large projects. Considering these factors, the categorization of critical success factors is partially based on the PDRI-Infrastructure tool as shown in Table 2.

Table 2. Different categories for critical success factors

Section	Critical Success Factors
Basis of Project Decision	A1. Project Type
	A2. Prefabrication methods
	A3. Competency of key project stakeholders
	A4. Training and workshops
	A5. Preliminary Project Schedule
Basis of Design	B1. Codes and Policies
	B2. Location setting
	B3. Civil and Structural Design
	B4. Research and development of the innovative construction method
	B5. Life cycle cost analysis
	B6. Design for Safety and Hazards
	B7. Monitoring and maintenance
Execution Approach	C1. Project Delivery Method
	C2. Project Quality Assurance and Control
	C3. Project Cost Estimate and Cost Control

	C4. Project Schedule and Schedule Control

The score sheet consists of three main sections, each of which contains a series of categories broken down into elements.

SECTION I: BASIS OF PROJECT DECISION

This section deals with information critical for understanding the project objectives. The completeness of the listed information demonstrates whether the project stakeholders are aligned adequately to fulfill the project's objectives and drivers.

A1. Project Type

This category defines the kind of project being proposed and why it is necessary. All the stakeholders need to understand the objectives and constraints related to the project. Key information included in this category are:

- Availability of funding (i.e., Bridge projects with funding of 5 million dollars are considered small projects, bridge projects that do not exceed 50 million are medium-sized projects, projects not exceeding 250 million dollars are large projects, and those projects exceeding 250 million dollars are considered very large projects).
- Initial estimates (e.g., construction, engineering, operating, and right of way costs)
- Project drivers (e.g., value/benefit, safety, security, profitability, and regulatory)
- Project constraints (e.g., geographic, governmental, and community concerns)
- Desired project results (e.g., capacity, refurbishment, compliance, and efficiency)
- Renovation and revamp projects' compatibility with existing facilities
- Configuration strategy, including access, geometric/alignment, and utilities; compatibility with other uses or adjacent projects and facilities
- Compatibility of this project with the program's dismantling/demolition requirements
- Others ……………………………………

A2. Prefabrication methods

This category defines the methods and location used for prefabrication, installation process, and constructability of the bridge through prefabrication. Key information included in this category are:

- Location of prefabrication of elements and systems (i.e., offsite factory, adjacent to the site, or near the site location)
- Review of shop drawings developed by the manufacturer of prefabrication elements and systems
- Roadway parameter data required for delivery of prefabricated elements and systems from the off-site factory (e.g., required clearances, reasonable detours, available work zones at the end of the bridge, available lane closures above or below the bridge)

- ❑ Assessment of staging areas for manufacture of prefabrication elements and systems adjacent to the site or near a site (e.g., ample room within the highway right of way to establish a staging yard, ensuring that the area is large enough for fabrication of elements, ensuring overhead wires can be easily relocated, relocation of any utilities above ground and underground)
- ❑ Availability of high-capacity construction equipment (e.g., overhead large-capacity cranes, longitudinal launching systems, lateral slide-in systems, and Self-Propelled Modular Transporters (SPMTs) for moving the prefabricated elements such as superstructure to the existing bridge location)
- ❑ Availability of stronger and lighter materials for improving the quality of bridge components
- ❑ Connection details and construction specifications
- ❑ Fulfills sustainability criteria (e.g., context-sensitive design and environmental requirements)
- ❑ Prefabricated bridge components are consistent with the historic bridge requirements
- ❑ Others ……………………………….

A3. Competency of key project stakeholders

This category deals with the identification of synergies and communication with key project stakeholders. Key information included in this category includes:

Identification and documentation of roles and responsibilities of the key project stakeholders

Establishment of positive team relationships among all the key project stakeholders to ensure a shared understanding of project objectives as well as promote efficiency and success of the project

All the key project stakeholders must be informed of the project decisions and given the opportunity to attend the project-planning meetings

Timely coordination with external project stakeholders such as between project team and highway agencies for design approval or coordination of project team with utility companies

Transparency to the public for ensuring proper public support and reducing problems during construction through user cooperation in using narrower lanes and driving at slower speeds

Use of initiative Everyday Counts (EDC) that combines input from the Federal Highway Administration (FHWA) and stakeholders such as state DOT officials, trade groups, and private industry professionals to deliver the project in less time and for less money

Stakeholders need to evaluate 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.

