University Transportation Research Center - Region 2

Final Report

Accelerating the Construction Process of Highway Bridges

Performing Organization: Syracuse University

July 2013

Sponsor:
University Transportation Research Center - Region 2

University Transportation Research Center - Region 2

The Region 2 University Transportation Research Center (UTRC) is one of ten original University Transportation Centers established in 1987 by the U.S. Congress. These Centers were established with the recognition that transportation plays a key role in the nation's economy and the quality of life of its citizens. University faculty members provide a critical link in resolving our national and regional transportation problems while training the professionals who address our transportation systems and their customers on a daily basis.

The UTRC was established in order to support research, education and the transfer of technology in the field of transportation. The theme of the Center is "Planning and Managing Regional Transportation Systems in a Changing World." Presently, under the direction of Dr. Camille Kamga, the UTRC represents USDOT Region II, including New York, New Jersey, Puerto Rico and the U.S. Virgin Islands. Functioning as a consortium of twelve major Universities throughout the region, UTRC is located at the CUNY Institute for Transportation Systems at The City College of New York, the lead institution of the consortium. The Center, through its consortium, an Agency-Industry Council and its Director and Staff, supports research, education, and technology transfer under its theme. UTRC's three main goals are:

Research

The research program objectives are (1) to develop a theme based transportation research program that is responsive to the needs of regional transportation organizations and stakeholders, and (2) to conduct that program in cooperation with the partners. The program includes both studies that are identified with research partners of projects targeted to the theme, and targeted, short-term projects. The program develops competitive proposals, which are evaluated to insure the mostresponsive UTRC team conducts the work. The research program is responsive to the UTRC theme: "Planning and Managing Regional Transportation Systems in a Changing World." The complex transportation system of transit and infrastructure, and the rapidly changing environment impacts the nation's largest city and metropolitan area. The New York/New Jersey Metropolitan has over 19 million people, 600,000 businesses and 9 million workers. The Region's intermodal and multimodal systems must serve all customers and stakeholders within the region and globally.Under the current grant, the new research projects and the ongoing research projects concentrate the program efforts on the categories of Transportation Systems Performance and Information Infrastructure to provide needed services to the New Jersey Department of Transportation, New York City Department of Transportation, New York Metropolitan Transportation Council , New York State Department of Transportation, and the New York State Energy and Research Development Authorityand others, all while enhancing the center's theme.

Education and Workforce Development

The modern professional must combine the technical skills of engineering and planning with knowledge of economics, environmental science, management, finance, and law as well as negotiation skills, psychology and sociology. And, she/he must be computer literate, wired to the web, and knowledgeable about advances in information technology. UTRC's education and training efforts provide a multidisciplinary program of course work and experiential learning to train students and provide advanced training or retraining of practitioners to plan and manage regional transportation systems. UTRC must meet the need to educate the undergraduate and graduate student with a foundation of transportation fundamentals that allows for solving complex problems in a world much more dynamic than even a decade ago. Simultaneously, the demand for continuing education is growing – either because of professional license requirements or because the workplace demands it – and provides the opportunity to combine State of Practice education with tailored ways of delivering content.

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UTRC-RF Project No: 49111-29-21

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16. Abstract

Functional obsolescence and structural deficiencies of highway bridges are posing significant threats to commuters and transportation agencies throughout the United States. Recently, New York State Department of Transportation (NYSDOT) classified approximately one quarter of its bridges as functionally obsolete and one-eighth as structurally deficient. Highway bridges located in urban areas are especially at high risk of functional obsolescence as the aging highway systems in these areas face significant increases in traffic volumes.

As a result of increasing needs associated with upgrades and repairs, the decision makers are urged to determine the best use of limited resources. In addition to mitigating risks that emerge from ordinary operating conditions, agencies also need to determine appropriate methods to reduce impacts of natural disasters and accidents as part of an emergency response system. Employing traditional construction methods for repair or upgrade activities may cause lengthy traffic disruptions, which results in high user costs and environmental impacts and raises issues of safety and congestion. Accelerated construction refers to project delivery methods that combine innovative construction techniques and contracting methods in order to reduce the environmental and socio-economic impacts of construction activities and to reduce the downtime of highway bridges.

The objective of this study was to investigate opportunities to reduce the negative impacts of bridge closures due to repair and upgrade activities by:

1. Exploring various alternative construction materials and methods, such as - use of prefabricated/precast systems, and innovative contracting methods such as A+B bidding, incentive/disincentive contract, and lane rental that can be used to accelerate construction activities of bridges.
2. Identifying important factors (both qualitative and quantitative) which affect the decision making procedures for selecting the most appropriate upgrade or repair strategy,
3. Providing a decision support framework that will allow evaluation of alternatives

In order to fulfill these objectives, a comprehensive review of the available literature was performed with a focus on accelerated construction methods and contracts, factors affecting decision-making procedures for selection of appropriate bridge upgrade and repair methods and contracting approaches. In addition, a national survey of state DOTs was conducted in order to determine the current state of practice throughout the United States.
The decision support framework developed in this study consists of Traditional vs. Accelerated Bridge Construction (ABC) Analytical Hierarchy Process (AHP) decision making model as well as flowchart models to select appropriate construction techniques and contracting alternatives. The framework altogether provides a systematic procedure for comparing various upgrade and repair strategies. Thus, decisions regarding selection of appropriate upgrade/repair methods and contracting approaches made using the above-mentioned models are expected to be more objective and justifiable. The models are also validated using several case studies in the state of New York.

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Executive Summary

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List of Acronyms

A/E – Architect Engineer
AASHTO – American Association of Transportation and State Officials
ABC – Accelerated Bridge Construction
ABCC – Accelerated Bridge Construction Components
ACTT - Accelerated Construction Technology Transfer
AHP – Analytical Hierarchy Process
APD – Alternative Project Delivery
CI – Consistency Index
CM – Construction Manager
CMA – Construction Management as Agency
CMR – Construction Management at Risk
DB – Design Build
DBB – Design Bid Build
EPS – Expanded Polystyrene
FHWA – Federal Highway Administration
FRP – Fiber Reinforced Polymer
FTA - Federal Transit Administration
GARVEE - Grant Anticipation Revenue Vehicle
GRS/IBS - Geo-synthetic Reinforced Soil Integrated Bridge System
HERS - Highway Economic Requirements System
I/D – Incentive/ Disincentive
ISTEA - Intermodal Surface Transportation Efficiency Act
LEDB – Low End DB Projects
MDBP – Mega DB Projects
MLDB – Mid-Level DB Projects
NBIAS - National Bridge Investment Analysis System
NCHRP - National Cooperative Highway Research Program
NEPA – National Environmental Policy Act
NYSDOT – New York State Department of Transportation
PBE – Prefabricated Elements
PBES – Prefabricated Bridge Elements and Systems
PBS - Prefabricated Systems
RI – Random Index
ROW – Right of Way
SCC – Self Consolidating Concrete
SDOT – State DOT
SEP - Special Experimental Projects
SPMT - Self-Propelled Modular Transporter
TEA - Transportation Equity Act

TIFIA - Transportation Finance and Innovation Act
TIG – Technology Implementation Group
TRB- Transportation Research Board
TRBNRC - Transportation Research Board National Research Council
UDC – User Delay Cost
UDOT – Utah Department of Transportation
UHPC – Ultra High Performance Concrete
USDOT- United States Department of Transportation

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Accelerating the Construction Process of Highway Bridges

1 Introduction

The state of New York possesses a highly developed highway system that includes more than 17,000 highway bridges. Although, the New York Department of Transportation (NYSDOT) owns only 44% of the bridges, the agency is in charge of inspecting 94% of the bridges. According to the data submitted to the Federal Highway Administration (FHWA) in April, 2010, 12% of the highway bridges in New York are classified as structurally deficient and about 25% are classified as functionally obsolete, under the broad federal standards. The problem of functional obsolescence is becoming visible in urban areas due to significant increases in traffic volumes. Failure to mitigate bridge deficiencies may result in sudden closure of critical transportation links or may even lead to collapse, causing loss of life and damage to property, and significant regional economic decline (NYSDOT 2011).

On the other hand, economic crisis and a high amount of other competing needs are forcing federal agencies to limit the funding available to state departments of transportation (DOT) to address those needs associated with highway bridges. According to the American Society of Civil Engineers (ASCE), it would take the United States DOT (USDOT) about $17 billion annually to improve the current situation of the bridges; whereas, the American Association of State Highway and Transportation Officials (AASHTO) report (2009) shows that USDOT can only spend $10.5 billion annually on bridges. The ASCE Report Card (2009) for America's Infrastructure graded the bridges "C" in the year 2009.

As the needs associated with upgrades and repairs exceed available funds; decision makers are urged to determine the best use of the limited resources. In addition to identifying bridges that present the highest risk and methods to mitigate these risks in ordinary operating conditions, agencies also need to determine appropriate methods to reduce impacts of natural disasters and accidents as part of an emergency response system. In a mature infrastructure system, upgrade or repair activities require either restriction or closure of parts of the system. Employing traditional construction methods during these activities cause traffic disruptions, which frequently result in high user costs and raises issues of safety and congestion. A systems approach to accelerate infrastructure construction is required to mitigate the impacts of extensive upgrade and repair activities that are likely to take place in the near future.

For this purpose, it is necessary to address concerns such as the following:

a) Which is more feasible among complete shutdown of the system, partial closure or detour?
b) Which factors should be considered in choosing the method of construction (i.e. lowest initial cost or lowest life cycle cost)?
c) Should decisions be based only on return on investment (i.e. the economic impact) or also on social impacts?

Most of the decision models consider only the use of short term (or initial), long term and/or user costs as decision-making factors. But, National Cooperative Highway Research Program (NCHRP), after studying various projects in the states that lead to accelerated construction, have identified several other factors which can influence accelerated construction decision making process. NCHRP's report on Best Practices in Accelerated Construction has explored several strategies to minimize the downtime of bridge structure, which depends on the following factors (NCHRP 2009):

a) Proper partnership among stake holders
b) Material availability and logistics
c) Detailed planning
d) Contracting strategies
e) Understanding and honoring public interest

Although several states are using accelerated construction techniques, a standardized guideline to assist these agencies for decision-making purposes does not exist. Most often, the problems faced are project specific, which makes it challenging to choose among various rehabilitation methods. Therefore, there is an urgent need for a planning tool that would assist in identification of the potential problems and the most efficient processes. A proper methodology is required to evaluate the benefits of the innovations and technologies to be implemented (Lee and Thomas 2007).

2 Objective and Methodology

Traditional methods for repair and upgrade of highway bridges create major inconveniencies for daily commuters and businesses, such as congestion, safety issues, and limited property access, which often becomes a cause of conflict between state highway agencies and abutting communities. Thus, given the high demands on aging highway infrastructure networks, agencies are now urged to investigate opportunities to expedite construction activities and brainstorm on the underlying factors to achieve a successful project delivery. From the contractors' perspective, planned acceleration of construction is necessary in order to maintain a high level of reputation and to allow the bridge to be accessible before special events (Anderson et al. 2010).

It is highly important to select the correct strategy for accelerated construction, which otherwise can result in higher life cycle costs, higher user costs, more traffic disruptions, increased accident rates and more adverse environmental impacts, thereby creating a completely unsustainable environment. Existing decision models fail to assist agencies in selecting the most suitable sets of activities with regards to accelerated bridge construction (ABC) strategies.

The goal of this study is to investigate opportunities to reduce the negative impacts of bridge closures as a result of repair and upgrade activities. The specific objectives to achieve this goal are -

1. To explore various alternative construction methods, such as the use of new construction materials e.g. fiber reinforced polymers (FRP); prefabricated/precast systems; and innovative contracting methods, such as A+B bidding, incentive/disincentive contract, and lane rental, that can be used to accelerate construction of highway bridges,
2. To identify the important factors (both qualitative and quantitative) that affect the decision making procedures for selecting the most appropriate upgrade or repair strategy, and
3. To provide a decision support framework that will allow evaluation of alternatives.

In order to fulfill these objectives, a thorough research was needed on the accelerated construction strategies employed by state DOTs, with an objective to determine the current state of practice in accelerated construction. Particularly, the research methodology included completion of the following activities:

1. A comprehensive review of the available literature to understand the best practices in ABC.
    a. Studying innovative construction methods. Some of these methods as mentioned in the literature (Salem et al 2006; Vecchio and Diana 2007; Schexnayder et al 2006; Cho 2007; ASCE 1998) are:
        i. Prefabricated components of bridges
        ii. Heavy cranes/transporters to the bridges
        iii. Prefabricated super-structure units
        iv. Precast sub structure units
        v. High performance and fast setting concrete, etc.
    b. Studying various innovative contracting methods (both traditional and innovative) such as:
        i. Design Bid Build (DBB)
        ii. Incentive/Disincentive
        iii. A + B contracting
        iv. Lump sum incentive
        v. Design Build
        vi. Lane Rental
    c. Studying existing decision models that assist in selecting appropriate accelerated bridge construction techniques and contracting methods
2. Survey of the State Departments of Transportation to determine the current state of practice by:
    a. Identifying the states that have implemented ABC.
    b. Acquiring information on the projects in which ABC was used.
    c. Studying accelerated bridge construction techniques and contracting methods employed in different projects.
    d. Collecting data related to the factors that affected decision-making processes in the mentioned projects. Some of these factors included the followings -

i. Initial construction cost
ii. User costs
iii. Maintenance costs
iv. Traffic flow
v. Safety

3. Determination of qualitative and quantitative factors that influenced the decision making processes regarding selection of accelerated bridge construction techniques and contracting methods based on the information obtained from;
   a. Literature review
   b. Questionnaire surveys of state DOTs
   c. Interviews with DOT personnel

4. Development of a flexible decision support platform that will allow, on a case-by-case basis, determining the significance of each factor and comparing various accelerated bridge construction strategies in terms of these factors.

5. Validation of the decision model by:
   a. Conducting formal interviews with the personnel from New York State DOT and the highway industry
   b. Applying the model to a real life bridge project in the state of New York

6. Finalizing the model and preparing a final report that will facilitate implementation of the research and will provide recommendations for state DOTs with regards to accelerated bridge construction.

Figure 1 presents the methodology in a nutshell.

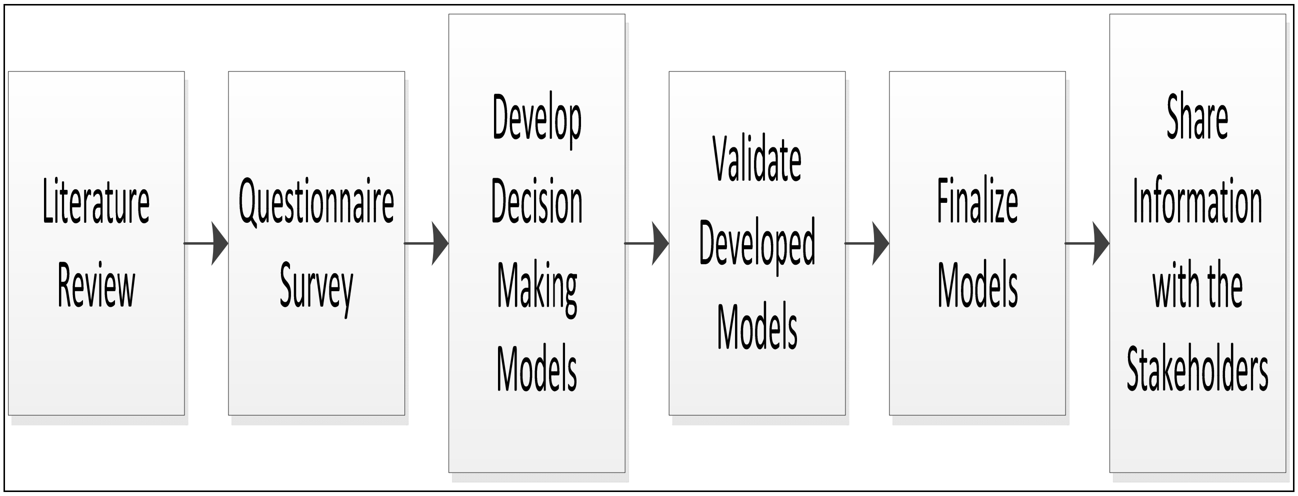


Figure 1: Methodology

3 Background Information

3.1 The Need and Definition of Accelerated Construction

According to the data provided by AASTHO, estimated budget needed by USDOT to "maintain the existing level of bridge deficiencies and keep the physical condition and operational performance of highway system at a level sufficient to prevent average highway user costs from rising above the existing level" for a period of 20 years, from 2005 to 2024, is $78.8 billion (in constant 2004 dollars) (AASHTO 2007). It was also indicated that the average annual maximum investment level for the 20 year period was $ 131.7 billion invested by all levels of government to implement all cost-beneficial improvements on the highways and bridges. The Highway Economic Requirements System (HERS) model estimates a total investment backlog of $525.5 billion nationwide, based solely on current conditions and operational performance of the highway system, of which 86.1% of the backlog is in the urban areas. In addition, National Bridge Investment Analysis System (NBIAS) computed an economic bridge investment backlog of $98.9 billion which makes the total highway and bridge backlog equal to $622.4 billion (FHWA and FTA 2008).

Majority of the 600,905 bridges across the country were built in 1950s and 1960s. According to the data provided by the USDOT (2009), 12.1% of the bridges in the United States are categorized as structurally deficient and 14.8% are categorized as functionally obsolete. A bridge is indicated as "structurally deficient' when one or more of its important components are found to be in a poor, damaged and deteriorated condition, which may sometimes result in lowering of the load bearing capacity of the bridge. A "functionally obsolete" bridge does not have a structural deficiency, but it can no longer comply with the current standards to carry the present volume of traffic. Between years 2005 and 2008, the number of deficient bridges in the urban areas increased by 2,817, due to the effect of increasing traffic volumes on aging highway infrastructure (ASCE 2009). It is imperative to take corrective measures to rehabilitate deficient bridges in a timely manner to avoid the social, environmental and economic impacts associated with such deteriorating system.

Failure to address needs associated with those deficiencies may result in bridge closures or traffic restrictions, which in turn causes problems such as traffic congestions, lengthy detours for commuters and emergency vehicles, and illegal detours through residential areas (ASCE 2009). These problems may result in severe socio-economic impacts as a result of high user costs. User cost may be defined as travel time related costs in construction work zones, incurred due to reduced speed during the time period between slowing and returning to approach speed, and formation of queues in heavy traffic (Richman 1976). It can also present itself in the form of safety cost; as previous experience in highway construction zones shows a considerable occurrence of incidents and destructive accidents (TRBNRC 1998). In addition to property damage and life loss, accidents inevitably cause disruptions in traffic flow. In work zone areas, where the capacity of the highway is lower than normal operating conditions, an accident can result in highly elevated levels of congestion. This increased level of congestion increases commuters' travel time (Reigle 2000). In addition to these socio-economic impacts, congestion increases emission levels of the motor vehicles which depend significantly on driving patterns such as idling, accelerating, decelerating and cruising and may present severe adverse impacts on the environment (Lewis 1999).

With increasing demand on aging transportation infrastructure as well as economic, social, and environmental impacts of work zones, agencies can no longer afford to perform repair and/or upgrade projects in extended periods of time. Thus, seeking methods to accelerate construction for the alleviation of the commerce is gaining immense importance (NCHRP 2009).

In 1996, Transportation Research Board published Special Report 249, entitled "Building Momentum for Change", which called for the creation of a strategic forum to promote accelerated construction techniques and concepts. Based on this recommendation, TRB Task Force A5T60 was formed in 1999 with the following objectives:

- Remove barriers to innovation;
- Advocate continuous quality improvement and positive change;
- Enhance safety and mobility;
- Encourage the development of beneficial strategies; and
- Create a framework for evaluating proposed innovations.

The Federal Highway Administration (FHWA) and the Technology Implementation Group (TIG) of the American Associations of State Transportation Officials (AASHTO) joined with the task force. This led to the development of Accelerated Construction Technology Transfer (ACTT) program (TRB 1996). FHWA defines accelerated construction as "a strategic process that uses various innovative techniques, strategies, and technologies to minimize actual construction time, while enhancing quality and safety on today's large, complex and multiphase projects". Successful completion of an accelerated construction project depends on several factors, such as - good communication and coordination among stakeholders; careful planning of issues related to the rights of way, existing utilities and railroad tracks, traffic engineering, safety, intelligent transportation systems, condition of the structure; and developing innovative financing and contracting methods to support fast track process without compromising health and safety of the workers and commuters. Some of the other factors include geotechnical condition of the structure, type of materials that will be used, accelerated testing, maintenance issues, eco-friendly design and public relations (FHWA 2007a).