Others ……………………………

A4. Training and workshops

A list of general training and workshops that should be provided to the workforce and stakeholders to ensure quality and safety in the project include:

- ❑ Specialized training of designers and field staff

- Training contractors on areas such as optimization of design; effective coordination with consultant, client, subcontractor, and subconsultant; identification of sensitive activities to be performed in a timely manner using critical path method; logistics of transporting assembled bridges; reducing costs; and understanding how to obtain permits for wide loads
- National Traffic Incident Management Responder Training
- Training on construction technology tasks such as modern concrete technology; use of steel, timber, etc. in bridge construction; understanding erection procedures and erection drawings, among others
- Specialized training for masons and field labor
- Training in ABC methods for emergencies among bridge engineers such as to conduct detailed vulnerability assessments, develop effective security and emergency response plans that cover all eventualities.
- Training contractors in using innovative technology
- Web-based training modules for ABC and rapid delivery construction projects
- Training workshops on constructability
- Training technicians in the specialized manufacturing process of prefabricated elements and systems
- Training on the safe and economical design of ABC technology for repair and replacement of bridges
- Training in slide-in bridge construction method as an alternative to incremental launching
- On-the-job training for engineers working on the ABC project
- Certifications and training of construction personnel, continuing education of engineers in rapid construction techniques and construction management for ABC courses at universities
- Others ……………………

A5. Preliminary Project Schedule

The preliminary project schedule should be documented, analyzed, and agreed upon by the key project stakeholders. It can be developed through the identification of the primary critical path which may also include key project participants. Key information to consider includes:

- Project milestones (i.e., funding approval, permitting, contracts, environmental, engineering, construction, commissioning, and start-up)
- Planning for procurement (long-lead or critical pacing of equipment/material and contracting)
- Necessary submissions and approvals (e.g., regulatory, environmental)
- Contingencies (e.g., site conditions, unusual schedule considerations, scope change, weather)
- Renovation and revamp projects interface with existing operations and are many times performed in conjunction with other ongoing projects. The schedule should contain input from appropriate personnel to coordinate required disruptions.
- Others ………………………

SECTION II: BASIS OF DESIGN

This section incorporates processes and technical information elements that need to be considered for a full understanding of the engineering or design requirements necessary for the project

B1. Codes and Policies

The codes, policies, and standards that govern the project design should be identified, documented, and evaluated for schedule and cost impact. Items that should be considered include:

- ❑ National, local, or organizational/corporate codes
- ❑ ABC design codes, policies, and construction specifications
- ❑ AASHTO LRFD bridge design specifications
- ❑ National, state/provincial, and local government permits
- ❑ Regulatory and utility commissions, including construction
- ❑ Utilization of design standards (e.g., owner's, contractor's, mixed)
- ❑ Others ……………………………….

  Additional items to consider for renovation and revamp projects
- ❑ Assessment of original intent of codes and regulations, and any "grandfathered" requirements
- ❑ Setting design goals to take advantage of system or facility outages/shutdowns
- ❑ Verification of accuracy of as-built drawings
- ❑ Reconciliation of as-built specifications against current specifications

B2. Location setting

The project requirements should be compared with the available site characteristics for all sites considered for the project to identify the feasibility such as high-level requirements for adaptation and future growth. Key information included in this category are:

- ❑ Accessibility during and after construction (e.g., roads, approaches, bridges)
- ❑ Existing utility identification and adjustment (alignment with the existing right-of-way, required clearances and boundaries, associated permits and regulations, access points, timelines for agreements and relocation, utility corridors)
- ❑ Complete condition assessment of existing facilities and above and below ground infrastructure
- ❑ Potential compliance issues (e.g., natural resource surveys, stormwater, pollutants and environmental compliance issues, climatic data, cultural resource surveys)
- ❑ Verify existing geographic, mapping, right-of-way, and geographic information including geographical information system (GIS) data
- ❑ Preliminary topographic survey, including recovery of existing monuments
- ❑ Above and below ground utility information (e.g., crossing and/or parallel)
- ❑ Existing conflicting structures
- ❑ Requirements for right-of-entry and surveying consultants
- ❑ Sensitive areas (e.g., historical, archaeological, environmental, and cultural)
- ❑ Soil compaction, seismic, and foundation requirements (i.e., rock)
- ❑ Soil treatment or removal/replacement requirements

- ❑ Factors such as dust, emissions, noise, light, and erosion control
- ❑ Weather and climate impact
- ❑ Hydraulic information (e.g., surface, groundwater, and meteorological characteristics)
- ❑ Environmental requirements (e.g., stormwater runoff, air quality, monitoring)
- ❑ Identification of national, regional, and local jurisdictional environmental assessment
- ❑ Existing environmental mitigation and remediation plans affecting the current project
- ❑ Location/arrangement drawing to identify the location of each major project item (e.g., location, including coordination of location among all items, coordinates, and interfaces with existing facilities)
- ❑ Constrained right-of-way zones areas (i.e., choke points, retaining walls, cut and fill slopes)
- ❑ Vertical and horizontal alignment
- ❑ Special load requirements (e.g., seismic, ice, wind, thermal and heavy load)
- ❑ Uncertainty of as-found conditions (e.g., sub-base conditions; location, condition, and capacity of piping, electrical system components, installed equipment, and existing safety devices; structural integrity; hazardous materials)
- ❑ Others …………………………………………….

B3. Civil and Structural Design

All the civil and structural requirements should be identified or developed and then documented as the basis of design. Items that should be considered include:

- ❑ Owner specifications/standards (e.g., material procurement, the basis for design loads, capacity, vulnerability, and risk assessments)
- ❑ Physical and seismic requirements
- ❑ Overall project site plan including future expansion
- ❑ Construction materials (e.g., concrete steel) meet client and jurisdictional standards
- ❑ Sustainability considerations, including certifications such as Envision
- ❑ Definition of nomenclature and documentation requirements for civil drawings (e.g., grading/drainage/erosion control/landscaping, minimum clearances, corrosion control/protective coatings)
- ❑ Early contractor involvement
- ❑ Others ………………………….

  Additional items to consider for renovation and revamp projects
- ❑ Existing structural conditions (e.g., building framing, harmonics/vibrations, foundations)
- ❑ The potential effect of vibration, restricted headroom, and noise
- ❑ Underground interference

B4. Research and development of the innovative construction method

ABC technology is constantly evolving through research and development of innovative construction methods. Key information included in this category are:

- Methods to monitor foundations and improve resilience against earthquake, scour, and impact damage
- Corrosion mitigation techniques and strengthening methods (e.g., fabrication of stronger girders by eliminating the need for shear stiffeners with the use of folded web plates in steel girders)
- Use of construction technology (e.g., building information modeling (BIM), geographical information system (GIS)) for project management to achieve faster implementation and improved coordination among project stakeholders
- Use of Alternative Technical Concepts (ATCs) to gain competitive benefits in terms of modifying the project's scope of work (e.g., deliver the project on budget; reduce the impact on the public by the efficient flow of regional and local traffic safely; incorporate an innovative design that fosters faster construction; quality control and inspection; demonstrate quality construction, and encourage green techniques
- Identification of transportation and erection issues including loads and equipment, total bridge movement systems such as self-propelled modular transporter (SPMT), etc.
- Implementation of rapidly assembled connection details and joints that are constructible, durable, and repairable
- Quality assurance measures for accelerated techniques for substructure and superstructure construction
- Implementation of contracting strategies that encourage speed and quality
- Others ………………………….