NCHRP (2009) conducted a domestic scan to analyze the best practices in accelerated construction. Until 2008, over 130 bridges were constructed across the country using accelerated construction methods (NCHRP 2009). Although agencies are spending considerable time and efforts to complete bridge repair and upgrade projects with minimum adverse impacts, a standardized guideline, which would assist stakeholders in decision making procedures regarding ABC techniques and contracting methods does not exist. This project intends to address this need by conducting a comprehensive research on factors that affect decision making processes regarding the selection of ABC techniques and contracting methods, and providing a decision support platform that will assist in determining the most suitable accelerated construction strategy given the characteristics of the bridge to be repaired and/or upgraded.

3.2 Accelerated Bridge Construction Components

Currently several ABC components (ABCC) are being used for faster project delivery. These components can be widely categorized into Prefabricated Bridge Elements and Prefabricated Bridge Systems. Some of these are used more frequently than others in ABC projects. The purpose of using ABCC is to incorporate innovation in the construction process and to minimize interruption of the existing daily traffic. Several ABCC that are currently used are showed in Figure 2 and will be explained in the following sections (FHWA 2011).

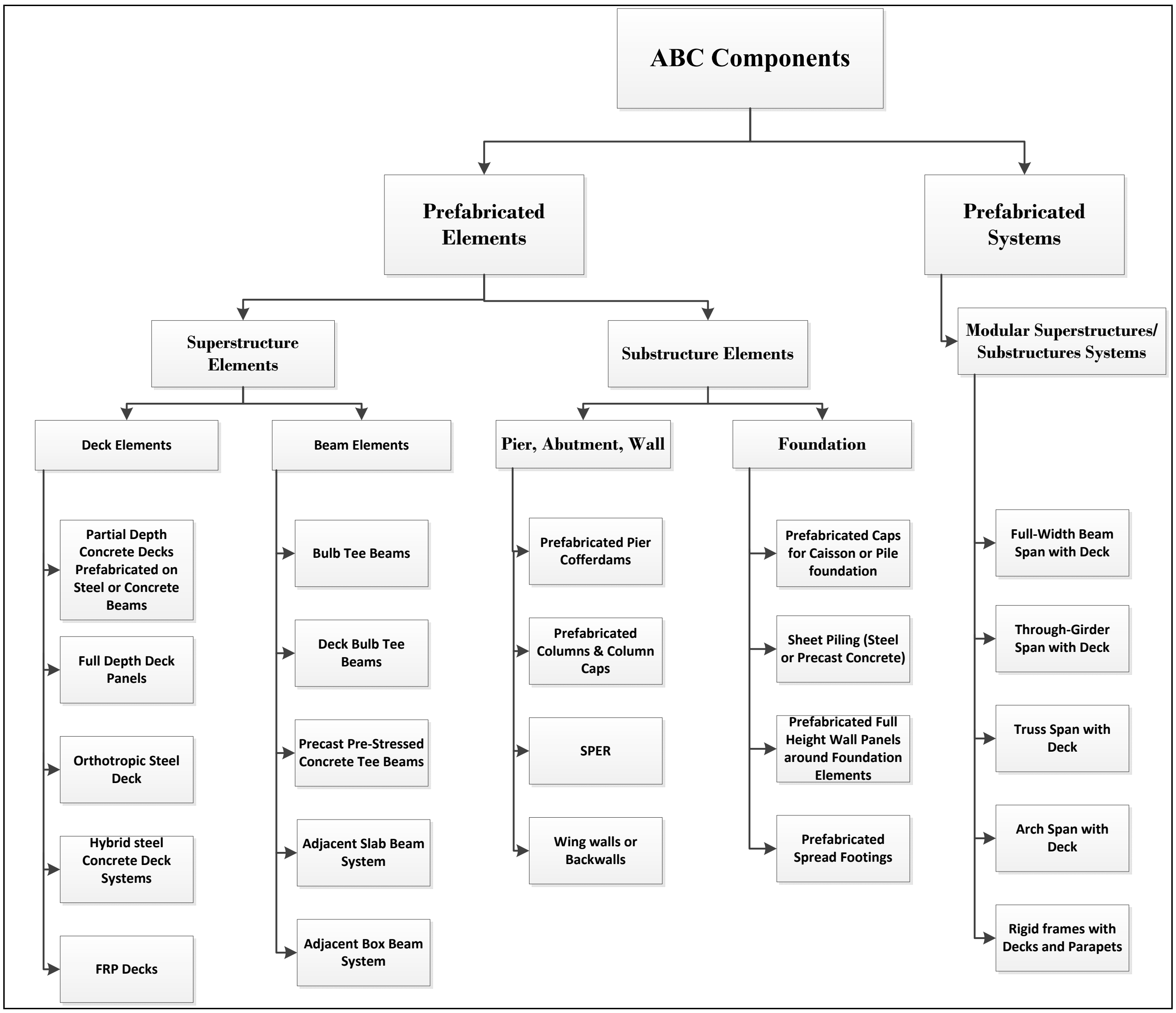


Figure 2: Accelerated Bridge Construction Components

3.2.1 Prefabricated Bridge Elements (PBE)

A prefabricated bridge element (PBE) refers to a single structural component of the bridge and is the most frequently used sections for any kind of accelerated construction. These elements are fabricated away from the site in a regulated environment and are then brought to the site for installation. These elements might include bridge decks, beams, pier caps, columns, footings, retaining walls, abutments or wing walls (FHWA 2011). There are several advantages of using precast elements over the traditional cast-in-place bridge construction. Some of them are as follows:

- Fabrication of the bridge elements away from the site allows for undertaking earthwork activities and foundation construction simultaneously, which thereby shortens construction schedule and reduces impact on daily traffic.
- Fabrication in a regulated environment and flexible time frame permits consistency of material use and better quality concrete, thus making it more durable providing a service life of 75 to 100 years.
- Worksite risk may decrease considerably due to reduced onsite project duration.
- Impact on "environmentally sensitive locations", such as - wetlands etc. can be reduced.

PBE can be used in new construction as well as for repair and rehabilitation. A wide variety of materials can be used for PBE, ranging from concrete and steel to lightweight and corrosion - resistant fiber-reinforced polymer (FHWA 2011). A comprehensive review of the state of practice of PBE has been provided in the following sections.

3.2.1.1Superstructure Elements

3.2.1.1.1Deck Elements:

Partial Depth Concrete Decks Prefabricated on Steel or Concrete Beams: This system was originally developed in Germany. The thickness of these panels generally ranges from 3.5 to 4 inches and they are generally placed on top of the beams on interior bays (FHWA 2009). The beams, when erected, are being joined by the edges of the deck, thereby, removing the need of additional formwork for the cast-in-place concrete. This eliminates the need of conventional wood or steel stay-in-place formworks, which had to be installed between the beam flanges having very little clearance and reduces construction duration. The precast concrete deck panels are at first placed temporarily "on bedding strips on the top of the flanges" and then concrete is cast underneath the panels, which then sets and acts as a continuous support. This, thereby, reduces risk by providing a secure platform to work on as soon as the beams are erected (FHWA 2009).

Studies have proved the following advantages of partial depth concrete decks:

- Partial Depth Concrete deck system is stronger and stiffer than traditional full-depth cast-in-place concrete decks.
- The panels act as structural members in the deck system and being cast upon by another layer of concrete they together exhibit composite action thereby negating the need of horizontal sheer reinforcement (FHWA 2009).

During fabrication of the panels, it is recommended to use pre-stressing as the primary reinforcement (FHWA 2009). The force and the size of the pre-stress strands should be monitored carefully and should be kept on the lower side to reduce the risk of cracking and to minimize the development requirements of the strands (FHWA 2009)

Full-Depth Deck Panels: These are pre-fabricated panels of full thickness placed either on pre-stressed beams or steel framing (FHWA 2005). Overlays of concrete, steel, fiber-reinforced polymers, aluminum, etc might be used in some cases. Construction time is considerably reduced, as there is no need for formwork erection and setting of cast-in-place concrete. Connection is made with the steel beams with the help of studs placed in the pockets of the deck (FHWA 2005).

Hybrid Steel-Concrete Deck System: This technique has been invented by the Japanese (FHWA 2005). Here steel beams join the longitudinal girders, which may extend beyond the edge girders, transversely. The top flanges of the transverse beam support the longitudinal deck reinforcement, while the bottom flanges support the steel formwork at the bottom of the slab. The system is then made composite by pouring cast-in-place concrete. This deck formwork system with reinforcement being light in weight does not need any heavy lifting equipment (FHWA 2005).

Orthotropic Steel Decks: These are larger deck members that can be used with wider girders (FHWA 2005). These are lighter in weight and allow the longitudinal installation of the superstructure, without affecting the adjacent traffic by providing a secure working surface just after erection. This technique was used in Japan, where the German technology of putting 1.4-inch overlays of guss-asphalt and 1.6-inch of open gap-graded asphalt as the top most layer, was used (FHWA 2005).

Fiber Reinforced Polymer (FRP) Decks: FRP has been used in many industries, especially in the aerospace industry for years, although its implementation is quite new in the construction industry. FRP has the flexibility to be manufactured into desired structural shapes by using different types of fibers, sometimes combined with polymer resins, using standard manufacturing processes, like - pultrusion and vacuum assisted resin transfer. The type of fiber used (in most cases carbon fiber or glass fiber) determines the properties of the fabricated member. Some of the advantages of FRP over other conventional structural materials are high strength, lightweight, high stiffness to weight ratio, corrosion resistance and high quality. These decks are useful when there is a restriction for self-load of the structure as it also increases the traffic load carrying capacity by a considerable amount. FRPs molded as cellular panels can be treated as full-depth deck panels (FHWA 2009).

3.2.1.1.2 Beam Elements:

Prefabricated beam elements can be categorized into two types i.e. "full-width" beam elements and "deck" beam elements (FHWA 2012). "Full -width" beam elements can be launched in place either by rolling, sliding, or lifting into place. Once installed, they allow immediate placement of decks. “Deck” beam elements can shorten the time of activities required for the onsite beam. Some of the examples of Deck Beam Elements are as follows (FHWA 2012):

Bulb Tee Beams: Standard Bulb tee beams are pre-stressed precast "I" shaped beams, which differ from the traditional "I" beams in two ways: First, the bottom flange is larger and can accommodate more strands and secondly, the width of the top flange is around four feet. The efficiency of the system is considerably increased by these two features, although the top flange being thin does not provide any structural assistance. That is why; concrete decks are cast on the flange, so that they act as a composite member (FHWA 2009).

Deck Bulb Tee Beams: This is a modification of the standard bulb tee beams, where the top flange is made wider almost around eight feet, and it can act as the structural deck of the bridge. Thus, the beam when joined together in the field forms a beam/ deck system. Deck bulb tees have many advantages over the conventional concrete box girders in terms of ease of access for inspections and simpler fabrication process and elimination of the void forms to be filled with concrete (FHWA 2009).

Precast Pre-stressed Concrete Tee Beams: These Tee Beams can be of various types and can be customized according to the requirements of the state. For example, Texas DOT had modified their deck slab beam with tee flanges that protruded out of the sides and they also used a double tee section. The connections between the beams are established by welding anchor plates and by grouting. Some states have used double tees, triple tees and even quad tees. Quad tee system was built by NYSDOT, which had the width of a two-lane road (FHWA 2009).

Adjacent Slab and Adjacent Box Beam Systems: These systems have been in use for years by many state DOTs. The depth of the adjacent box system is more than 21 inches and is more than the depth of the adjacent slab system or the deck slab system. The width of the beam generally ranges from three feet to four feet. Both adjacent slab and box beam systems act as the structural deck of the bridge and thus eliminates the need of a separate concrete deck. The beams are generally placed adjacent to each other and connected with lateral tie system and grout. A bituminous wearing surface is also laid on the beams. The use of asphalt overlay with waterproofing membrane is recommended for protection from the effects of deicing chemicals. The entire superstructure can be completed in three days with the help of these techniques (FHWA 2009).

3.2.1.2 Substructure Element

3.2.1.2.1 Pier, Abutment and Wall Elements:

Like other precast elements, prefabricated pier elements also help in project acceleration by eliminating the need of traditional pier construction. It is a sequential process of form installation, reinforcement steel placement, onsite concrete pouring and curing (FHWA 2012). Some of the pier elements and systems are listed below:

Prefabricated Pier Box Cofferdams: Pier footings constructions on piles over water are one of the most difficult tasks for a substructure (FHWA 2009). Traditional methods include complex sheeting systems and cofferdams. Large diameter drilled shafts have made it possible to construct columns in shorter time and also to reduce the number of shafts required for each column. Pre-fabricated box pier cofferdams were used in many projects to drain water at the point of connection of the bridge footing and drilled shaft. The precast box, once placed on the drilled shaft, can be sealed with small amount of tremie concrete around the shaft. Use of High Performance Concrete can increase the durability of the pier footing system against corrosion. This method makes the process easier than conventional deep cofferdams, and tedious dewatering systems in deep water (FHWA 2009).

Prefabricated Columns/ Piers and Column Caps (separate or combined): Prefabricated columns or pier elements eliminate the needs of conventional way of constructing forms and pouring concrete at a higher level above the ground (FHWA 2009). Due to the repetitiveness of the process, prefabricated piers help in accelerating the substructure construction process. These elements are useful for construction over water bodies or sites with heavy utilities around. Conventional Pier Cap construction involves series of complicated construction processes, which include shoring and forming. Using precast columns or column caps require careful consideration of the connections. There are many combinations possible for precast concrete columns and column caps (FHWA 2009). They are:

- Precast Piers Caps on Cast-in-Place Concrete columns and Piles
- Precast Pier Caps on Precast Columns

- Precast Pier Caps on Steel Piers
- Precast Pier Cap on Precast Concrete Pile Bents
- Multiple Precast Concrete Caps joined together
- Multiple Precast Concrete Columns joined together

Note: Figures illustrating some of the elements above can be found on the FHWA website: http://www.fhwa.dot.gov/bridge/abc/prefab_def.cfm

SPER Method: Sumitomo Mitsul Construction Company developed this method called the Sumitomo Precast form for resisting Earthquakes and for Rapid Construction (SPER) (FHWA 2005). This method is utilized to accelerate the construction of piers using precast concrete panels, which are used as a formwork for cast-in-place concrete and acts as a structural member at the same time. Concrete panels used are generally 100 mm thick. Two formworks (inner and outer) are used for tall panels, while shorter ones need only outer formwork. Formwork segments are placed on each other and joined with the help of epoxy adhesives. The panels are constructed as channel shape members to reduce weight for easier hauling. Lateral reinforcements are built in channel sections, which are joined together by couplers. The vertical reinforcements are launched around the inner and outer formworks and are then cast with concrete. High-strength concrete can also be used for cross ties to reduce fabrication time by diminishing congestion. The seismic performance of the system has been found to be close to that of traditional cast-in-place system (FHWA 2005).

Abutment Systems: Prefabrication of abutment system, although not very common among the states, helps in accelerating the abutment construction (FHWA 2009). Some of the most commonly used abutments in the country are integral and semi-integral abutments other than conventional freestanding abutments. Both types of abutments consist of prefabricated elements and can be configured into any shape required. Abutments are of various types. Cantilever Wall Abutments not only support the superstructure but also retain the soil at the edges. As in other components, there are several ways to install prefabricated abutment components. One kind of abutment is called the stub abutment that supports the soil higher than the superstructure thickness.

Although stub abutments increase the length of the end spans, they are economically more feasible. On the other hand, full height abutments help in reducing the length of the spans but are harder to construct. In both cases, the precast members are designed similar to the cast in place abutments except for the connections with grouted reinforcing slice couplers that are used in place of conventional construction joints (FHWA 2009). Another type of abutment is called Spill-through Abutments, which is used to take some soil pressure off the abutment by putting in large voids in the stem.

Precast Concrete Integral Abutments are prefabricated along with the superstructure elements (FHWA 2009). Integral abutments eliminate deck joints, which are prone to maximum deterioration. Another advantage of integral abutments is that most of the load is passed on to the superstructure, which has a higher resistance capacity than the abutments. Integral abutments can be placed on single row of piles that can be designed in a manner to move with the bridge due to temperature variations. Thus, this method eliminates the need of spread footing or multiple rows of piles to act against the soil pressure. Again the Integral abutments can be of two types i.e. fully integral abutments with full moment connection with the superstructure and semi-integral abutments with pinned connection allowing rotation of the superstructure over the substructure (FHWA 2009).

Wing walls or Back-walls: Wall members can also be prefabricated away from traffic and then installed at the bridge site (FHWA 2012). This saves the effort and time required for conventional abutment and wall installations, such as formworks, steel reinforcement placement, concrete placement, and curing. Unlike traditional methods, precast elements can be fabricated at the same time when other ground works such as embankments are being prepared. Wing walls can be of different types as well. Flying wing walls are small abutment walls extending from the abutment stem without any footings and vertical support. The vertical moment connection transfers the soil forces to the abutment stem. (FHWA 2012). Back walls are generally used to retain soil just behind the end of the beams. Precast back walls can be connected to the precast concrete abutment stem in a similar fashion as that of stem to footing. Moment connections of these elements can be provided using grouted reinforcing splice couplers. (FHWA 2009)

3.2.1.2.2 Foundation

Foundations are sometimes necessary for new ABC projects or repair or rehabilitation projects with damaged foundations. ABCs involving only superstructure construction can use existing foundation, but in case of increase in load carrying requirements new foundations are necessary. Some of the various foundation components used in ABC are described below:

Sheet Piling (Steel or Precast Concrete): Sheet piling is generally necessary for retaining the earth, in case new foundation is required. Sheet piles can be prefabricated either by concrete or steel (FHWA 2011). Precast concrete sheet piles can be installed in place and then can be joined together by caps on top to form a complete structure. The piles can be constructed with interlocking edges to avert any relative movement between the piles. Steel sheet piles can be of two types i.e. closed sheet piling and open sheet piling. In case of closed piles, sheets can be configured into any shape (oval or rectangle). On the other hand, open sheet piles are "C" shaped and are held by anchorage installed in the approach fill (FHWA 2011).

Pre-fabricated Spread Footings: These kinds of spread footings are grouted into place over a sub-grade prepared on leveling bolts (FHWA 2011). Sheer Keys are provided at the joints between the footings and are sealed with non-shrink grout. Some states have used highly workable concrete to fill the gap between footings and sub-grade. In cases where the size of the footing is too large, several small footings can be used for the ease of transportation. Precast concrete can be used to build continuous footing, which can support the dead load of the bridge. Pouring concrete on reinforced bars extending out of the precast footings can join the multiple prefabricated elements, and the composite section is capable of carrying various types of load (FHWA 2011).

Pile Cap Footings: Pile caps can also be prefabricated offsite and then can be connected to the pile using grouted pockets (FHWA 2011). Recent research studies showed that Corrugated steel pipe voids can also be used for connection, as these can provide considerable punching sheer resistance and also moment resistance, thereby, improving the seismic performance of the structure (FHWA 2011).