B5. Life cycle cost analysis

This element deals with the value engineering method for reducing construction costs. Key information that should be considered includes:

- Cost-effective materials and construction techniques
- Use of prefabricated elements and system
- Sustainability considerations (e.g., pollution abating concrete, LED lighting, recycled materials, etc.)
- Policy requirements, accountabilities, deliverables, procedures
- Operations and maintenance consideration
- Use of high-performance materials and high-strength girder steel
- Use of software such as Primavera for life cycle cost and schedule risk analytics
- Emergency inspections (e.g., for accidents, floods, earthquakes, hurricanes, etc.)
- Use of sensors and devices such as structural health monitoring system
- Use of effective rehabilitation and repair strategies
- Others ……………………….

B6. Design for Safety and Hazards

Documentation of safety and environmental hazards as well as ways to mitigate them should be prepared in all ABC projects. Many jurisdictions, or organizations, will have their own specific compliance requirements and the owner should clearly communicate the requirements, methodology, and responsibility for the various activities to the project team. Key information that should be considered includes:

- ❑ Handling of hazardous materials (i.e., chemicals, explosives, silica, carbon monoxide)
- ❑ Enhancing the construction site environment through the inclusion of prevention methods in all designs that impact workers and others on the premises
- ❑ Elimination of hazards and controlling risks to workers to an acceptable level "at the source" or as early as possible in the life cycle of items or workplace
- ❑ Incorporation of design, redesign, and retrofit of new and existing work premises, work processes, substances, products, machinery, equipment, facilities, tools, structures, and the organization of work
- ❑ Operational safety features (i.e., clear zones, barrier replacement, sight distances)
- ❑ Hazard and operability (HAZOP) requirements
- ❑ Others ……………………………

B7. Monitoring and Maintenance

All the operation and maintenance design requirements should be identified or developed, and then documented as part of the basis of design. Items to consider include:

Long-term operation and maintenance responsibility to include utility agreements
Accessibility and egress requirements for operations and maintenance
Temporary structures for maintenance
Required provisions for safe maintenance/operation including out of service
Storage and fabrication facilities for repair parts
Surface finishes (e.g., paint and hot dip galvanized)
Right-of-way vegetative clearing and maintenance
Remote monitoring/operating capabilities
Others ……………………

SECTION III: EXECUTION APPROACH

The element in this section is mainly focused on critical project activities such as procurement, owner approvals, and coordination among key project stakeholders.

C1. Project Delivery Method

The identification and delivery of the project including equipment and materials are very important. This strategy should also include procuring professional services. Issues to consider should include:

- ❑ Procedures and plans for procuring professional services (e.g., consulting, design, testing) and construction services (e.g., Construction Manager-General contractor, design/build, design-bid-build)
- ❑ Bid evaluation, terms and conditions, and selection of vendors/suppliers

- A procurement responsibility matrix (including authority and responsibility for engineering, design and professional services, construction, materials, commissioning, and start-up materials)
- Quality requirements of materials and services, including acceptance testing and onsite vendor support service
- Value engineering or use of alternative technical concepts (ATCs) for proposed modifications to contract requirements before the bidding or proposal process
- Others ………………………

C2. Project Quality Assurance and Control

Quality Assurance/Quality control plan should include owner requirements, the material origin/sourcing/traceability requirements, definition of owner witness/hold points, field inspections and documentation requirements/inspections for governing authorities/permits/local codes, and design review. These procedures should include:

Assurance of contracted professional services
Quality management system requirements, including audits (i.e., International Organization for Standardization (ISO) 9000)
Responsibility for QA/QC during design and construction
Requests for Information (RFIs), redlines/conformed to construction/as-builts, changes, and modifications, Oversight of submittals, progress photos
Environmental Quality Control
Performance testing to assure conformance to specifications (e.g., slump test, welding, coating, compression test)
Correction of equipment, construction, and non-conforming materials
Non-destructive evaluation and visual inspection in the field
Use of prequalified products
Contractor transport and erection plan acceptance
On-site fabrication certification
Fit up tolerances
Connections in the field including grouting
Field repair
Field survey and layout
Field erection and monitoring of stresses related to moving PBES components
Training/Qualifications for Construction Inspection
Plant certifications
Others ……………………