Note: Figures illustrating some of the elements above can be found on the FHWA website: http://www.fhwa.dot.gov/bridge/abc/prefab_def.cfm

3.2.2 Prefabricated Bridge Systems (PBS)(Modular Superstructure/ Substructure Systems)

Prefabricated bridge systems could be superstructures, substructures and/or complete bridge modules. Superstructure systems consist of modules of both deck and primary supporting members and can be placed on existing or new substructures with minimal disruption of mobility. Substructure systems, mostly abutments and piers, can also be included in the module. Some of the examples of PBS are:

- Full-Width Beam Span with Deck
- Through-Girder Span with Deck
- Truss Span with Deck
- Arch Span with Deck
- Rigid frames with Deck and Parapets

These systems are brought to the site on special transporters and then either rolled, slid, lifted or launched in place by specialized machineries. Once installed, the bridge can be opened for traffic without the need of any further construction. Proper planning, quality design, use of high-performance materials and proper launching mechanism play an important role towards project success (FHWA 2012). Some of the advantages of PBS are as follows:

- Minimization of utility relocation
- Avoiding right-of-way acquisition
- No change in existing roadway alignment
- Avoiding temporary alignments
- Elimination of temporary bridge structures
- Minimization of traffic phasing and staging (FHWA 2012)

3.2.3 Self-Consolidating /Fast Setting/ High Performance Concrete

Quality and productivity are highly important in the precast concrete construction. But these have to be weighed against higher price, shorter construction time, increased labor cost, as well as high level of workability, strength and durability. Self Consolidating Concrete (SCC) is a specially proportioned hydraulic cement which can be used to achieve these properties in an efficient manner (NCHRP 2009a). SCC has high workability and can flow under its own weight through dense reinforcements without the need of any mechanical consolidation. This considerably reduces the risk of segregation and eliminates the noise due to vibration (NCHRP 2009a). Some of the advantages of SCC are:

- Fabrication of highly reinforced precast elements of any cross-section using a much simplified process
- Faster assembly rates and thus savings on labor cost for placement, vibration and finishing
- Regulated and safe working environment
- Improved quality and uniformity of the members, reducing surface irregularities (NCHRP 2009a)

Using SCC for prefabrication should abide by certain standards and requirements. Materials play a very important role in determining the quality, appearance, strength and other characteristics of the concrete. National Cooperative Highway Research (NCHRP) program has put together certain guidelines for material selection, workability test methods, mix design, concrete properties at different stages and production control of precast and pre-stress bridge elements using SCC and this can be found in NCHRP's report on "Self-Consolidation Concrete for Precast, Pre-Stressed Concrete Bridge Elements" (NCHRP 2009a).

In addition to various kinds of cements, supplementary cementitious materials (i.e. fly ash, silica fumes, ground granulated blast-furnace slag, fillers, etc.) and different grades of aggregates, chemical admixtures also play an important role in the fabrication of precast members. Chemical admixtures help in reducing water cement ratio, accelerating strength development without compromising on desired workability. They also eliminate voids in concrete and thereby increase stability. Some of the commonly used admixtures for precast members are Set-Accelerating Admixtures, High Range Water Reducing Admixtures, Air Entraining Admixtures and Shrinkage Reducing Admixtures (NCHRP 2009a).

Ultra high-performance concrete (UHPC) is often used for prefabricating elements and has a very high strength value ranging from 22,000 psi to 36,000 psi. These are prepared by a combination of very fine materials, which makes the concrete durable. The thickness of the bridge elements can be reduced considerably by using UHPC (FHWA 2005).

3.3 Accelerated Bridge Construction Techniques

3.3.1 Rapid Embankment Construction

3.3.1.1 Expanded Polystyrene (EPS) Geofoam

In this method, large blocks of expanded polystyrene are used for embankment construction. This does not act as a support for the bridge abutment and just acts as a filling material around piles or integral abutments (FHWA 2011). These are extremely lightweight components that help in preventing the preload settlement and can be constructed very quickly. But the system needs a layer of sub-base below the pavement to withstand the wheel load. Again the foams tend to get damaged by gasoline; therefore, efforts should be made to protect it from gasoline spills. The foams are not recommended to be placed in regions having high water tables, which may exert uplift forces on the foam. These can be used at places with high probability of long-term settlement, as it can reduce the weight of the embankments substantially, thus eliminating the need of any pre-load time (FHWA 2011).

3.3.1.2 Accelerated Embankment Preload Techniques

Embankments over certain soils such as clay are prone to long term settlements. Thus, construction of embankments over these kinds of soil is tricky and time consuming. In the conventional method, these soils are preloaded for several months or sometimes for years to expedite the consolidation process by removing water from the voids before starting the construction process. Current innovations have made it possible to accelerate this process by four or more times with the help of stone columns and wick drains (FHWA 2011).

3.3.1.3 Column Supported Embankment Technique

The time consuming preloading process for compressible soils can be eliminated by the column supported embankment technique in which soil structures like closely placed piles or stone columns are constructed through the underlying soil. The structure, once constructed, can be covered by several layers of geo-synthetic reinforced soils to make it suitable for the new embankment (FHWA 2011).

3.3.2 Foundation Techniques

3.3.2.1 Continuous Flight Auger Piles

Deep foundation elements can be constructed rapidly using continuous flight auger (FHWA 2012). This process is also called Augured Cast-In-Place pile method, drilled displacement or screw piles. In a conventional process, augers or rock coring device are used to drill the shaft and remove the materials from the borehole. Reinforcement is then lowered in the hole followed by pouring of concrete in it. In continuous flight auger piles method, equipment capable of performing most of these tasks at the same time are used. Here, multiple augers are drilled into the ground continuously to the required depth and the augers, while pulled out, inject concrete at the same time. The process is completed by lowering of reinforcement into wet concrete (FHWA 2012)

3.3.2.2 Geo-synthetic Reinforced Soil Integrated Bridge System (GRS/ IBS)

This method combines foundation, abutment and approach embankment to form an integrated system (FHWA 2011). The substructure consists of several thin layers of soil and geo-synthetic reinforcements. High quality concrete block facing is used to retain the soil at the face of the abutment. It also helps in preventing erosion, but it is not a structural element of the system. The composite system is generally longer than the bridge superstructure and extends into the embankment. The unified structure eliminates the chances of differential settlement between the abutment seat and the backfill as they settle as a single mass. No bearings are required between the superstructure and the substructure. The system is also flexible in using different types of prefabricated decks, such as precast butted box beams, precast slabs or conventional stringer decks. Some of the advantages of this system are low initial and lifecycle costs, shorter construction duration, lesser labor and equipment use, and as mentioned earlier elimination of an approach slab. But at the same time there are some drawbacks to this method. For example, this method has only been used for spans less than 140 feet. This system is not very useful where shallow foundations cannot be used. Despite these limitations, this method is popular for single spanned rural county bridges (FHWA 2011).

3.3.3 Transportation/Lifting/ Placement Techniques

3.3.3.1Self-Propelled Modular Transporter (SPMT)

SPMTs are huge platform vehicles capable of carrying heavy weights ranging from 165 to 3600 tons (FHWA 2007b). These vehicles are computer controlled and have been used by many European industries, such as petrochemical, offshore, shipbuilding and power, for years. An SPMT unit consists of either six or four axle lines. Multiple wheels are arranged in pairs on each axle line. The spacing between the wheels is not more than 5 feet. Depending on the need, more than one unit can be put together both longitudinally and laterally to form a composite large vehicle. One driver, who walks along the units, operates the units. Sometimes two operators are required, when there is an independent setting of span ends. SPMTs have different types. The SPMTs capable of steering electronically can pivot 360 degrees around a point. The units, which are self-driven, can only rotate 60 degrees. The electronically steered system can travel in all possible horizontal directions as the wheels can rotate 360 degrees about the support. In loaded condition the moving speed of SPMTs generally ranges from 3 miles per hour to 7 miles per hour. The speed varies with the amount of load and the nature of the terrain and also the type of structure. Structures having high center of gravity cannot be moved quickly. The length of the unit depends on the number of axles e.g. four, and six axles will be 20 feet and 30 feet long respectively without the power pack unit, which is around 14 feet long. SPMTs are generally carried to the bridge construction site by road on flat-bedded trailers or by rail or water in flat rack containers (FHWA 2007b).

Some of the benefits of SPMT are as follows:

- **Reduction in Onsite Construction Duration:** Use of SPMTs can reduce the construction duration considerably. Conventional construction that used to take 2 - 3 months earlier, can now be completed in few hours using prefabricated bridge elements that can be transported by SPMTs. Thus, this decreases the bridge closure time, and thereby, reduces impacts on daily traffic and keeps schools, hospitals and other emergency response facilities accessible. Lesser construction time also reduces work zone hazard risks (FHWA 2007b).
- **Flexibility in Installation:** SPMT provides the contractor with the flexibility of fabricating the bridge members at a place of its choice and then bring it to the site from

any convenient direction. SPMT also allows very precise positioning of the bridge elements. As the bridge is being fabricated somewhere else, the contractors can spend sufficient amount of time to achieve the required quality. SPMT also eliminates the inconvenience caused due to height restrictions that may be observed for crane lifting activities (FHWA 2007b)

Some of the criteria, which may encourage the use of SPMT for a bridge construction, are as follows:

- Heavy daily traffic over the bridge and through the adjacent roadways that might be affected.
- Bridge is a part of an emergency evacuation route
- Bridge is located over a railroad or navigable waterway
- Bridge provides the only convenient means of access to schools and hospitals
- Impact of construction on business and local economy
- Work space constraints making the use of conventional cranes difficult
- Adjacent environment or locality is sensitive to air and noise pollutions
- Habitat of endangered species near the construction site
- Weather constraints e.g. cold weather or heavy snow (FHWA 2007b)

As the initial mobilization cost is considerably high, the cost should be carefully compared against the benefits that may be obtained through reduced construction duration, to evaluate the economic feasibility of the process (FHWA 2007b).

3.3.3.2Lateral Skidding/ Horizontal Sliding

Lateral skidding or Horizontal Sliding involves the construction of the bridge on the site adjacent to the proposed location on temporary supports that are connected to the bridge site with rails (FHWA 2011). Once built, the bridge is slid horizontally to its exact location using the hydraulic equipment or cables. The installation might need some vertical adjustments in the system. Lateral skidding is mostly suitable for bridge replacements. This can be carried out in various ways. The bridge can be constructed parallel to the existing bridge on temporary supports and once finished the existing bridge can be demolished followed by installation of new substructure, if necessary. Then, the new superstructure built is moved horizontally into place. In another method the construction of new substructure takes place under the existing bridge, if necessary, once the construction of the new bridge is complete. This is followed by moving the existing bridge away and sliding in the new superstructure in its place. Prefabricated substructures are commonly used in these cases to minimize the construction duration. Another technique that is in use is sliding away the old bridge on temporary supports adjacent to the current location and using it as a temporary bridge, while the new bridge is being constructed at the original place. Lateral skidding has made it possible to replace a bridge only using weekend closures, although the duration depends on the nature and size of the bridge (FHWA 2011).

3.3.3.3Longitudinal Launching

This type of launching of superstructure is useful for terrains not accessible by cranes, such as - deep gorges or valleys, or busy navigation channels etc. (NCHRP 2007). Here, the superstructure is constructed on a launching pit, which may be placed behind one or both the abutments. Due to large amount of moment created at the launching point, there are high chances of deflection in the superstructure. To negate the amount of deflection at the end of the cantilever during launching as well as when it reaches the support, temporary light-weight structures can be attached to the superstructure. Sometimes, intermediate towers are also built to minimize the amount of moment generated to reduce deflection. The superstructure, once fabricated, is jacked up and then slid or rolled over the span until it reaches the next support. This process is applicable for a wide variety of structures including concrete, steel and even curved structures. Longitudinal launching is of great help if the bridge is over a busy navigation route or underlying railroad or roadway. The use of conventional barges and cranes can be avoided, thereby, eliminating the impacts on traffic as well as accelerating the construction process. The launching duration depends on the bridge size and also on available space for the pit (NCHRP 2007).

3.3.3.4Crane Installation

Conventional cranes are one of the most commonly used equipment to install the prefabricated bridge elements (FHWA 2011). Previously, it was only used to launch beams and girders, but now prefabricated elements can be as light as the basic members of the bridge. In ABC, multiple cranes are used to launch modular systems. For heavier systems, modern high capacity hydraulic cranes have been designed, which can be mobilized easily and can be installed in a couple of hours. Another kind of cranes for heavy lifting purposes is Crawling

Cranes, which are capable of lifting 150,000 pounds at a radius of 100 feet, and the load capacity increases with decreasing radius. Before setting up any type of crane, technical feasibility studies should be performed in terms of various factors such as set up location, underlying soil capacity, and structures accommodating crane load (FHWA 2011).

3.3.3.5 Barge Float In

Water bodies present challenges for implementing ABC. However, modern equipment like barges has made it possible to transport prefabricated bridge elements to the site. The use of barges is governed by many factors, such as navigability of the water body, accessibility of the barge, tidal nature of the water body, depth of the water, and environmental constraints (FHWA 2011). Sometimes, if the water is not accessible by conventional barges, segmental barges are transported via road to the bridge site and then lowered on the water. The segments are then assembled on site to form full size barges. The modules can be put together in various ways depending on the amount and the nature of the loads. Before deciding to use barges, the depth of the water should be investigated using bathymetric surveys and draft depth should be studied for available barges (FHWA 2011).

3.3.3.6 Gantry Cranes/ Longitudinal Gantry

Gantry Cranes can be used for installing prefabricated elements. These cranes have different types. Transverse gantry cranes after installation, is capable of accessing the entire bridge span (FHWA 2011). The crane is designed in a manner so that traffic can pass beneath it when it is idling during peak hours. This type of cranes can be used for installing long span suspension bridges. Longitudinal gantry frames are another type of gantry system suitable for rehabilitation purposes. These can be fitted within truss framing and can be used to carry both old deck elements and new modules at the same time. Thus, both removal and replacement activities can be performed together. Larger longitudinal gantry cranes are of great help in inaccessible areas, like - highways with heavy traffic, wetlands, rivers etc. and can be used for segmental construction of bridges such as installing piling, drilled shafts, launching segments of superstructure and other bridge systems (FHWA 2011).

3.3.3.7 Others: Stranded Jacks, Bridge Pivoting

Specialized heavy-duty equipment are required to lift and place the prefabricated elements. Some of the commonly used ones are strand jacks and climbing jacks. Strand jacks lift elements with the help of cables while climbing jacks use hydraulics to push up the same. Strand jacks can be used to lift and ship bridge elements on water bodies using barges (FHWA 2011).

Bridge pivoting is another method used for installation of prefabricated bridges. Here, the superstructure is built on the site slightly away from the proposed location. Once constructed, the whole or part of the superstructure is placed on one end of the final location and is rotated along its transverse or longitudinal axis to be installed along its desired alignment. Transverse pivoting is also used for erecting arch superstructure, where it is placed vertically at the supports and then rotated gradually to its position with the help of cables (FHWA 2011).

3.4 Traditional Project Delivery

3.4.1 Design-Bid-Build (DBB)

Design-Bid-Build (DBB) is the method traditionally used for delivering bridge projects (Hancher 1999). Here, the owner enters into separate contracts with the providers of design and construction services. At first, qualified Engineers design the project and the project cost is estimated on a unit price basis. After the owner reviews the design, the project is bid out in the market and request for proposals from prospective contractors are solicited on a lump sum or unit price basis. This is followed by bid appraisal and handing over the project to the contractor with lowest responsive bid (Hancher 1999).

3.4.1.1 Advantages of DBB

In this traditional system the contractors are allocated a lesser amount of risk as they have to build the project according to the plans and specifications that are "certified" by the owner. The owner, on the other hand, can fund the project at a favorable price as the competition among the contractors produce the lowest possible cost for the project (Carpenter et al. 2003).

3.4.1.2 Disadvantages of DBB

Despite the conventional nature of the traditional project delivery, there are many limitations. As the construction process cannot start before the completion of the design, the whole system becomes slow and thus, is not suitable for expedited delivery of projects. In addition, the "over-the-wall" contractual framework hinders the implementation of advanced Life Cycle Cost Analysis concepts. As the owner already stipulates the specifications, there is not much room for innovation, as the contractor does not have any risks related to quality, performance or maintenance. Contractor's input being hardly present in design phase sometimes results in unrealistic design and gives rise to change order issues (Hancher 1999). Furthermore, the traditional system requires sufficient provision of in-house resources, which is difficult during periods of economic recessions, job cuts and hiring freezes. Over the last decades, the highway industry has realized the need to overcome these drawbacks (Hancher 1999). Again, in traditional project delivery, highway agencies generally use punitive strategies to accelerate highway projects focusing on liquidated damages, which do not prove to be effective (NCHRP

2009). As a result, several alternative project delivery (APD) approaches have been experimented throughout the U.S.

3.5 Alternative Project Delivery

Any project delivery method, other than traditional contracting methods, can be termed as Alternative Project Delivery (APD) (Carpenter et al. 2003). Innovative contracting or alternative project delivery methods (APD) can result in faster completion of projects, especially in areas that face heavy traffic congestion. APD methods have the potential to encourage contractor-induced innovation by providing contractors more freedom with regards to selection of material types and construction methods. In other words, contractors have the potential to employ construction techniques and modern technology that improve the quality of the project, and/or reduce the project duration. Accelerated Construction requires effective communication between design and construction teams as most often these phases are overlapped for fast track purposes. Employing APD methods can result in lower cost overruns that may otherwise occur due to schedule delays and/or change orders. All these factors together contribute to the benefits of public by reducing the impacts of construction activities and enhancing the quality of life (Carpenter et al 2003).

Some of the innovative contracting methods used successfully in bridge construction projects include Design Build (DB), where the public agency has a single contract with the company in charge of both design and construction (Fishman 2009); A+B Contracting, where the contract value includes both initial costs and costs due to duration of construction; lane rental, where the contractor is charged according to the length of time the lane is closed (Carpenter et al 2003); Construction Management at Risk (CMR) and Construction Management as Agency (CMA). Incentive/disincentive (I/D) scheme can be added to any kind of contracting method in order to increase the motivation of contractors.

3.5.1 Design Build

In Design Build (DB) delivery, the public agency has a single contract with the company, which is in charge of both design and construction. There are various types of DB contracts such as Design-Build-Operate-Maintain, Design-Build-Finance-Operate, Design-Build-Operate-Transfer, and Design-Build-Operate-Maintain-Warrant (Fishman et al 2009).

The Utah T2 Center has further categorized the DB projects depending on the scope and extent of the project (Carpenter et al 2003). They are i) Low-End DB Projects (LEDB), ii) Mid-Level DB Projects (MLDB) and iii) Mega DB Projects (MDBP). LEDB are small projects, which have time constraints and strict deadlines. The scope generally involves routine construction or reconstruction. As the project is small, there are less chances of innovation; but the DB option can be very useful for project acceleration as well as attaining the provisions of warranty after construction. MLDB are projects where the owners do not have sufficient in-house facility to implement advanced techniques and new technology. Thus, they hand it over to a single entity, often as a turnkey contract to utilize the expertise from the private sector. A warranty option is generally present in MLDB projects, so that the contractors pay attention to implementing innovations for their own benefit. The Design-Builder (i.e., DB contractor) is usually selected using a procurement method based on Best Value. Contract documents are highly important for these types of projects. The contracts, if not prepared properly, may give rise to dispute which cost both money and time. MLDB projects generally consist of bridge reconstruction and projects involving high inducement for innovative design and construction. MDBP are the projects, which due to its scope, budget and time constraints cannot be executed using traditional project delivery. The projects are generally large, extensive, and complex and have certain time limitations (Carpenter et al 2003).

3.5.1.1Advantages of Design Build

In DB delivery, the major benefit is that the designer and the contractor can work together (AASHTO 2007). Thus, the contractor can participate during the design phase and can monitor and rule out anything in design that may not be possible or convenient to build. In other words, the constructor can communicate their point of views efficiently to the designer, thus considerably reducing the chances of change orders. Here, construction and design phase can overlap and construction can commence even when only 50% design is complete. This facilitates the shortening of project schedule. Moreover, the owner only has a single point of responsibility and has fewer worries to deal with (AASHTO 2007).

3.5.1.2Disadvantages of Design Build

Some of the major barriers to DB are the legal restrictions and statutory policies for implementing DB method in public projects in many states (AASTHO 2007). Most of the public projects use tax payers' money and DB is not always the most economical option. Also, there is less opportunity for small local contractors, as many might not have the resources to carry out a DB contract. Projects were previously required to go through the National Environmental Policy Act (NEPA) process prior to preliminary engineering and handing over the project. This considerably slowed down the process and defeated the purpose of implementing DB. Later in mid-2006, this act was amended and then onwards, DB projects can commence before the completion of NEPA formalities (AASHTO 2007). Another potential drawback is the decrease of owner's control over the project. Chances of compromising the quality, in order to keep pace with the short project schedule, cannot be ruled out (Ghavamifar and Touran 2008).

3.5.2 Cost-Plus-Time (A+B Bidding)

Cost-Plus-Time approach uses both initial construction cost and project completion time as decision-making criteria for contractor selection (Carpenter et al 2003). The time involved is converted into its corresponding dollar values by calculating the user cost obtained by multiplying the user cost rate per day with the number of days of construction. Thus, this type of contract is often referred to as A+B Bidding or multi-parameter bidding. If the agency wants to encourage an early completion, A+B bidding is often used together with an incentive/disincentive (I/D) option. I/D are generally levied for the projects having high traffic volumes, lane closure, traffic restrictions where the user delay cost (UDC) may accrue with the time of construction. A+B Bidding with I/D is, therefore, used for rehabilitation and reconstruction of projects already in use, to enhance safety on the construction site and to reduce the effect of construction on the community (Carpenter et al 2003).

3.5.2.1 Advantages of A+B Bidding

One of the obvious advantages is reduction of project execution time, which can be augmented by the presence of I/D option. This may lead to enhancement of quality due to the innovative techniques used by the contractor to meet the deadline (Carpenter et al 2003).

3.5.2.2 Disadvantages of A+B Bidding

Many contractors may retreat from the bidding procedure, as they may not have sufficient resources to speed up the project schedule. Moreover, the state agency has to provide inspection and testing personnel for additional hours of work performed by the construction company (Carpenter et al 2003).

3.5.3 Lane Rental

In this type of contract the contractor is charged according to the time spent for construction activities in the traffic lanes (Carpenter et al 2003). This is mainly intended to accelerate the construction in places where traffic volume is high. The rates depend on the specific time and the amount of traffic volume in the place. The amount to be charged depends on the extent of impact on public. Some of the common types of lane rentals used are lane-by-lane rental, continuous site rental and bonus/rental charge methods. The lane-by-lane rental charges the contractor on the basis of number of lanes occupied at a time for construction. Continuous site rental charges the contractor on a day-by-day basis. Bonus/rental charge method considers the cost of construction as well as the cost of time for which the contractor occupies the lane or shoulder. These types of contracts are useful where the traffic cannot be stopped completely and diversions may not be economical (Carpenter et al 2003).

3.5.3.1 Advantages of Lane Rental

Lane rental helps in reducing the project time and in minimizing the impact on public, by allowing the contractor to work during suitable hours of traffic. On the other hand the contractors have to work efficiently as the time available is restricted. Thus, lane rental facilitates the overall growth of economy (Carpenter et al, 2003).

3.5.3.2 Disadvantages of Lane Rental

The only disadvantage may be the lack of knowledge and experience of majority of the contractors about this particular delivery method (Carpenter et al 2003).

3.5.4 Construction Management at Risk (CMR)

In Construction Management at Risk (CMR) project delivery method, the owner hires a construction manager who plays the role of the general contractor and assumes the risk and guarantees the price of construction (Mahdi and Alreshaid 2005). CM's expertise can also be used during the design phase for cost estimation, scheduling, quantity takeoff, material selection and choosing the suitable project alternative. In other words, CM's role changes from that of an advisor to that of the general contractor once the construction phase starts. The CM is also responsible for subletting the work to proper subcontractors, getting the project completed on schedule, and handling quality control tasks at the same time (Mahdi and Alreshaid 2005).

3.5.4.1 Advantages of CMR

One of the important advantages is that the CM not only assists in design process but also acts as a vendor when it comes to guaranteeing the cost of the project. The level of professionalism rises, as CM becomes the point of interaction for rest of the project stakeholders. CMR also allows fast tracking and flexibility in the selection of subcontractors (Mahdi and Alreshaid 2005).

3.5.4.2 Disadvantages of CMR

The owner still has multiple contracts to handle. Often premiums are placed for the selection of the CMR using best value procurement. Although the CM plays an advisory role in the design phase, the A/E is not obligated to accommodate CM's suggestions. CMR might be faster than traditional project delivery, but it is not as fast as DB project delivery (Mahdi and Alreshaid 2005).

3.5.5 Construction Management Agency (CMA)

This project delivery is quite similar to traditional project delivery, except the owner hires a CM to look over the project mostly during the design phase. Here, the CM's role is fully advisory. The CM does not provide any kind of guarantee and does not hold any subcontracts (Mahdi and Alreshaid 2005).

3.5.5.1 Advantages of CMA

Here, the owner is directly in charge of all the contracts, but at the same time it can use CM's expertise on estimating, scheduling and constructability. With skillful management, the owner can start construction even before the design phase is complete (Mahdi and Alreshaid 2005).

3.5.5.2 Disadvantages of CMA

As in traditional project delivery, CMA does not provide single point of responsibility i.e. the owner handles multiple contractors by itself. Again as no party guarantees the price, there are good possibilities of cost overruns (Mahdi and Alreshaid 2005).

The legal framework of the state, where the transportation project will be undertaken affects the choice of PDS, signifcantly. Traditional design-bid-build is the only choice for many states where APD is not allowed. Even when State Agencies are allowed to utilize APD methods, their level of authorization may vary, such as - (1) fully authorized, (2) authorized but needs extra approvals, and (3) authorized for a pilot program and/or with some limitation (Ghavamifar and Touran 2008).

3.6 Existing Decision Making Models

3.6.1 ABC Decision Making Process (FHWA 2011)

FHWA has prepared an ABC decision-making process to assist state DOTs in selecting the appropriate ABC techniques for a particular project. In the ABC manual published by FHWA, the ABC techniques are categorized into Foundation and Wall Elements, Rapid Embankment Construction, Prefabricated Bridge Elements and System, Structural Placement Methods and Fast Track contracting. The process helps the agency to choose the appropriate ABC method based on the challenges and restrictions associated with the project. These constraints are again grouped according to the site, staging area, traffic management, right of way, utilities, local government regulations and structure type options.

Site constraints are major governors of the decision making process. If the bridge is above or across a water body, then the factors to be considered are navigability, tidal patterns, suitability for barges and other environmental constraints. If the bridge is over or adjacent to an existing highway, then it should be checked whether the site has the required clearance and whether there is need for lane closures above or below the bridge. Again it should be checked whether there are spaces available to be used as work-zones at the end or adjacent to the bridge. Bridges on railroad crossings may face several challenges such as sufficient clearance throughout the whole construction period, weight restrictions, available track closure schedules, and any temporary protection mechanism for the rails. Additional caution is required, if the track is electrified and the alternative should be selected accordingly. The geotechnical specifications should be examined to check whether the soil has the sufficient load bearing capacity to withstand the weight of the equipment.

Traffic management is an important issue to be considered as it has a great impact on user costs. Selection of alternatives will depend greatly on the length and delay caused due to the detour and also the time period for which the detour will be in place. Temporary routes will require proper traffic signaling and timing. Mass transit routes and school bus routes will again determine detours placement. Construction staging might be required for cases when detours are not feasible although it increases the risk by a considerable amount. ABC decisions might also be affected by the cost of construction staging In addition to costs associated with implementing ABC. If none of the above options are workable or feasible, then temporary bridges might have to be used. However, that will cause substantial increase in project duration and also project cost.

Right of way (ROW) is one of the major concerns for most of the infrastructure projects. The selection of the construction techniques may depend on the availability of right of way for staging on the bridge site, crane placement, and some clearance adjacent to the bridge. If ROW is not available, then it should be checked whether the space could be leased temporarily.

Presence of above ground and underground utilities affect the selection procedure of the construction method. Crane operations are mostly governed by the presence of overhead utility lines. If lines do not provide sufficient clearance or cannot be moved temporarily to a different location, then gantry cranes and SPMTs (or other appropriate equipment) can be used. Again, the moving of overhead utilities should be planned well ahead of time and should be put into contract to prevent construction delays during the ABC process.

Governmental regulations play an important role in any infrastructure project. ABC decisions should be made in consideration of the impacts on the community, such as event schedules, school bus routes, local festivals etc. In addition to the above criteria, technical specifications of the bridges are to be investigated to select the most convenient and feasible method of installation depending on the particular bridge type and site condition.

Four different ABC decision-making models have been prepared by FHWA in form of flowcharts for

I. Superstructure Construction over Roadway or Land
II. Superstructure Construction over Railroad or Transit
III. Superstructure Construction over Water or Wetland
IV. Substructure Construction

The flow charts are listed in the figures below:

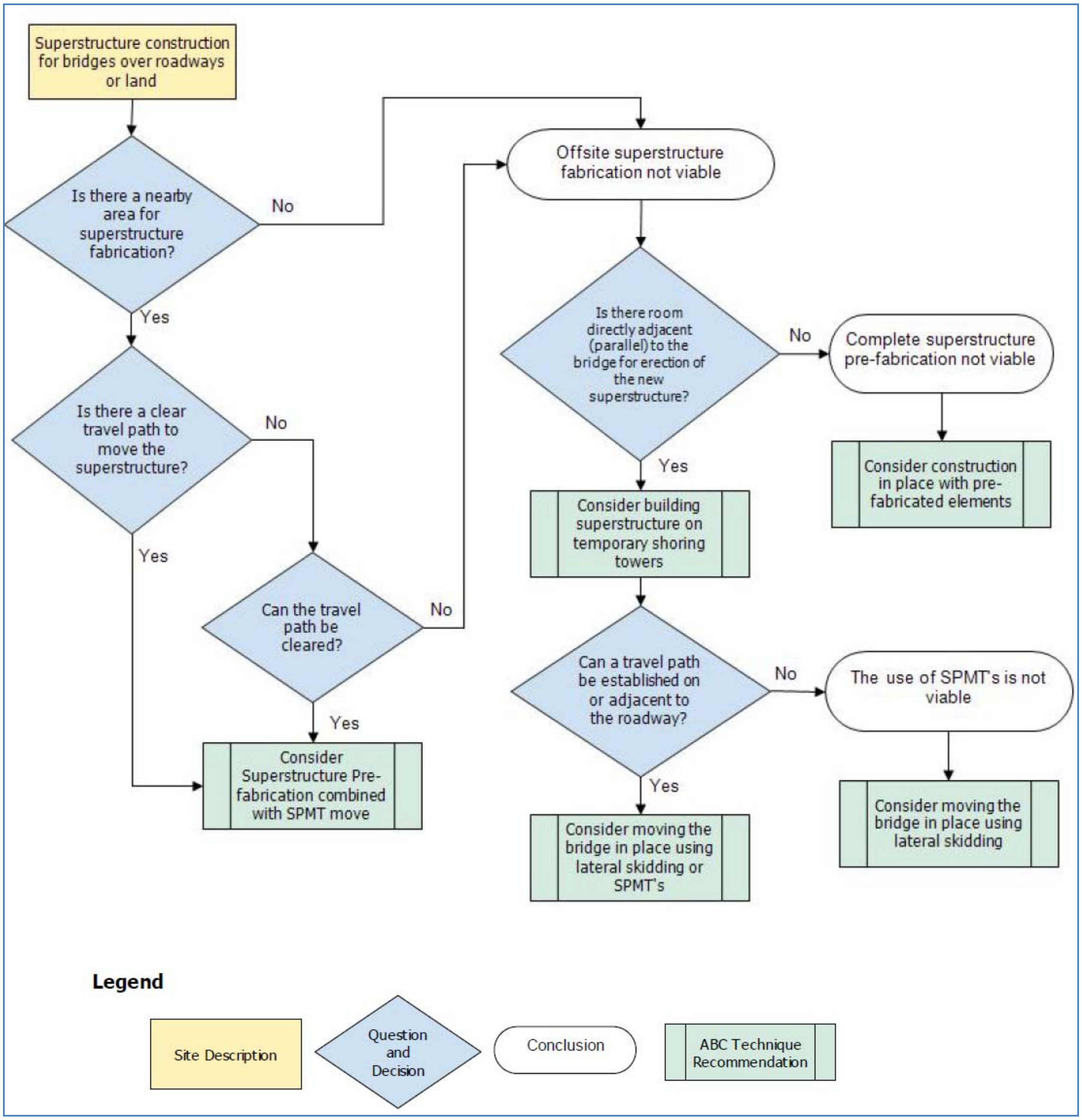


Figure 3: ABC Decision Making Model for Superstructure Construction over Roadway or Land (FHWA 2011)

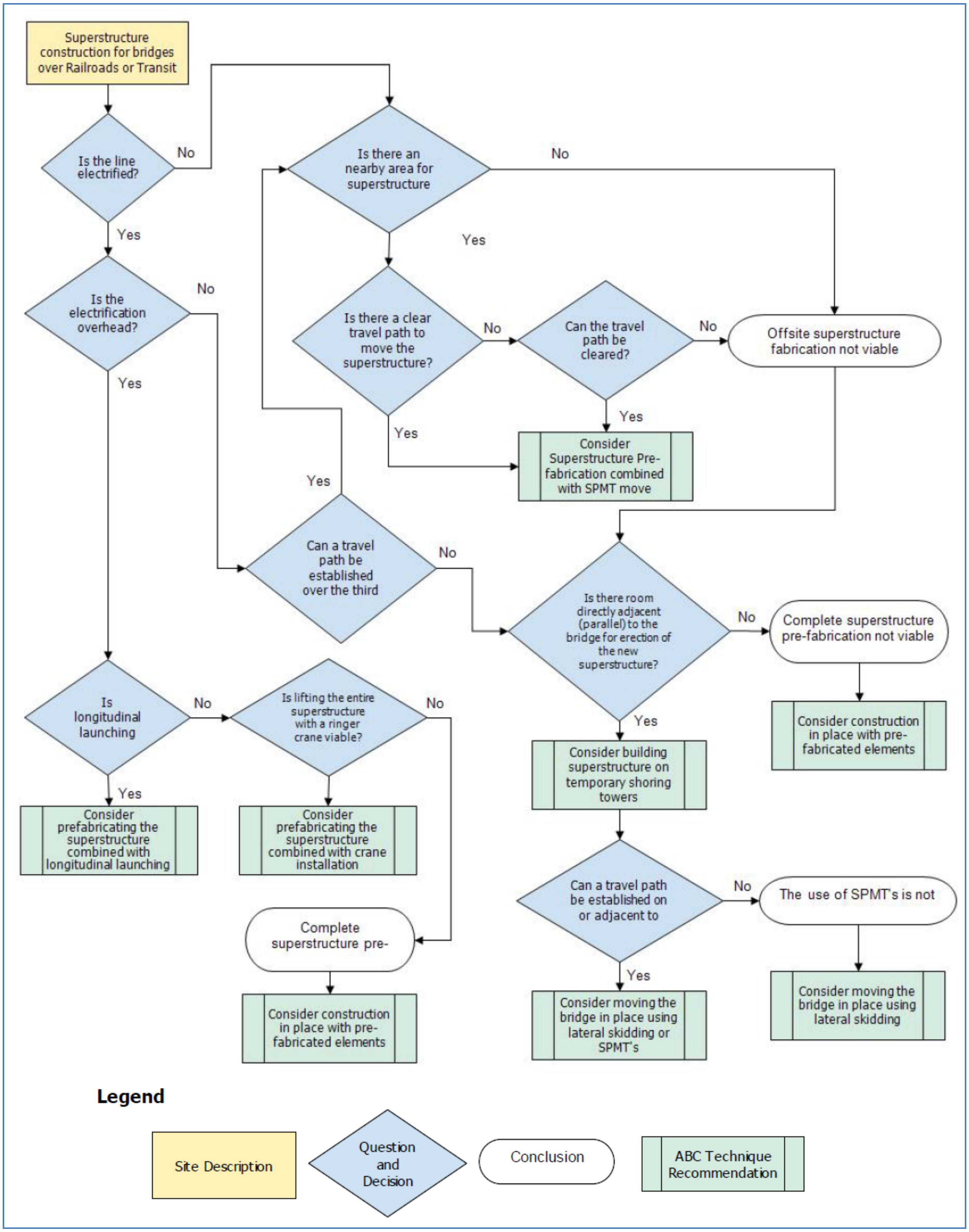


Figure 4: ABC Decision Making Model for Superstructure Construction over Railroad or Transits (FHWA 2011)

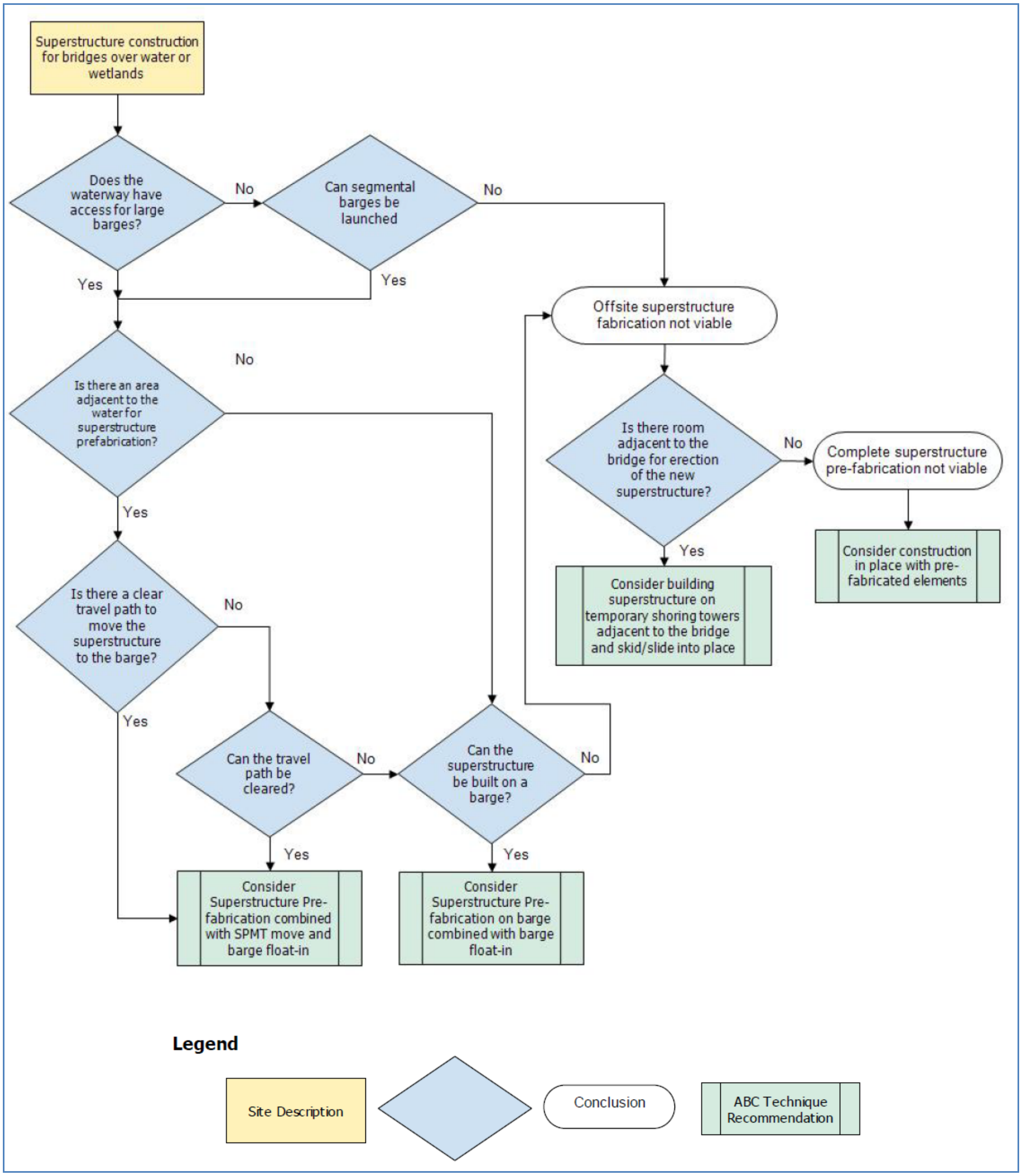


Figure 5: ABC Decision Making Model for Superstructure Construction over Water or Wetlands (FHWA 2011)