C3. Project Cost Estimate and Cost Control

Cost estimates should be developed and documented by project teams throughout the planning and execution phase. These documents need to include the required level of detail and accuracy for the project phase. Such cost estimates could also be used to manage contingencies, and track and control costs. Issues to consider should include:

- Direct and indirect design, engineering, construction, commissioning, and contingency costs
- Utility adjustment and right of way cost
- Penalties, Incentives, disincentives, and liquidated damages
- Environmental, permitting, and public communication costs
- Taxes, financing fees, and utility consumption costs
- Procedures for cost control have been developed and may include information sources, cash flow, estimate forecast, and budget tracking, change management, cost breakdown structure, payment schedules, and project and financial control software.
- Others ………………………

C4. Project Schedule and Schedule Control

An appropriately detailed project schedule should be developed, documented, and analyzed. Each organization should also establish and document a method for measuring and reporting progress with responsibilities assigned. Items to consider should include:

- ❑ Input from appropriate project personnel (e.g., owner/operations/third party, construction/estimating, utility adjustments, right-of-way, procurement, environmental/permitting, design/engineering)
- ❑ Conformance with preliminary project schedule including milestones and appropriate contingency
- ❑ Specific schedule considerations (e.g., hourly schedule, required submissions, and approvals, tracking of outage dates, right-of-way land acquisition, procurement of long lead items, commissioning)
- ❑ Schedule control procedures (e.g., resource loading, reporting requirements, responsibility)
- ❑ Use of scheduling software (e.g., Building Information Modeling (BIM), Primavera)
- ❑ Others …………………………

Furthermore, the research plans to leverage existing ABC project databases to identify success weightings based on meeting project goals and avoiding risks. On the other hand, purposive sampling refers to a judgmental sampling method in which individuals are selected to be part of the sample based on the researcher's judgment as to which individuals would be the most useful or representative of the entire population. Therefore, interviewing ABC project stakeholders and contractors to collect information related to specific success criteria is required when meeting tight time constraints similar to those posed by ABC projects. Similarly, the snowball sampling technique will be implemented to increase the reach of the project by requesting the targeted individuals to suggest other individuals with similar expertise (Babbie 2014). An Institutional Review Board (IRB) approval will be pursued, and any personal or proprietary information collected from individuals that provided data to support the research effort will be kept confidential. In particular, responses will be coded during the analysis to ensure projects and individuals are anonymous.

CHAPTER 4. DATA ANALYSIS

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 in order to test the hypothesis that scores are derived by assessing successful ABC projects and correlate the levels of project performance.

4.1. 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 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 3.

Table 3. 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.

4.2. 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 4ss. To calculate the normalizing multiplier for level 1, equation 1 was used:

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

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

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

Table 4. 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

4.3. 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 5 which also includes the total, average, and percentage of 1000 weights.

Table 5. 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 on 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.

4.4. Analyzing the Weighted ABC Success Index Elements

Table 6 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 6. Top six ABC success index element 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 in a timely manner 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 and 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.

4.4. 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 6. 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.