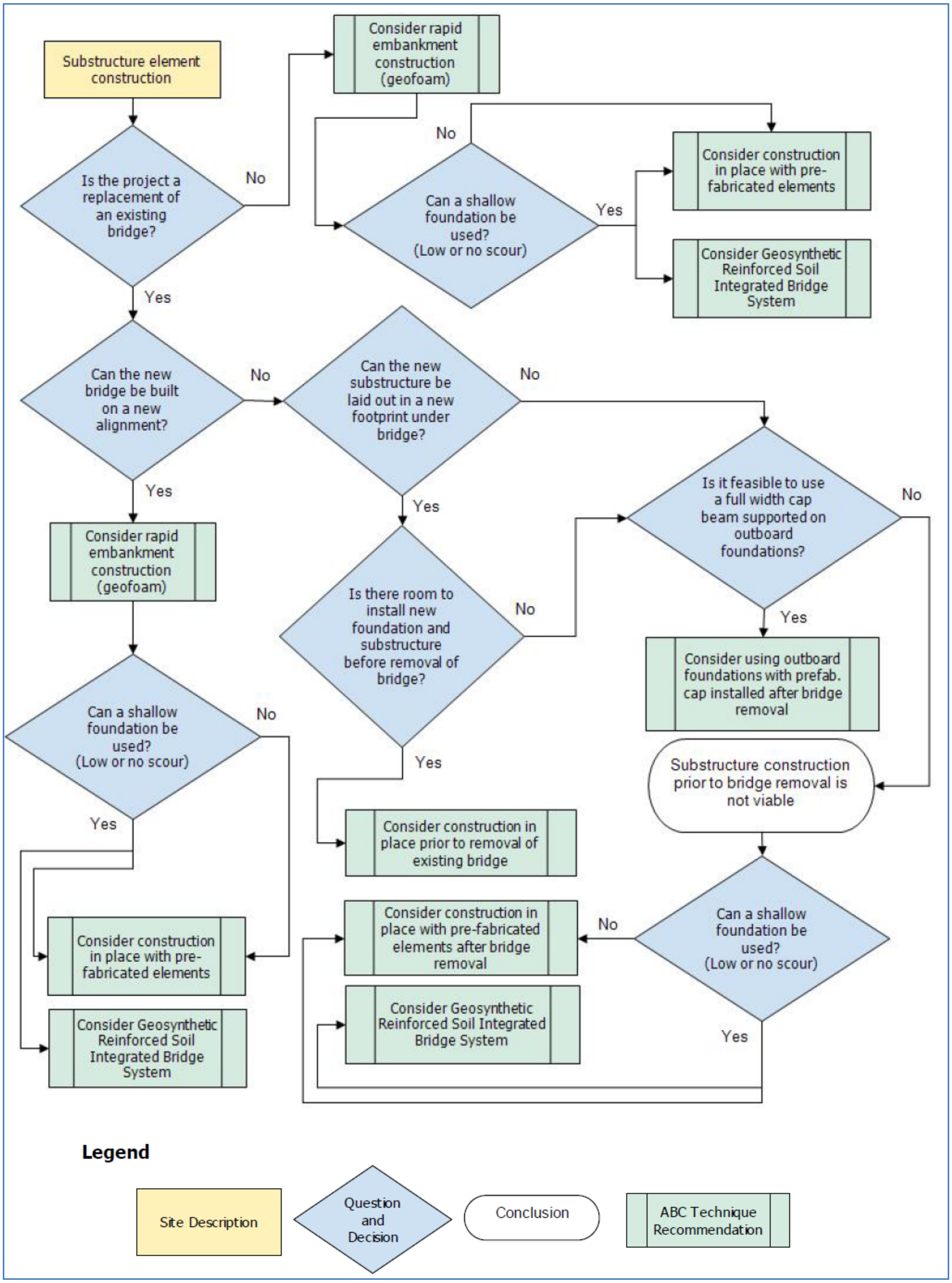


Figure 6: ABC Decision Making Model for Substructure Construction (FHWA 2011)

3.6.2 Utah Department of Transportation (UDOT) ABC Decision Making Process (UDOT 2010)

UDOT uses an ABC Decision Making Process for their project development. The decision making process was prepared in consideration of some key goals of UDOT, i.e. accelerating the design and construction process, thereby, decreasing the user costs caused due to delays, promoting innovation in their project delivery process, and maintaining the economic feasibility of the project. The model has been subdivided into two parts i.e. ABC Rating Procedure and ABC Decision Flowchart and is based on eight factors listed below:

- Average Daily Traffic
- Delay/Detour Time
- Bridge Classification
- User Costs
- Economy of scale
- Use of typical details
- Safety
- Environmental Issues
- Railroad impacts

Each factor is given a specific weight so that they are in accord with the department's objectives. The factors are then assigned a value and the overall score is calculated. The rating score is calculated as a percentage in terms of the ratio of the weighted score to the maximum score possible. The ABC rating scores ranges from 20 to 50 and has three categories. Different categories have different entry points in the ABC decision-making flowchart, which can then be used to draw a conclusion. Whether ABC should be used or not for a particular project can be determined from the ABC Rating Procedure. After the factors, such as project schedule, environmental issues, total project cost, site conditions and high-level indirect costs (for example: political capital, safety or possible impacts to the stakeholders) are determined, the ABC flowchart can be used to decide on the construction approach. Figure 7, 8 and 9 are representations of ABC Rating System and ABC Decision flowchart.

Utah Department of Transportation 4501 South 2700 West Salt Lake City, UT 84114	Project:	Hypothetical Bridge Project		
	By:	JJS	Checked:	CELS
	Date:	8/30/2010		8/30/2010
	Sheet No.	1	of	3

ABC Rating Procedure June 2010

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

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

Figure 7: ABC Rating System (UDOT 2010)

Utah Department of Transportation 4501 South 2700 West Salt Lake City, UT 84114	Project:	Hypothetical Bridge Project		
	By:	JJS	Checked:	CELS
	Date:	8/30/2010		8/30/2010
	Sheet No.	2	of	3

ABC Rating Procedure — **June 2010**

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

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

ABC Rating Score: 64

The ABC Rating Score is driven by the four most heavily weighted factors: Average Daily Traffic, Delay/Detour Time, User Costs and Safety. For a detailed explanation, review the narrative on page 4 of the ABC Decision Making Process.

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

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

Figure 8: ABC Rating System (Contd.) (UDOT 2010)

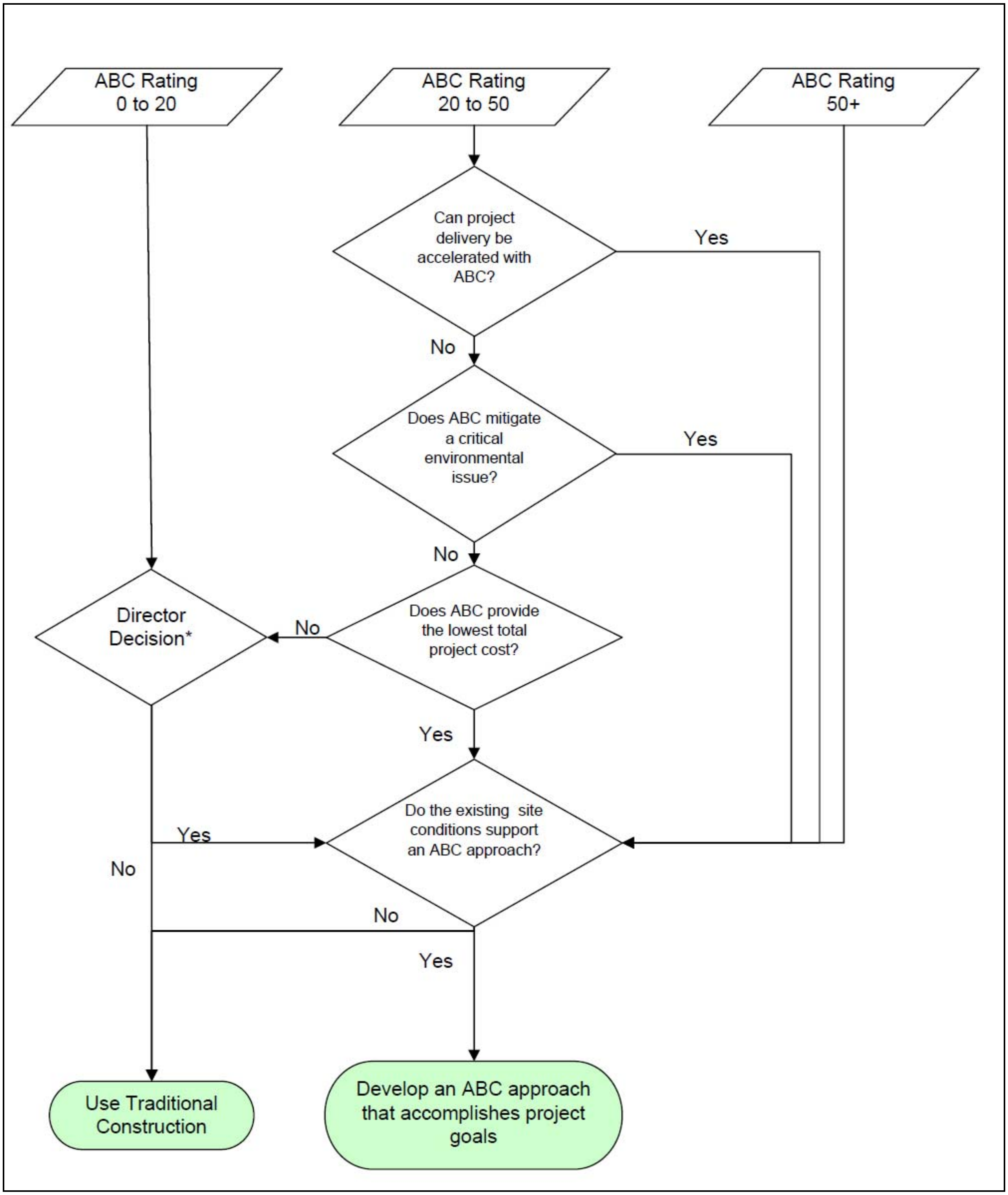


Figure 9:ABC Decision Flowchart (UDOT 2010)

3.6.3 Framework for Prefabricated Bridge Elements and System Decision Making (Ralls 2006)

In many cases, prefabrication is preferred over cast-in-place construction as it has the potential to provide significant advantages in terms of life cycle costs and overall quality of the structure. Prefabrication may also reduce the time-required onsite to repair or upgrade a bridge, thereby negating the impact of construction on traffic, environment, businesses and communities around the site. In addition, the use of the new FRP bridge deck reduces the dead weight of the bridge, increases live load carrying capacity, enhances durability, and extends the service life of the bridge. Prefabricated Bridge Elements and Systems (PBES) framework is developed by Ralls (2006). PBES assists in deciding whether prefabrication is suitable for achieving accelerated bridge construction at a particular site. This framework consists of the following three sections:

1. A flow chart for high level decision making
2. A matrix for detailed analysis of various factors
3. An in-depth discussion on various factors

The flow chart shown in Figure 10 was developed to assist in high level decision making procedures on whether to use prefabricated bridge elements (Ralls 2006). The matrix developed in this study consists of 22 questions and is shown in Figure 11. The decision maker answers these questions as “Yes”, “No” or “Maybe” by checking appropriate boxes for each option. The final decision is determined by counting the number of checked boxes.

The decision making process for selecting an appropriate construction strategy requires consideration of tradeoffs between various factors such as cost; flow of traffic; disruption to local businesses and communities. The process developed in the study of Ralls (2006) allows the user to assign certain weights to various factors but fails to provide a methodology to calculate these weights.

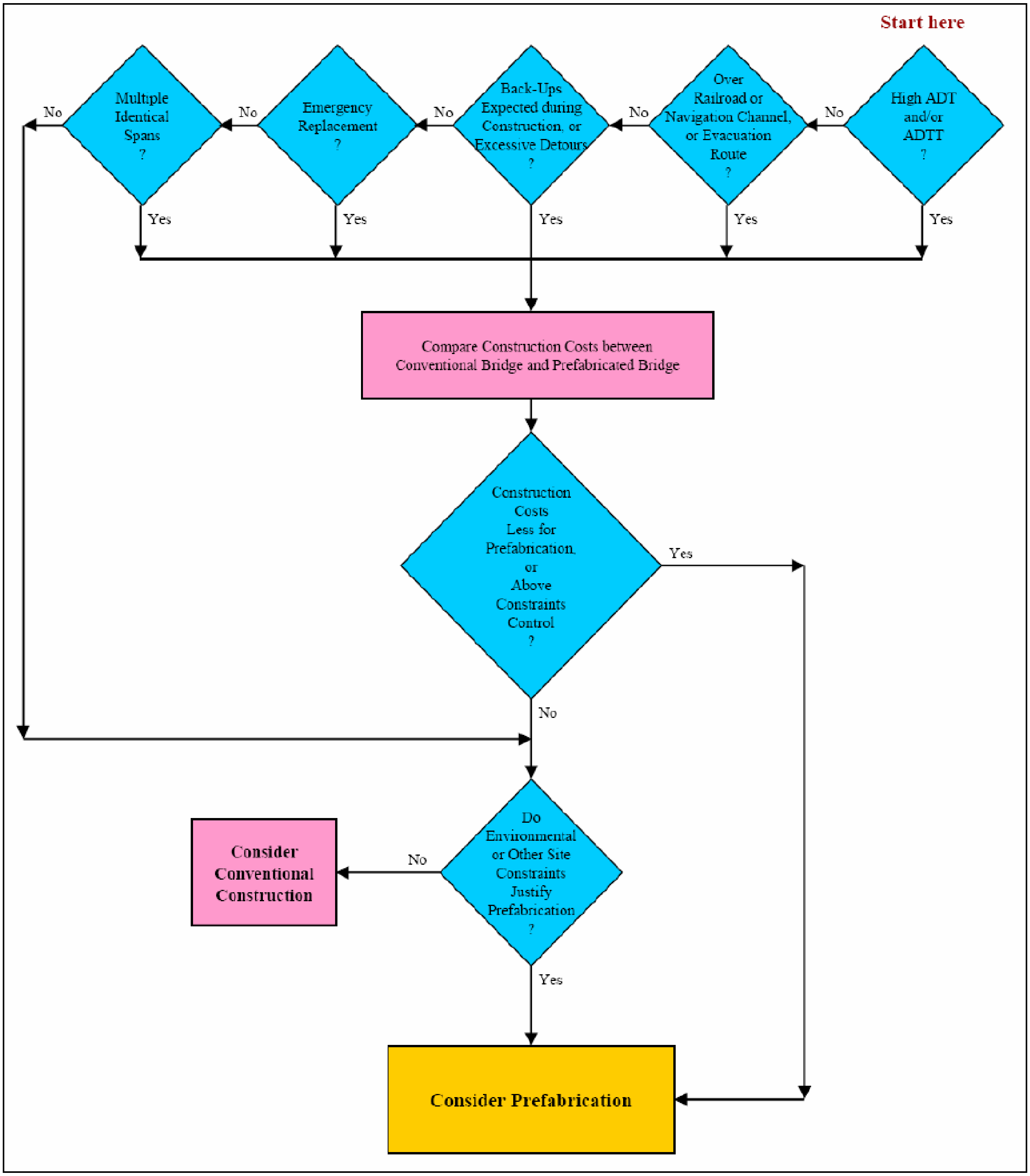


Figure 10: Flowchart for High Level Decision- Making Process (Ralls 2006)

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

Note: One or two of the above factors may warrant the use of prefabrication to achieve rapid and limited-impact onsite construction. Alternatively, the user may wish to assign weights to the above questions based on the unique circumstances of the project in order to determine whether prefabrication should be used. In any case, prefabrication offers advantages for projects with a majority of "Yes" responses; a more detailed evaluation using the considerations in the next section would then be appropriate.

Figure 11: Matrix Questions for High-Level Decision on Whether a Prefabricated Bridge should be used in a Project (Ralls 2006)

3.6.4 Model for evaluating Bridge Construction Plans (El-Diarabi and O' Connor 2001)

This model was developed to evaluate bridge construction plans during the design phase of a project. It can be used to balance the impacts of bridge construction procedures on traffic flow and business activities. Five major factors (i.e. safety, accessibility, carrying capacity, schedule performance and budget performance) were considered in this model. An additional set of 22 factors was developed to support the major factors through observation of construction sites and collecting information from industry experts. The model was evaluated by another group of experts and was validated in a case study. The weights of the factors were determined as follows:

- Safety (24%)
- Accessibility (19%)
- Carrying Capacity (19%)
- Schedule Performance (19%)
- Budget Performance (19%)

These weights were used in a decision-making matrix as shown in Figure 12.

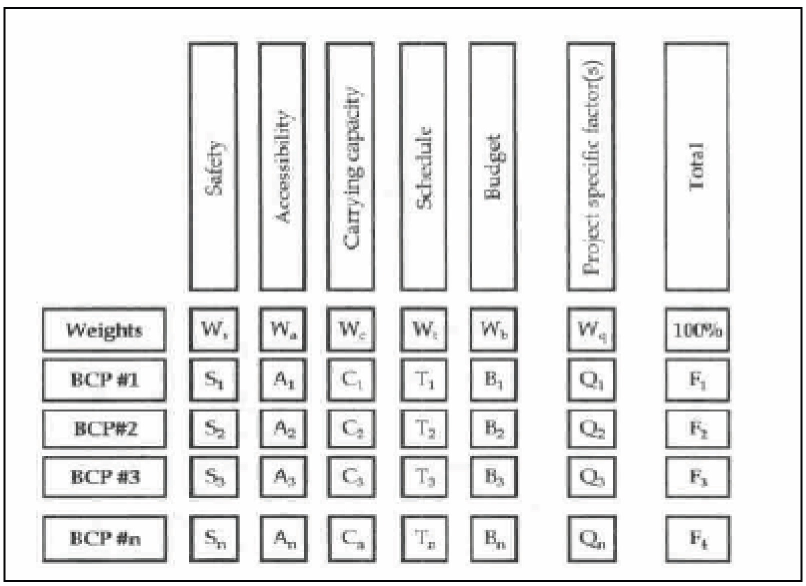


Figure 12: Bridge Construction Plan Objective Matrix (El-Diarabi and O' Connor, 2001)

The final score for each plan is derived by using the following formula:

$$F_i = (W_s \times S_i) + (W_a \times A_i) + (W_c \times C_i) + (W_t \times T_i) + (W_b \times B_i) + (W_q \times Q_i)$$

where, S_i , A_i , C_i , T_i , B_i , Q_i indicate scores of i^{th} bridge construction plan for Safety, Accessibility, Carrying Capacity, Schedule Budget and Project Specific Factors rated on scale of

1 to 10 (with 10 being the best score), and W_s, W_a, W_c, W_t, W_b, W_q indicate weights for Safety, Accessibility, Carrying Capacity, Schedule Budget and Project Specific Factors, respectively. The construction plan with the highest score is considered to be the best amongst alternatives (El-Diraby and O'Connor 2001).

One of the major drawbacks of the model is that it cannot be customized according to the priorities, constraints, and necessities of an individual project. In addition, the methodology used to derive the numerical values of weights was not provided.

4 Questionnaire Survey

The methodology included a questionnaire survey of the State Departments of Transportation to determine the current state of practice. For that purpose a thorough literature review was conducted on ABC approaches including construction techniques and project delivery methods. States, which have implemented ABC, were identified and a list of experienced bridge professionals involved was prepared.

4.1 General Information

The questionnaire started with whether in last five years the agency used accelerated construction as a strategy to reduce construction project delivery time or not. If ABC was implemented then an estimate on the percentage of ABC projects to overall projects was asked to be provided. And, if ABC was never used in any of the projects then the reason behind not using ABC was asked. Only the agencies that utilized ABC were requested to fill the remaining parts of the survey.

To understand the extent of success of accelerated highway bridge construction, it is useful to know whether the ABC projects were completed with satisfactory quality on or ahead of schedule, within budget, and with no accidents. Then a list of ABC techniques was prepared after a comprehensive review of relevant literature. The agencies were asked to select the ABC techniques and also to specify the number of projects completed under each technique.

4.2 Project Delivery

As mentioned in the previous sections, project delivery or contracting methods are one of the key factors toward faster project completion. Thus, all the APDs mentioned in Section 3.5 were listed in the questionnaire for the participants to specify the number of projects completed using each project delivery selected.

Incentives/ Disincentives (I/Ds) clause was found to be one of the most common options used by the agencies to accelerate bridge construction. This clause can be put into any kind of project delivery, and as the amount of incentive often depends on the time saved, it encourages the agencies to shorten the construction schedule (NCHRP 2009b). But at the same time, risk on the constructors' part increases considerably. Therefore, the incentive provided should compensate for the increased risk and provide contractors with sufficient motivation. I/Ds can either be put into various sections of the project or at the end of project completions. I/Ds to "interim milestones" might involve completing a section and/ or a particular task to reduce user delays by opening a connector or ramp in a populated or heavy industrial area. I/Ds to "project milestone" can be implemented to fix the completion date for which most part of the project items are sufficiently completed and the bridge can be operational (NCHRP 2009b).

Phased construction or Multiple Contracts are sometimes used to reduce the construction time if the project has a large scope (Hall et al 2010). In this case the project is divided into different contracts, which can be carried out separately at the same time to accelerate the construction process. The contracts may also be handed over to different contractors. The disadvantage of this process is multiple points of contract. As phased construction can also be used with any project delivery, the survey participants were asked to specify the number of ABC projects performed using phased construction under each contracting method (Hall et al 2010).

Mahdi and Alreshaid (2005) have identified several factors behind the selection of contracting methods, I/D clause and phased construction alternatives. They are as follows:

I. Time constraints
II. Budget constraints
III. Time for bid preparation
IV. Precise cost estimate during the bidding phase
V. Scope of the project (size and complexity)
VI. Owner's involvement and control over design
VII. Owner's understanding of project scope
VIII. Owner's benefit from cost saving
IX. Quality of design
X. Quality of construction
XI. Clarity of scope (Any chances of substantial design changes during the construction?)
XII. Flexibility of redesign after the contract is awarded on a negotiated budget
XIII. Value engineering (effectiveness and constructability of design)
XIV. Familiarity with scope
XV. Contractor's involvement during design

XVI. Coordination and communication among the project stakeholders (Owner, Contractor and Designer)
XVII. Risk allocation (Owner's effort to minimize risk on its part)
XVIII. Competitive bidding
XIX. Owner's preference of the contractor and negotiation
XX. Legal restrictions for using alternative project delivery
XXI. Project financing (Money available for project initiation, mobilizing and construction)
XXII. Experience of the constructor
XXIII. Potential for claims and disputes (Mahdi and Alreshaid, 2005).

4.3 Factors affecting ABC decision making process

According to NCHRP's scan report, ABC techniques can be utilized in either Emergency or Planned Projects. Accelerated Construction projects triggered mostly due to unforeseen incidents such as "Act of Nature", accidents and structural failure can be categorized as Emergency Construction (NCHRP 2009b). Highest degree of acceleration is often needed to restore normal traffic flow, with minimum impact on adjacent traffic. ABC is said to be planned if it is performed in a predefined way for a regular project to minimize the effects of construction on daily commuters, businesses and economy. One of the factors that might lead to the use of accelerated construction might be the fact that the infrastructure involved is critical to its surroundings in terms of ease of accessibility. The project deadline can also be governed by specific local events such as beginning of the school year, sports events, festivals etc. (NCHRP 2009b).

Impact on traffic flow is one of the major concerns in any highway bridge construction project and can also be treated as one of the governing factors for ABC decision-making (NCHRP 2010). During the last 40 years, vehicle miles travelled have increased by 194 percent while the highway lane miles increased only by 6 percent. Business travel has been at par with the social and employment situation, but recreational travel has increased considerably over the past years. As almost 88 percent of the workers use their private vehicle to go to work, any construction activity at the bridges may disrupt the already burdened traffic network (NCHRP 2010)

From the previous sections it is evident that budget constraints plays an important role in ABC decision making. Another major factor might be the time required for the financing to be available (Puentes and Prince 2005). Usually, State Highway Agencies (SHA) tend to adopt the traditional "pay-as-you-go" form of financing, where the SHA after analyzing the total funds available from federal and state sources, try to allocate an appropriate amount of money for future projects. Under this mechanism, the state usually is provided funding on an installment basis over several years, which is not suitable for ABC (Puentes and Prince 2005). In recent years, it is realized that States can no longer depend upon the revenue collected from the gas tax. In fact, the increasing fuel efficiency of the vehicles does not "refill" the Highway Trust Fund (HTF) at the same speed of the required repairs making this mechanism inadequate for funding new bridge projects. As a result, agencies have been relying more on bonds, which are basically a form of debt to finance future projects (Puentes and Warren 2005).

In transportation, "Innovative Financing" can be defined as a supplementary bridge financing method that incorporates a set of non-conventional techniques, meant to benefit the funding aspect of the project. This type of financing option is quite new to transportation unlike the other sectors of construction (FHWA 2002). The economic recession has a significant impact on the State DOTs' budget, making them insufficient to meet the increasing needs of highway facilities. The Intermodal Surface Transportation Efficiency Act of 1991 (ISTEA), and the Transportation Equity Act for the 21st Century (TEA - 21) have provided the transportation decision-makers an opportunity to make use of the new financial strategies and to manage both federal and state funds to extract additional money for the future projects. Some of the most popular financing options are - Grant Anticipation Revenue Vehicle (GARVEE) (Puentes and Warren, 2005), Section 129 Loans, State Infrastructure Banks, Transportation Finance and Innovation Act (TIFIA) (FHWA 2002), etc. Most funding options help in accelerating the project, which in turn saves significant amount of money by negating the price rise due to inflation. The user benefits can also be realized earlier due to shorter project durations (FHWA 1996).

Federal Requirements in many states may sometimes hinder accelerated construction (AASTHO 2007). As mentioned in earlier sections, traditional project delivery is prevalent in transportation infrastructure. However, following various experiments conducted on the federally initiated Special Experimental Projects (SEP) 14, which focused on innovative contracting, delivery methods other than traditional project delivery are being gradually used in transportation projects on a case by case basis as some of the innovative project deliveries are still illegal in many states under current procurement laws and regulations (AASTHO 2007).

Environmental Requirements are other major reasons of project delays (AASTHO 2007). These are governed by the National Environmental Policy Act (NEPA), which constitutes several individual statutes and regulations related to natural, social and built environments. Some form of federal permission is required for most of the statutes or agreement. Although NEPA was established to select among the alternatives weighing issues related to air, water, parkland, historic properties, rare and endangered species etc., it seldom serves the purpose of comparative assessment and tradeoffs because of its narrow focus and thereby, hinders project development. Major confusions are caused by multiple agencies, all having their own different interpretation of policies and regulations (AASTHO 2007).

Right-of-way acquisition in most cases delays transportation project delivery and can play an important role in ABC decision-making process (AASTHO 2007). Right-of-way personnel often have hard time going through a time consuming process of receiving the final design for the amount of property to be procured from A/Es and then to secure the right-of-way by a specified time. The situation is aggravated by disputes, which have to be resolved within the already congested justice system. Experienced personnel have come up with several strategies to cope up with this problem, which includes better communication and flexible negotiations with property owners, and concurrent right-of-way acquisition with construction, and also reformatting federal and state procedures, which can facilitate earlier acquisition of right-of-way. However, changes in governmental provisions may result in an increased share of risk for project stakeholders (AASTHO 2007).

4.4 Survey Results

The questionnaire included a total of ten questions. DOT officials from 26 states expressed their interest in the study, among which 21 experienced bridge personnel completed the survey. The States, which participated in the survey, were California, Colorado, Connecticut, Delaware, Hawaii, Illinois, Iowa, Missouri, Nebraska, Nevada, New Jersey, New York, North Carolina, South Dakota, Texas, Tennessee, Pennsylvania, Utah, Washington, Wisconsin, and Wyoming. Almost 50 % of the participants were designated as reputed bridge engineers and the rest were mostly transportation and structural engineers. The summaries of the responses for each question are presented below.

Question 1: In the last five years, has your agency used accelerated construction as a strategy to reduce construction project delivery time? If "Yes", please indicate below the percentage of AHBC projects to overall construction projects executed? If "No", please explain why it has not been used so far?

Out of the 21 responses received, 18 state DOT officials responded that they used ABC techniques although the extent of implementation varied considerably from state to state and also some of the states did not keep track of the ABC projects. Figure 13 represents the percentage of ABC projects over total number of bridge projects in 14 states. The remaining four states were unable to specify the number.

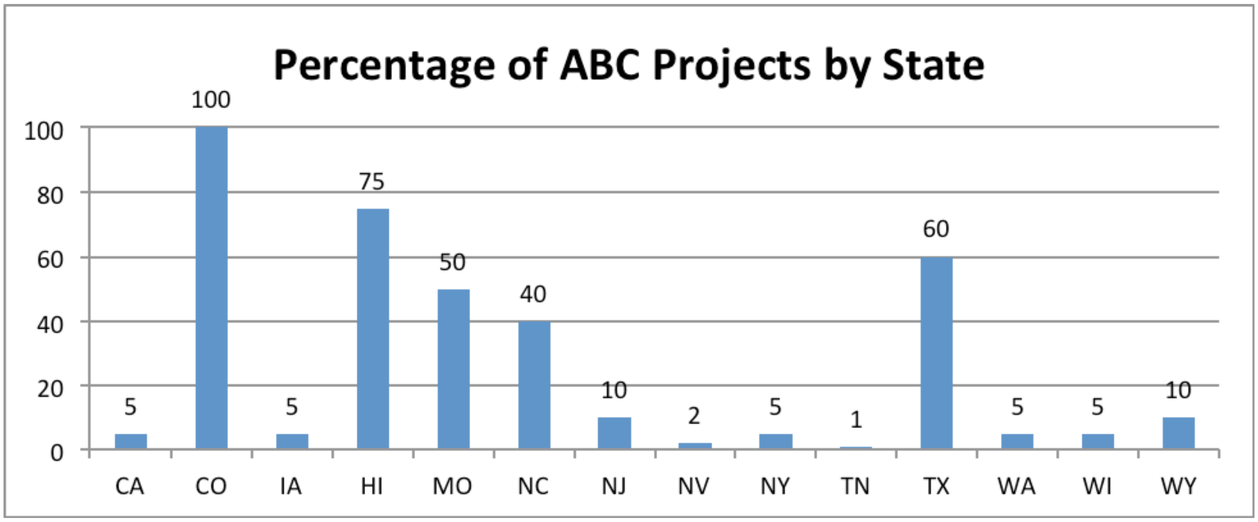


Figure 13: Percentage of ABC Projects by State

Colorado DOT (CDOT) claimed that almost all the bridge projects performed were ABC projects, since all girders or CBC members were prefabricated at precast plants, then shipped and installed at the bridge sites. There were some cast in place members used on bridges, but CDOT preferred precast members to speed bridge constructions, such as - precast full depth deck, precast stay-in-place deck forms, precast wing-walls, precast box culverts, precast abutments and piers.

Texas DOT (TxDOT), one of the States that uses AHB construction often, had been informally tracking ABC projects, but exact numbers were hard to quantify, especially with older projects. Although they were in the process of improving tracking, it is stated that it was a relatively time-consuming effort. Extending back to the early 1990's, TxDOT has let a total of just over 50 bridge projects involving unique accelerated features. This compared with an average letting volume of 637 bridges annually. On average, TxDOT only uses unique ABC technique on less than 1% of bridges. However, TxDOT did use prefabricated bridge construction techniques that they considered to be standard practice and did not include these projects in their tracking. These standard techniques might be considered unique accelerated construction techniques in other states. Examples include a wide variety of precast pre-stressed beam sections (including side-by-side sections that eliminate deck concrete such as box beams, double tees, and decked slab beams), and partial depth precast deck panels and stay-in-place metal forms. Approximately half of the bridges contracted by TxDOT involved pre-stressed I-beams, and of these, approximately 85% used partial depth precast panels to "accelerate" construction. The TxDOT has a large volume of bridge class culverts. If these were included as "accelerated" construction strategies, then approximately 60% of TxDOT bridge projects could be considered to utilize ABC. TxDOT uses accelerated construction contracting strategies on approximately 33%.

South Dakota is one of the states that did not use ABC. According to one of SDDOT officials, traffic congestion in South Dakota was generally not an issue and corresponding user costs for conventional construction vs. ABC typically did not justify added costs of many Prefabricated Bridge elements and Systems (PBES) applications. However, the SDDOT regularly used prefabricated bridge beams, precast concrete box culverts and miscellaneous prefabricated bridge related items on highway structure construction projects. SDDOT utilized a modular transporter system to launch and set a large truss superstructure over a railroad yard within a 21 hour allowed window of time (done back in early 2000's). The SDDOT was also working on developing guidelines for ABC techniques for state projects, taking into account parameters reflecting traffic counts, economy and construction funding availability.

In addition, local agencies in SD regularly utilized side by side deck concrete double tees, side by side deck concrete bulb tees and precast concrete box culverts. This was not necessarily done for reduction in project construction delivery time but for simplicity in short span bridge applications or remote locations where availability of ready mix concrete may be limited. However, there was a side-by-side box girder bridge recently constructed by the City of Sioux Falls on a very busy street where AHBC methods were implemented and benefits were realized.

Similarly Illinois used standard precast, pre-stressed, concrete deck beams and precast culverts on a regular basis. This may be considered AHBC using precast bridge elements but it was quite a routine procedure in the state.

Connecticut DOT (CONNDOT) recently did not have any projects that met the criteria outlined in item number one of the questionnaire. They were working on several projects that they planned to recommend for AHBC, but they were currently in design and the final determination was still awaiting the project team's final recommendation.

Question 2: Please specify the percentage of ABC projects completed on or ahead of schedule, within or below budget, with acceptable quality and workmanship and with no accidents?

Eleven participants responded to this question. The percentage of projects satisfying all the four criteria were on the higher side. As all the four criteria were equally important for project success, they were given equal importance. Figure 14 demonstrates the level of achievement of each success criteria in terms of percentage of projects against the state DOTs that responded. The average of project completion percentage was calculated as shown in Figures 15, 16, 17 and 18.

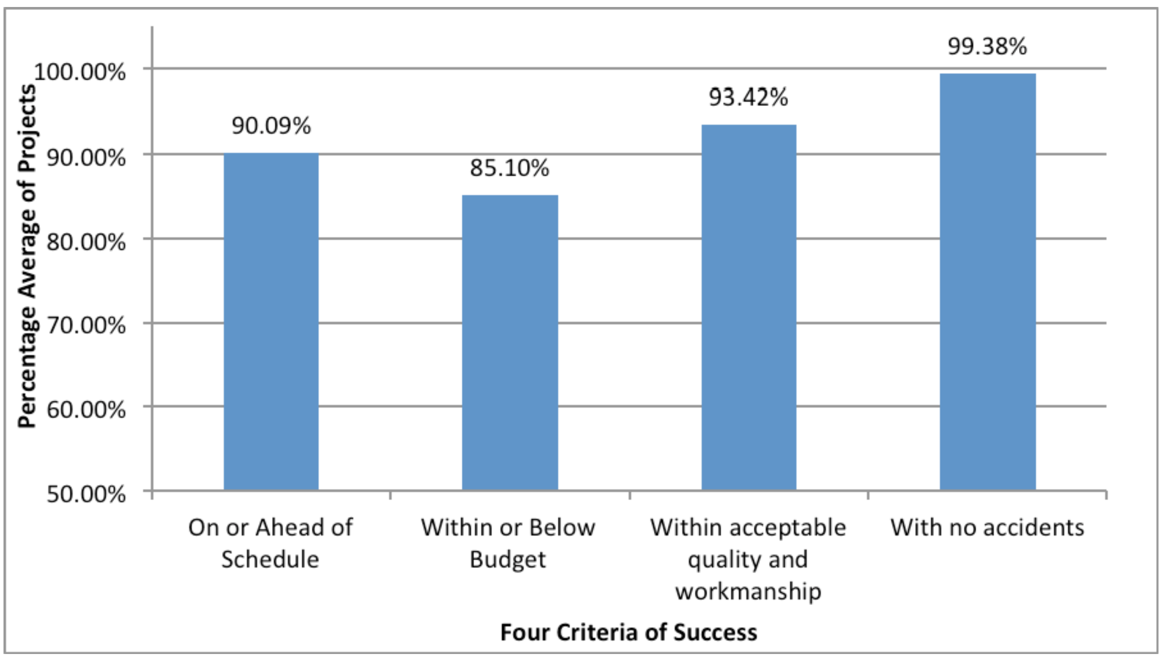


Figure 14: Success Rate of ABC Projects

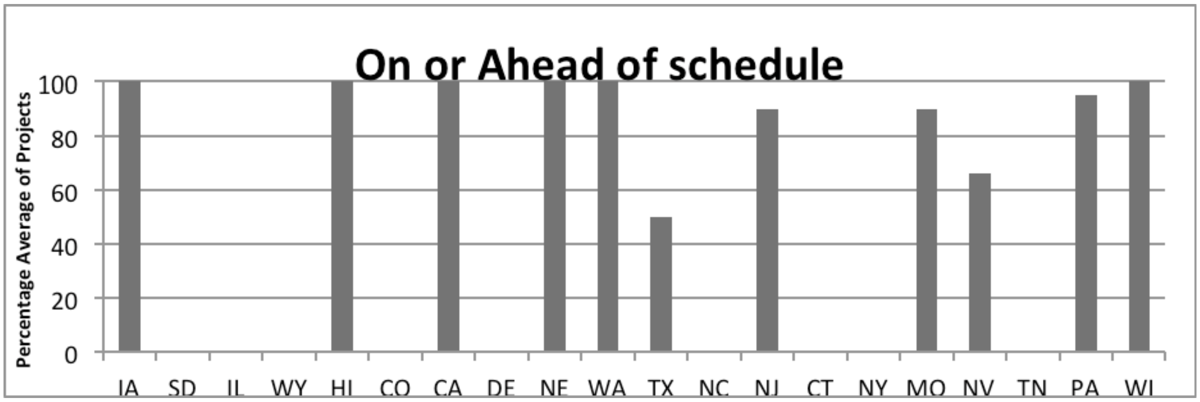


Figure 15: ABC Projects Completed on or ahead of Schedule by State

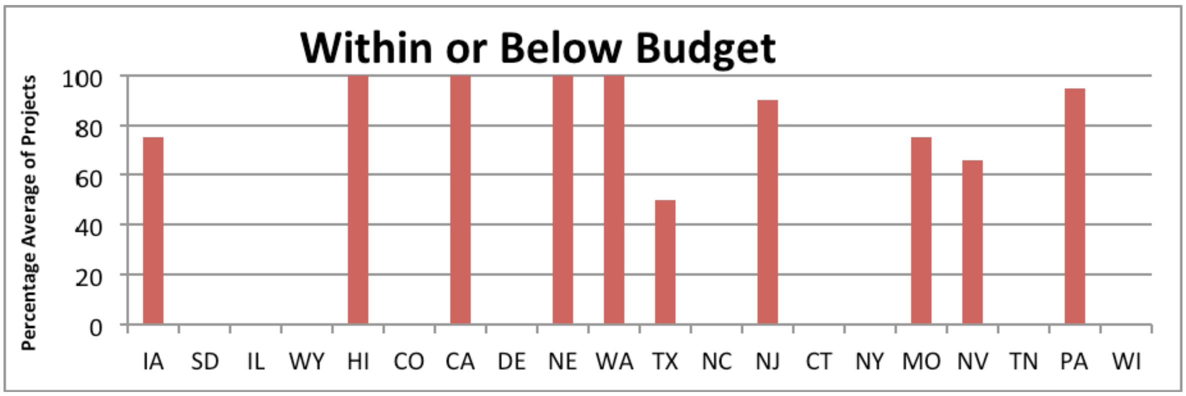


Figure 16: ABC Projects Completed within or below Budget by state

Figure 17: ABC Projects Completed within Acceptable Quality and Workmanship by state

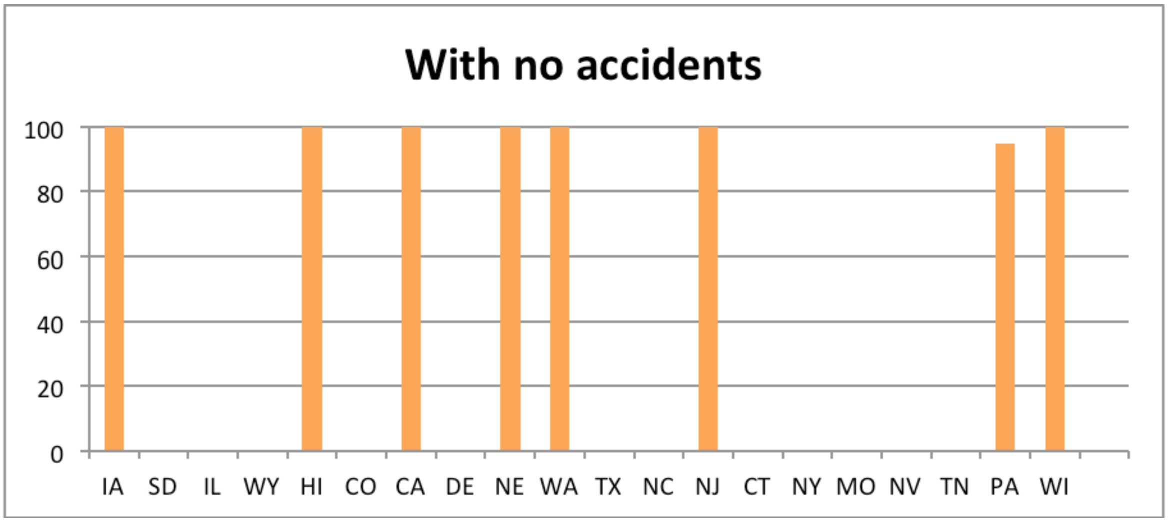


Figure 18: ABC Projects Completed with NO Accidents by state

Question 3: Please select one or more construction method(s) that are utilized during your agency's ABC projects. Please specify inside the brackets, the number of ABC project(s) for which the method was utilized

As the data obtained for this question were limited, inconsistent and varied from state to state, all the responses are listed in Table 1. But it was observed that the states actively implementing ABC used Prefabricated Components of Bridges very often.