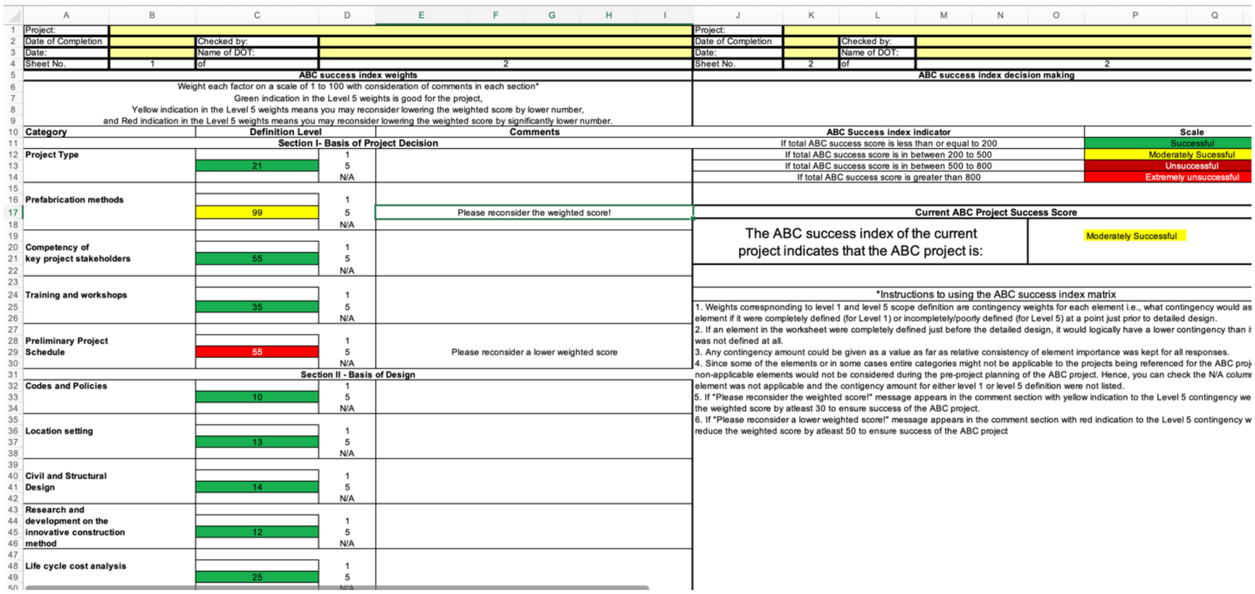

Figure 7. A systematic color-coded interactive tool to highlight the success of the ABC projects

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

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

One example of how the index may support ABC contractors’ successes is to prioritize safety through 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.

CHAPTER 5. RECOMMENDATIONS

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 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.

CHAPTER 6. 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 are able to 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.

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APPENDIX A

<table>
<tr><th colspan="6">Background Information</th></tr>
<tr><td>Name</td><td colspan="5"></td></tr>
<tr><td>Date</td><td colspan="5"></td></tr>
<tr><td>Company</td><td colspan="5"></td></tr>
<tr><td>Department/Division</td><td colspan="5"></td></tr>
<tr><td>Company Address</td><td colspan="5"></td></tr>
<tr><td>City</td><td></td><td>State</td><td></td><td>Zip Code</td><td></td></tr>
<tr><td>Phone</td><td colspan="5"></td></tr>
<tr><td>Email</td><td colspan="5"></td></tr>
<tr><td colspan="3">Years of Project Management/ABC Experience</td><td colspan="3"></td></tr>
<tr><td colspan="6">Please describe some ABC projects that you have recently completed</td></tr>
<tr><td colspan="6"></td></tr>
<tr><td colspan="3">Annual dollar value of projects worked on or estimated over the last 3 years:</td><td colspan="3"></td></tr>
<tr><td colspan="6">Percentage of Experience Spend on the Following Types of ABC Projects:</td></tr>
<tr><td colspan="3">New Construction</td><td colspan="3"></td></tr>
<tr><td colspan="3">Renovation/Rehabilitation/Revamp/Add-on</td><td colspan="3"></td></tr>
<tr><td colspan="6">Assessed Projects Background Information</td></tr>
<tr><td>Name of Project</td><td colspan="5"></td></tr>
<tr><td>City</td><td></td><td>State/Province</td><td></td><td>Zip Code</td><td></td></tr>
<tr><td colspan="6">Brief Project Description:</td></tr>
</table>

Was the project new construction, renovation/revamp, or both?	
Would the project be considered a pedestrian bridge/ Culvert/ double-decked bridge/ train bridge/ Vehicle traffic bridge?	
Please describe the driver of this project (e.g., necessary maintenance or replacement, innovation, technology upgrade, governmental regulation, other):	

Project Schedule Information		
Please provide the following schedule information (if known)		
Item	**Planned (Date- Month/Year)**	**Actual (Date-Month/Year)**
Start Date of Detailed Design		
Completion Date of Detailed Design		
Start Date of Construction		
Completion Date of Construction		
Do you have any comments regarding any causes or effects of schedule changes (e.g., special causes, freak occurrences, etc.)?		