Table 1: ABC Techniques Implemented by state DOTs

ABC Technique	States DOT	Number of Projects in which the technique was implemented
Prefabricated Components of Bridges	IA	12
	WY	Implemented but number not specified
	HI	13
	CO	65
	DE	20
	NE	1
	WA	10
	TX	53
	NC	276
	NJ	Implemented but number not specified
	NY	>50
	MO	200 (For Year 2011)
	NV	3

ABC Technique	States DOT	Number of Projects in which the technique was implemented
	TN	Implemented but number not specified
	PA	40
	WI	2
	UT	140
Heavy Cranes/ Transporters to Bridges	CO	1
	CA	4
	NE	1
	NC	2
	NJ	Implemented but number not specified
	NY	3
	UT	2
c. Stay -in-place steel forms	WY	Implemented but number not specified
	HI	1
	CO	5
	CA	3
	DE	15
	TX	Can't quantity, but very common especially at end diaphragms
	NY	Most Projects
	MO	35 (For year 2011)
	PA	30
	WI	2
	UT	As a standard practice stay-in-place metal forms are not allowed
d. Concrete filled steel grid decks	NY	Used in New York City But number ot specifies
	PA	2
e. Fast Setting Hydraulic Cement Concrete	TX	Can't quantify, but not common
f. Rapid Strength Concrete	IA	8
	TX	Can't quantify, but not common
	NJ	Implemented but number not specified
	MO	5

ABC Technique	States DOT	Number of Projects in which the technique was implemented
g. Cast-in-place/ post-tensioned (CIP/PS) box girder with transverse girders and large edge beams spanning column support	Was not used by any state who participated in the survey	
h. Precast sub structure units	IA	4
	WY	Implemented but number not specified
	CO	14
	CA	2
	WA	5
	TX	Trestle pile bents too numerous to quantity, precast bent caps or columns 17 (32% of the unique AHBC set
	NC	10
	NJ	Implemented but number not specified
	WI	3
i. High performance and fast setting concrete	IA	8
	CA	1
	TX	Can't quantify, but not common
	NJ	Implemented but number not specified
	NY	11 (UHPC between precast units)
j. "Deck less" bridges (Adjacent box or bulb "T" beam)	IA	2
	WY	Implemented but number not specified
	DE	5
	TX	13 (25% of the unique AHBC set)
	NC	3
	NY	5 (Deck Bulb T or Next Beam)
	MO	150 (For year 2011)
	PA	6
	UT	5 depending on traffic volume but not an ABC element
h. FRP modular bridge decks	IA	2
	TX	1 Tried once, too expensive
	MO	150
	PA	6
i. Self Propelled Modular Transporter	WA	2

ABC Technique	States DOT	Number of Projects in which the technique was implemented
	TX	1 Tried once, too expensive
	WI	1 (Proposed)
	UT	25
j. Others (Please add the other techniques used with the number of project(s) in which it was utilized)	CO	13 (Precast Full Depth Deck or CBC)
	TX	Full Depth Precast Deck Panels [1 (2% of the unique AHBC set)] FRP Beams [2 (4% of the unique AHBC set)] Arch Bridges to Minimize Impact Below [2 (4% of the unique AHBC set)] Precast Segmental [3 (6% of the unique AHBC set)]
	UT	Bridge longitudinal launch - 2 spans, Bridge slide-in-method 10 spans

Question 4: Please specify the number of ABC projects performed under each of the following contracting procurement techniques, with or without an Incentive/Disincentive (I/D) clause. Also, please identify the factors (using the list of factors provided in Appendix 1) affecting the decision making process for the project delivery, under each project delivery checked.

The purpose of this question was to understand the factors, which played an important role in the selection process of an appropriate project delivery method. The information obtained for this question was also limited. Some responders stated that they did not keep track of project delivery methods. The factors selected for each contractual method are listed in Table 2.

Table 2: Type of Project Delivery used by state DOTs and factors considered during the selection

Project Delivery	State DOTs	Total Projects Performed	Factors affecting the Project Delivery selection process
DBB I/D	IA	12	Time Constraints, Budget Constraints, Time for Bid Preparation, Precise Cost Estimate during bidding phase, Owner's involvement and control over design, Familiarity of scope,
	WY	36	
	HI	4	
	CA	5	
	WA	5	

Project Delivery	State DOTs	Total Projects Performed	Factors affecting the Project Delivery selection process
	NC	276	Contractor's involvement during design, Risk allocation
	PA	10	
	WI	6	
DBB	HI	6	Time Constraints, Budget Constraints, Time for Bid Preparation, Precise Cost Estimate during the bidding phase, Owner's involvement and control over design
	CA	5	
	DE	40	
	NV	2	
	TN	2	
	PA	10	
DB with I/D	WA	3	Time Constraints, Scope of the project (Size and Complexity)
	NY	3	
	TN	1	
	PA	10	
	WI	1	
DB	HI	4	Time Constraints, Time for bid preparation, Precise cost estimates during the bidding phase, Owner's understanding of the project scope.
	DE	1	
	NV	1	
	PA	10	
A+B with I/D	IA	1	Time constraints
	PA	10	
A+B	DE	1	
Lane Rental with I/D	IA	1	Time constraints
	PA	10	
Lane Rental			
CMR with I/D			
CMR			
CMA with I/D	NE	4	
CMA			

Question 5: Please specify the number of ABC Projects performed using Phased Construction under each of the contracting methods. In phased construction the project is divided into different contracts, which can be carried out separately at the same time to accelerate the construction process. The contracts may also be handed over to different contractors. Please state in the space provided below factors other than time, considered (if any) for selecting phased construction:

Phased construction was found to be one of the most scarcely used strategies for ABC. Washington DOT used phased construction in one of the projects using Design Build project delivery. Nebraska DOT used phased construction in three of their projects using construction management agency method and the factors affecting their decision making were time constraints, time for bid preparation, precise cost estimate during the bidding phase, owner's involvement and control over design, owner's benefit from cost saving, quality of construction, clarity of scope, value engineering, legal restrictions for using alternative project delivery, project financing, and potentials for claims and disputes.

Question 6: Please rate the impact of the following factors on the decision making process of ABC projects (i.e. to accelerate vs. not to accelerate), on a scale of 0 to 10, where 0 represents no impact and 10 represents maximum impact.

Out of 18 SDOT participants, 17 responded to this question. To examine the importance of each factor, average value of the scores provided by the participants on a scale of 0 - 10 were calculated. The resultant average values are shown in Figure 19. Standard deviation and coefficient of variation were calculated and the results are shown in Table 3. Critical infrastructure element, impact on traffic flow, safety, impact on community, and impact on local business and large employers were found to be among the most important decision making factors in ABC projects.

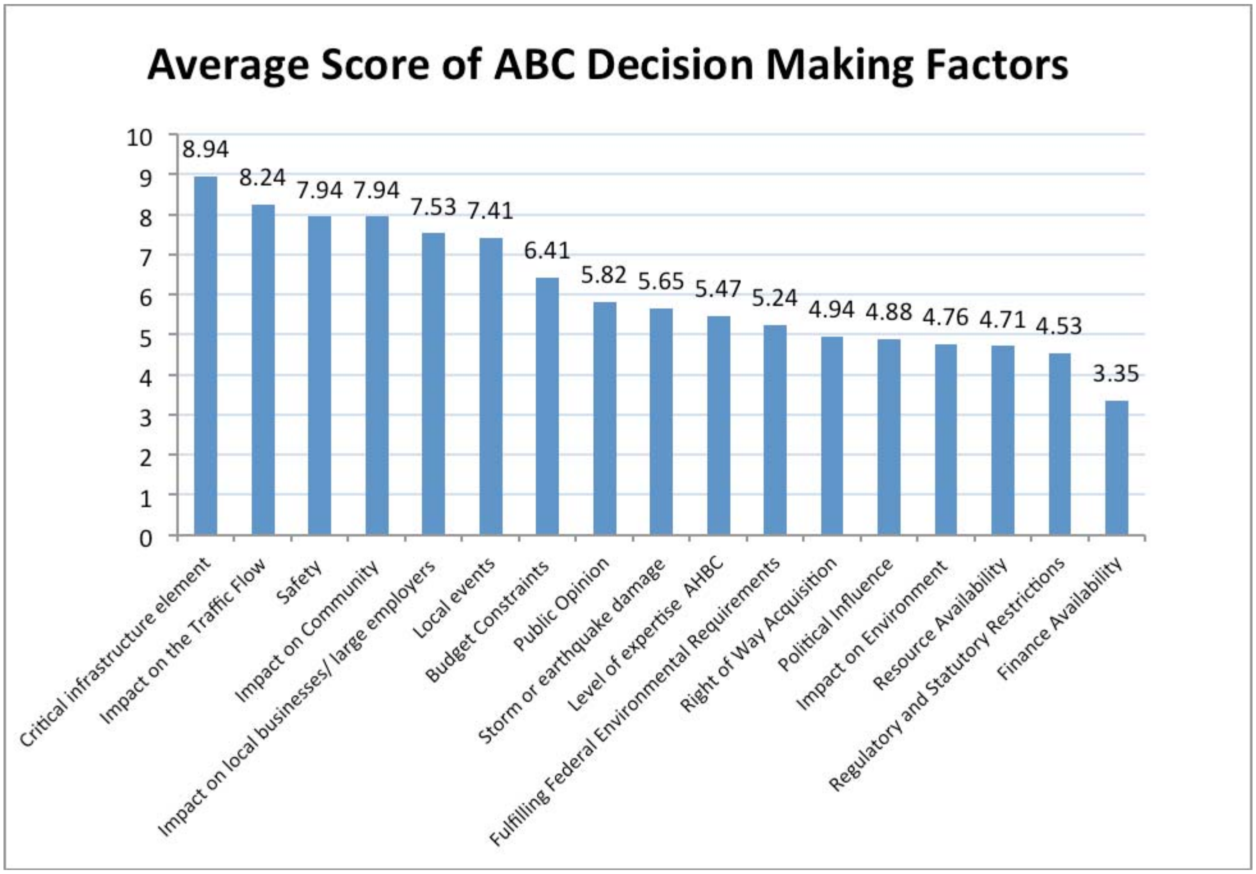


Figure 19: Average Score of ABC Decision Making Factors

Table 3: Summary Statistics of Decision Making Factors

Factors	Average	Standard Deviation (StdDev)	Coefficient of Variation (%) (CV)
Critical infrastructure element (e.g. the only bridge or access to a particular area)	8.94	1.09	12.17
Impact on the Traffic Flow	8.24	1.71	20.82
Safety (Motorist, Construction Worker, and Pedestrian)	7.94	1.89	23.76
Impact on Community (e.g. reduced access, detours, emergency services, etc)	7.94	1.89	23.76
Impact on local businesses and large employers (e.g. airports, postal, package service companies, etc.)	7.53	2.21	29.37
Local events (e.g. project to be completed before school begins, sport events, festivals etc)	7.41	1.46	19.70
Budget Constraints (How much money is available?)	6.41	2.40	37.42
Public Opinion	5.82	1.94	33.38
Storm or earthquake damage	5.65	3.66	64.74
The level of expertise and confidence the agency has in AHBC	5.47	2.58	47.10

Factors	Average	Standard Deviation (StdDev)	Coefficient of Variation (%) (CV)
Fulfilling Federal Environmental Requirements (e.g. National Environmental Policy Act (NEPA) process)	5.24	2.73	52.11
Right of Way Acquisition	4.94	2.79	56.55
Political Influence	4.88	3.08	63.08
Impact on Environment (Ecosystems, Air Pollution and Noise Pollution etc.)	4.76	2.86	60.07
Resource Availability (Labor, Material and Equipment)	4.71	2.71	57.59
Regulatory and Statutory Restrictions	4.53	3.48	76.92
Finance Availability (How fast is the financing available?)	3.35	3.55	105.94

Question 7: Please rate the impact of following challenges/ constraints (on a scale of 0 to 10), which may hinder or delay the ABC process, where 0 represents "Not Challenging" and 10 represents "Most Challenging"

Seventeen participants rated the challenges or constraints, which may hinder or delay the ABC process. The challenges/ constraints were ranked by their average ratings and basic statistics were also calculated and demonstrated as shown in Figure 20 and Table 4. Coordination with railroad facilities while working on or around railroad properties was found to be one of the greatest challenges that could affect ABC decision-making. TxDOT added one more constraint to the ones listed in the questionnaire survey. According to them the largest hindrance was “need”. TxDOT built a significant number of “capacity added” projects to address increasing levels of traffic. These projects typically involved the reconstruction of corridors that involve bridges and measurable roadway reconstruction, where bridges were not on the critical path for the overall project. Other than the cases of replacement due to condition, it was relatively rare to have bridge construction projects where the bridge was the main construction task.

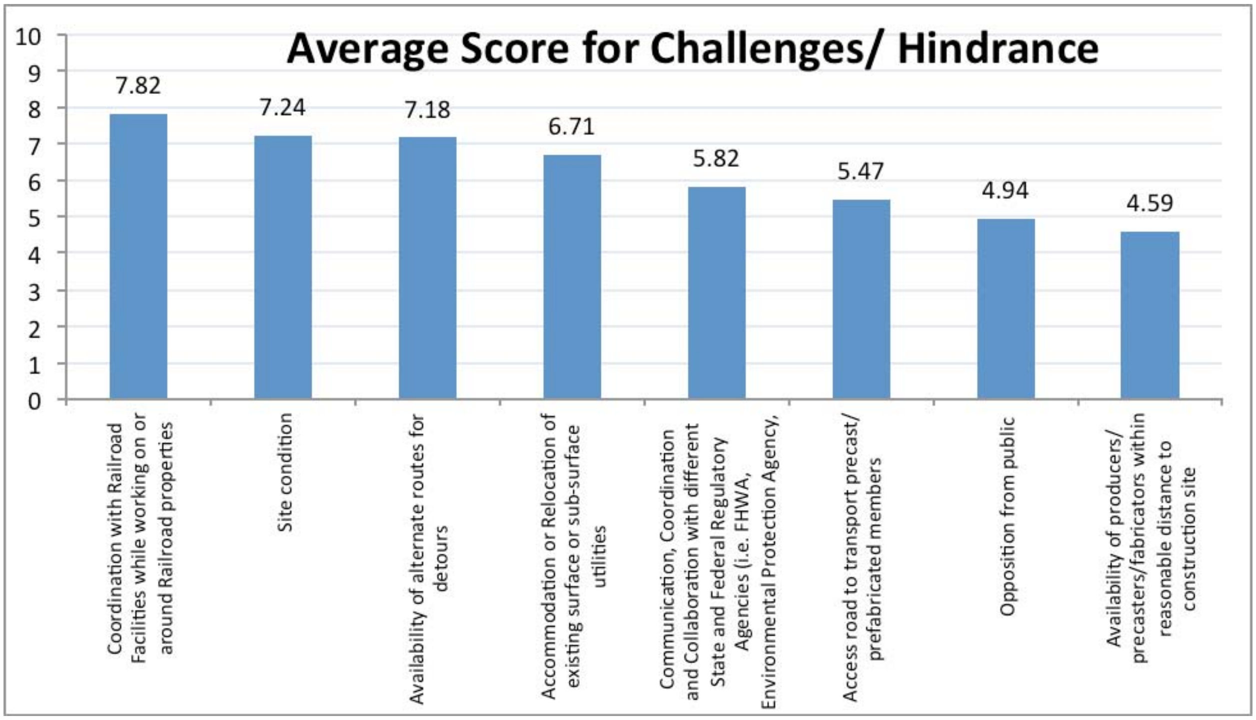


Figure 20: Average Score for Challenges/ Hindrance

Table 4: Summary Statistics of Challenges / Hindrance

Challenges	Average	StDev	CV
Coordination with Railroad Facilities while working on or around Railroad properties	7.823529	2.068674	26.4417
Site condition	7.235294	2.10741	29.1268
Availability of alternate routes for detours	7.176471	2.530694	35.26377
Accommodation or Relocation of existing surface or sub-surface utilities	6.705882	1.723539	25.7019
Communication, Coordination and Collaboration with different State and Federal Regulatory Agencies (i.e. FHWA, Environmental Protection Agency, U.S. Coast Guard, Historic Preservation Agencies etc.)	5.823529	1.944071	33.38304
Access road to transport precast/prefabricated members	5.470588	2.648529	48.41397
Opposition from public	4.941176	3.815603	77.22053
Availability of producers/precasters/fabricators within reasonable distance to construction site	4.588235	3.241505	70.64818
Lack of historical traffic or construction data (e.g. Temporal Traffic Volume, Crash Data, Bridge Inspection Reports, Bridge Performance, ROW acquisition time etc.)	4.529412	3.164602	69.86784

Question 8: Among ABC projects, please indicate the percentage of projects performed under each of the following categories.

Based on the 16 responses received, 87.9 % ABC projects were planned while 12.1% ABC projects were triggered by emergency circumstances. The percentages of Accelerated and Planned ABCs in different states are shown in Figure 21.

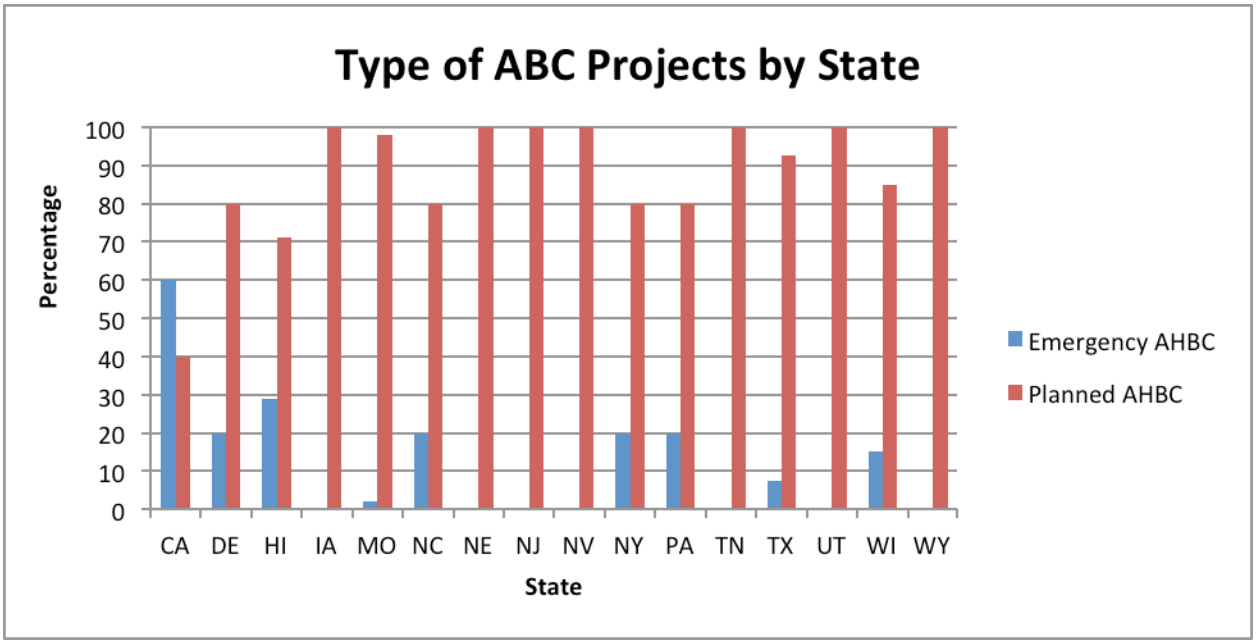


Figure 21: Type of ABC Projects by State

Question 9: Please specify the type of cost(s) considered by your agency for selecting ABC alternatives. Please rank them on a scale of 0 - 5 depending on their importance for the decision making process (where, 0 represents no importance and 5 represents maximum importance).