<table>
<tr><th colspan="3">Project Cost Information</th></tr>
<tr><td colspan="3">Please provide the following cost information to the nearest $10k</td></tr>
<tr><td>Item</td><td>Budgeted Costs at start of Detailed Design</td><td>Actual Cost at the End of Project</td></tr>
<tr><td>Total Design Costs*</td><td></td><td></td></tr>
<tr><td>Construction Costs</td><td></td><td></td></tr>
<tr><td>Owner’s Contingency</td><td></td><td></td></tr>
<tr><td>Other**</td><td></td><td></td></tr>
<tr><td>Total Installed Cost</td><td></td><td></td></tr>
<tr><td colspan="3">Please describe any other costs listed above that were realized on the project:</td></tr>
<tr><td colspan="3">* - Total design costs include all engineering and architect fees, including feasibility studies, planning, programming, etc.</td></tr>
<tr><td colspan="3">**-Other costs may include major equipment procurement, owner’s project management costs, etc.</td></tr>
<tr><th colspan="3">Project Change Information</th></tr>
<tr><td colspan="2">What were the total number of change orders issued (during both detailed design and construction)?</td><td></td></tr>
<tr><td colspan="2">What was the total dollar amount (US Dollars) of all positive dollar amount change orders?</td><td></td></tr>
<tr><td colspan="2">What was the total dollar amount (US Dollars) of all negative dollar amount change orders?</td><td></td></tr>
<tr><td colspan="2">What was the net project duration change resulting from change orders? (+/- in days)</td><td></td></tr>
<tr><td colspan="3">Do you have any comments regarding any causes or effects of significant change orders (e.g., special causes, freak occurrences, etc.)?</td></tr>
</table>

<table>
<tr><td colspan="2"></td></tr>
<tr><td colspan="2" align="center">Financial Information</td></tr>
<tr><td>What level of approval was required for the project? (e.g., local, regional, corporate, board of directors, other)</td><td></td></tr>
<tr><td>On a scale of 1 to 5 (1 being far short of expectations, 5 being far exceeding expectations at authorization), how well was the actual financial performance of the project matched expectations?</td><td></td></tr>
<tr><td colspan="2" align="center">Customer Satisfaction</td></tr>
<tr><td>Reflecting on the overall project, rate the success of the project using a scale of 1 to 5, with 1 being very unsuccessful and 5 being very successful</td><td></td></tr>
<tr><td colspan="2">Do you have any additional comments regarding customer satisfaction?</td></tr>
<tr><td colspan="2"></td></tr>
</table>

Project Score Sheet- Unweighted

Section I- Basis of Project Decision							
Element	NA	1	2	3	4	5	Comments
A1. Project Type							
A2. Prefabrication methods							
A3. Competency of key project stakeholders							
A4. Training and workshops							
A5. Preliminary Project Schedule							

Definition levels

NA = Not Applicable

1= Complete Definition

2= Incomplete or poor definition

Section II- Basis of Design							
Element	NA	1	2	3	4	5	Comments
B1. Codes and Policies							
B2. Location setting							
B3. Civil and Structural Design							
B4. Research and development on the innovative construction method							
B5. Life cycle cost analysis							
B6. Design for Safety and Hazards							
B7. Monitoring and maintenance							

Definition levels

NA = Not Applicable

1= Complete Definition

2= Incomplete or poor definition

Section III- Execution Approach							
Element	NA	1	2	3	4	5	Comments
C1. Project Delivery Method							
C2. Project Quality Assurance Control							
C3. Project cost estimate and cost control							
C4. Project Schedule and Schedule Control							

Definition levels

NA = Not Applicable

1= Complete Definition

2= Incomplete or poor definition