From the responses obtained it was clear that for both Emergency and Planned ABC, Initial Cost of Construction played an important role in the decision-making. The average score for initial cost was 4 for emergency ABC and 4.11 for planned AHBC. But when it comes to User Costs i.e. due to delays, traffic accidents etc., it can be concluded that it was as important as initial construction in case of emergency AHBC and it came after initial cost in case of planned

ABC. Life Cycle Costs was rated third by the participants for both emergency and planned ABC. The score summary has been presented in Table 5

Table 5: Importance of Cost for different types of ABC

Type of Costs	Average Score	StDev	CV
Emergency ABC			
Initial Cost (Construction Cost)	4.00	1.080	27.003
User Cost (Delays, Traffic Accidents, Etc.)	4.00	1.414	35.355
Life Cycle Costs (Future Maintenance and Repair Costs)	2.91	1.375	47.269
Planned ABC			
Initial Cost (Construction Cost)	4.12	1.054	25.589
User Cost (Delays, Traffic Accidents, Etc.)	3.73	1.486	39.816
Life Cycle Costs (Future Maintenance and Repair Costs)	3.20	1.373	42.913

Question 10: Please prioritize factors considered for calculating user costs on a scale of 0 to 5 (where 0 represents no priority and 5 represents highest priority)

Fifteen responses were obtained for this question. After calculating the average scores, increased travel time due to detours was found to have the maximum priority for calculating user costs closely followed by delayed and increased traffic, safety and disruption of local business due to closure and detours respectively. The results are summarized in Table 6.

Table 6: Scores of Factors affecting User Cost

Factors	Average	StDev	CV
Increased travel time due to detours	4.20	0.775	18.443
Delayed and increased traffic	4.07	0.961	23.635
Safety	3.53	1.727	48.864
Disruption of local business due to closure/ detours	3.20	1.474	46.049

5 ABC Decision Making Process

The ABC decision making model can be of great assistance for the stakeholders during the planning stage. The model has two sequential phases. The first phase assists in higher-level decision-making where the stakeholders can evaluate the priority of ABC over conventional construction using an Analytical Hierarchy Process (AHP) Model. In Phase 1, if ABC is found to be suitable for the particular project, then the decision making process should be continued to Phase 2; otherwise conventional construction method should be selected. Phase 2 deals with selection of appropriate ABC Components or ABC Techniques and Project Delivery using the decision-making flowchart.

5.1 PHASE I

In previous sections, the factors affecting the ABC decision-making process were identified. Out of several multi-attribute decision-making models available, Analytical Hierarchy Process was selected to provide weights to the factors identified.

5.1.1 Analytical Hierarchy Process (AHP) (Saaty 1982)

The analytical hierarchy process is a flexible pair wise comparison model, which can be customized by an individual according to his or her needs depending on the nature of the problem. Thomas Saaty at the Wharton School of Business developed AHP in 1970. AHP incorporates the typical human nature, such as logic, intuition, experience, judgment and personal values in its analysis rather than having a predetermined way of thinking. AHP considers all the possible factors available to reach at a conclusion thus treating the problem as a system (as a whole). Sometimes several iterations might be necessary to get accurate results for complex problems. Factors can be added and revised later in the AHP model, if necessary and thereby perfection can be obtained by running the model several times. AHP also takes into account opinions of different people in the group, thus incorporating the judgment and expertise of the experienced people in the field thereby cross-validating the result.

Some of the benefits of using AHP are as follows:

- It can be used to model a wide range of unstructured problems in an easily understood way by integrating deductive and system approaches.
- It allows interdependence of elements in a system without insisting on linear thinking.
- AHP can incorporate rational thinking and natural tendencies of human mind to sort and group similar elements in every level.
- AHP provides the user with a scale to measure intangible factors and also helps in placing priorities to factors.
- Logical consistency of the judgments is considered while priorities are determined.
- AHP allows users to consider the relative priorities of attributes in a system to select the best alternative among the potential candidates for a given goal.
- AHP helps in understanding the problem in a more systemic way through repetition so as to have a clear definition of the problem to facilitate proper judgment and logical decision-making.

AHP starts with setting up of hierarchies to structure the problem into its constituent parts for a detailed and reasonable decision. There are two objectives for arranging the goals, attributes, issues and stakeholders in a hierarchy i.e. to obtain a clear picture of complex relationships that might be present in the problem and also to ensure that issues are compared in the same order of magnitude in weight or impact on solution. The factors identified should be arranged into homogeneous groups and should relate meaningfully to the next higher level. In this way the relative importance or impact of the elements in the lower levels can be calculated.

After setting up the hierarchic structure as shown in Figure 22, the major factors influencing the outcome of the decision are identified. Then, it is important to find out whether all the factors have equal effects on the outcome or some of them are more important than the others. This is achieved through the process of priority settings. For this purpose, the criteria, sub criteria, properties of the alternatives under consideration along with the alternatives are logically placed in the hierarchy "so that the elements in each level are comparable among themselves in relation to the next higher level." Priorities are then assigned to elements for each criterion of the higher level. Finally, overall priorities are obtained by a final weighing process, which includes multiplying the priorities in the lower level for a certain criterion in the higher level with the weight of the criterion. Weights for all the elements in the level are added to obtain the overall priority of the hierarchy as a whole followed by selection of only the elements having highest impact on decision-making. Elements having little impact might be dropped.

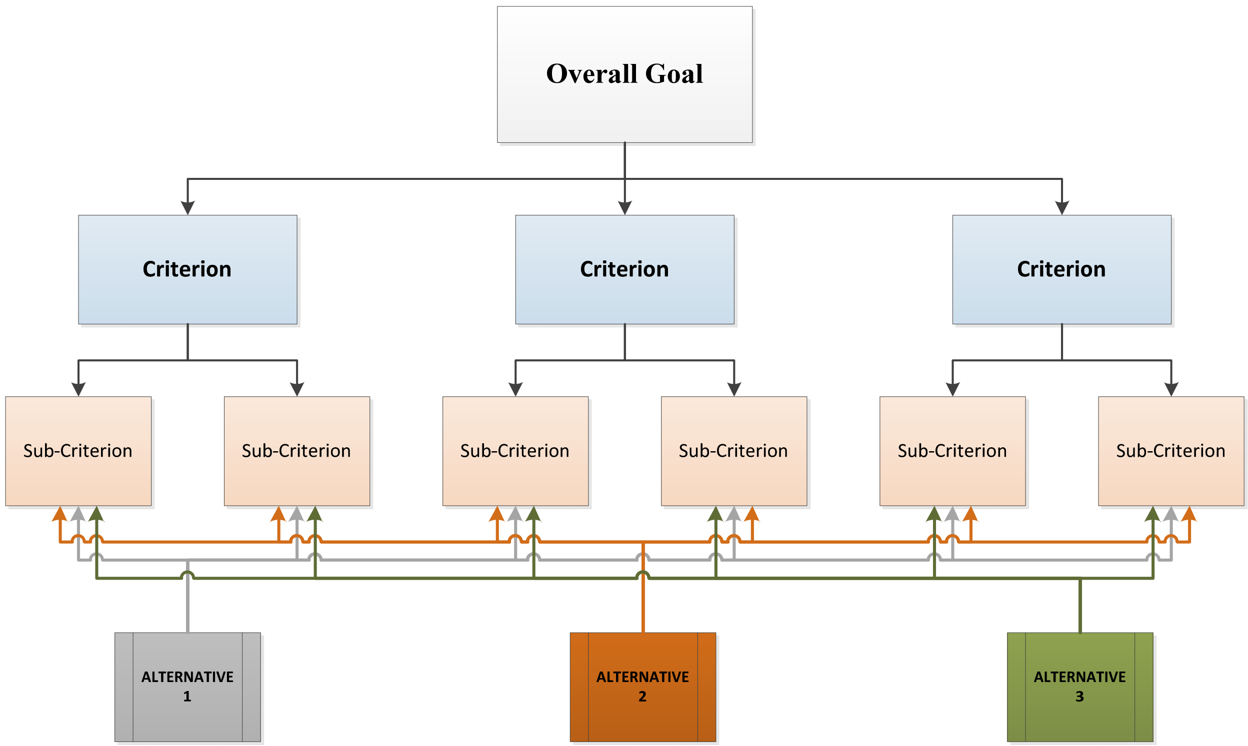


Figure 22: Schematic Representation of Decision Hierarchy (Saaty 1982)

The decision making model using AHP can be prepared using the following steps:

Step 1: Defining the problem and the desired goal

Step 2: Structuring of the hierarchy from an overall managerial point of view as discussed earlier

Step 3: Formation of pair wise comparison matrix featuring the impact of each element on the governing criterion on higher level of the hierarchy. While comparing two elements, it is often preferred to give a judgment indicating the dominance as a whole number. In the matrix the element on the left is "by convention examined regarding its dominance over an element at the top of the matrix." Thus, the matrix is designed so as to have space for the number as well as its reciprocal in diagonally opposite places.

Thus, for setting up priorities of elements, pair wise comparison is used to compare the elements under a certain criterion. Pair wise comparison is preferably done in a matrix format, which depicts two aspect of priority: dominating and dominated. The matrix is a simple but very useful tool for structuring of frameworks, which can be used for:

- Testing Consistency
- Obtaining additional information from all possible comparisons
- Analyzing sensitivity of overall priorities with change in judgment

For the pair wise comparison process, one criterion from the top of the hierarchy is selected first for making the first comparison. Then the elements to be compared (i.e. A1, A2, ... An) are placed both horizontally and vertically on the axis of the matrix as shown in Figure 23.

C	A1	A2	. . .	An
A1	1			
A2		1		
A3				
.				
.				
.				
An				1

Figure 23:Sample Matrix for Pair Wise Comparison

The elements in the left most column (C) is compared against elements in the rest of the columns (A1, A2,... An). The value in each box corresponds to how strong an element is compared to the other element. It should also be kept in mind that the relationships are properly established between the elements in one level with the property of next higher level. According to Saaty, question should be phrased carefully before putting the value. For example, if the problem is dealing with probability criteria then it should be asked "How much more probable or likely is one element than another?" Sometimes elements can be dominated by the property, during which it should found out how one element is stronger than the property in terms of domination, impact and possessiveness.

The matrix is, therefore, filled with numbers representing the relative importance of one element over the other with respect to its property. The scale of pair wise comparison has been shown in Table 7. The scale contains all the integers from 1 to 9, each number denoting a certain level of importance between elements or properties. The best way to use this scale is to decide on the verbal interpretation of the points first and then assigning the corresponding value to a comparison while considering social, psychological, or political problems.

Table 7: The Ratio Scale for AHP Pair-wise Comparison (Saaty 1982)

Intensity of Importance	Definition	Explanation
1	Equal importance of both elements	Two elements contribute equally to the property
3	Weak importance of one element over another	Experience and judgment slightly favor one element over another
5	Essential or strong importance of one element over another	Experience and judgment slightly favor one element over another
7	Demonstrated importance of one element over another	An element is strongly favored and its dominance is demonstrated in practice
9	Absolute importance of one element over another	The evidence favoring one element over another is of highest possible order of affirmation
2,4,6,8	Intermediate values between two adjacent judgments. Intensities 1.1, 1.2, 1.3 etc. can be used for elements that are very close in importance	Compromise is needed between two judgments
Reciprocals	If activity *i* has one of the preceding numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	

Thus, when one element in the matrix is compared with itself, for example A1 with A1, then a value of 1 should be entered. Hence, the diagonal boxes of the matrix should always be filled with 1. The rule is always to compare the first element of a pair i.e. the element in the left hand column with the second i.e. the one in the row on the top. The reciprocal values are just the vice versa of the former.

Step 4: Obtaining the judgment for preparing the set of matrix. Expert opinion can be obtained regarding the importance or impact level of the elements under consideration. If there are multiple judgments, their geometric mean can be used for decision-making.

Step 5: Collecting all the pair wise comparison data, which includes unit value in the main diagonal and reciprocals below the diagonal. This is followed by obtaining the priority value and testing the consistency.

Step 6: Completing steps 3, 4, and 5 for all levels and categories in the hierarchy

Step 7: Using of "hierarchical synthesis" to assign weights to the priority vectors with the weights of the criteria. All the weights corresponding to those in the next lower level are then added and the overall priority vector for the lowest level of hierarchy is obtained. In case multiple outcomes, average values may be used.

Step 8: Evaluating the consistency for the whole hierarchy. Each consistency index after being calculated are multiplied by the priority of the corresponding criterion and then the products are added. The sum is then divided by using random consistency index "corresponding to the dimensions of each matrix as before". The consistency ratio should be less than or equal to 10 percent. If the value is more than 10 percent, then it means quality of the information is poor and the structure of the problem or the way the questions are posed should be improved. Sometimes, it might be necessary to revise Step 2 completely to make sure whether similar elements are not put together under the same criterion.

5.1.2 ABC vs. Traditional Decision Making Model using AHP

5.1.2.1 Defining the Problem and the Desired Goal

The objective of this phase of the decision-making problem is to evaluate the utilizing of ABC versus conventional construction methods. The goal of any typical bridge construction is to complete the project in least amount of time in an economical manner with minimum effect on the existing traffic, nearby community, business and surrounding environment without compromising on safety.

5.1.2.2 Structuring of Hierarchy from an overall managerial point of view

The factors most likely to have an impact on the decision making process are identified. Seventeen factors were listed as criteria under the overall goal. The hierarchy created is presented in Figure 24.

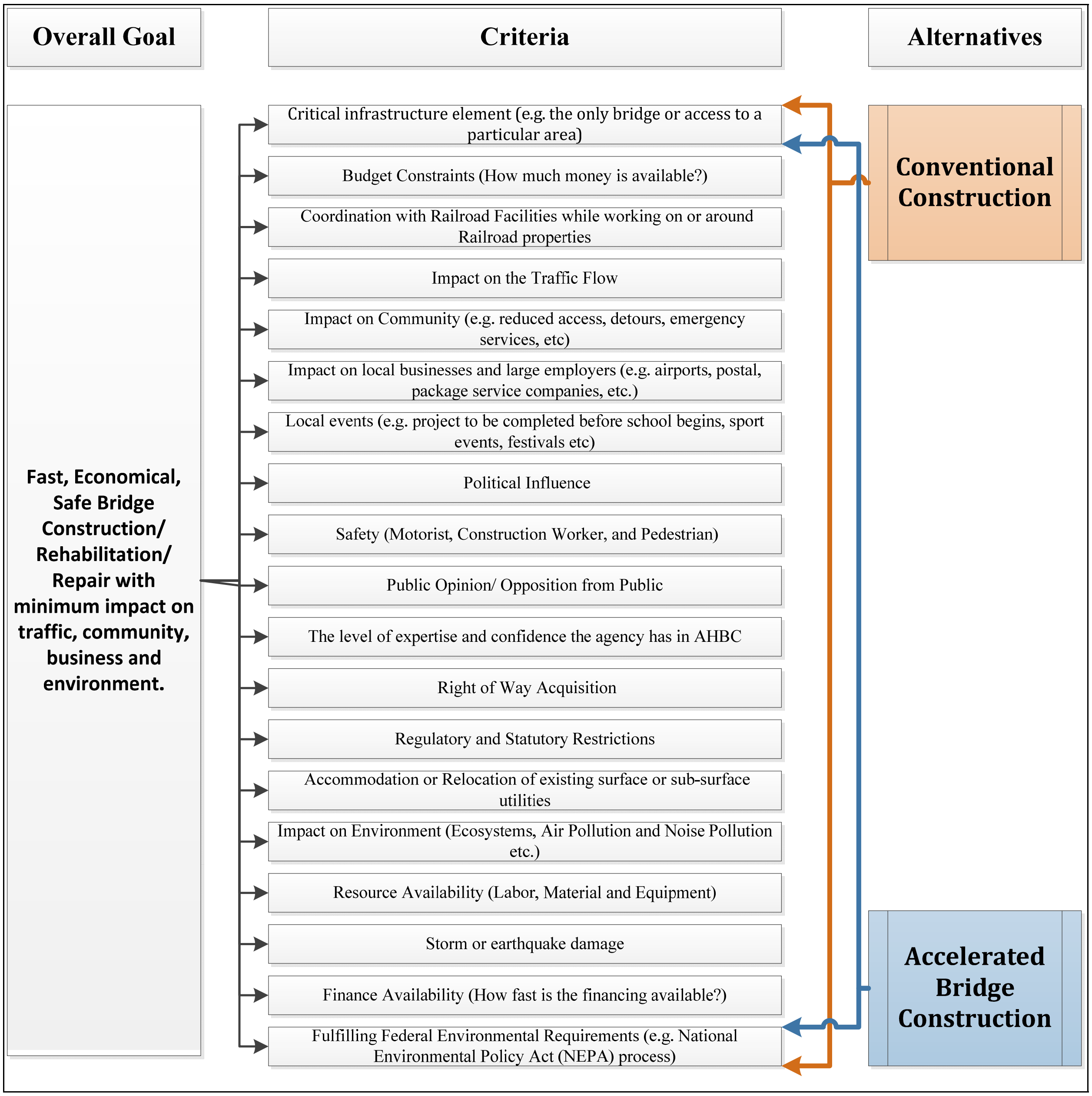


Figure 24: Hierarchy for ABC Decision Making Process

5.1.2.3 Formation of Pair-wise Comparison Matrix

The factors identified are compared with each other in a pair wise format to determine their relative importance among each other. For example A/B represents the pair-wise comparison of 'Critical Infrastructure Element' over 'Budget Constrain". If critical infrastructure factor is more important than budget constrain, then A/B can be written as 2/1 or 3/1 so on depending on the difference of the importance between the factors. As depicted in Figure 25, the figures below the diagonal of the matrix represent the reciprocal of the corresponding figure in the matrix above the diagonal.

PAIR-WISE COMPARISON MATRIX		A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
Critical infrastructure element	A	1	A/B	A/C	A/D	A/E	A/F	A/G	A/H	A/I	A/J	A/K	A/L	A/M	A/N	A/O	A/P	A/Q	A/R	A/S
Budget Constraints	B	B/A	1	B/C	B/D	B/E	B/F	B/G	B/H	B/I	B/J	B/K	B/L	B/M	B/N	B/O	B/P	B/Q	B/R	B/S
Coordination with Railroad Facilities	C	C/A	C/B	1	C/D	C/E	C/F	C/G	C/H	C/I	C/J	C/K	C/L	C/M	C/N	C/O	C/P	C/Q	C/R	C/S
Impact on the Traffic Flow	D	D/A	D/B	D/C	1	D/E	D/F	D/G	D/H	D/I	D/J	D/K	D/L	D/M	D/N	D/O	D/P	D/Q	D/R	D/S
Impact on Community	E	E/A	E/B	E/C	E/D	1	E/F	E/G	E/H	E/I	E/J	E/K	E/L	E/M	E/N	E/O	E/P	E/Q	E/R	E/S
Impact on local businesses/ large employers	F	F/A	F/B	F/C	F/D	F/E	1	F/G	F/H	F/I	F/J	F/K	F/L	F/M	F/N	F/O	F/P	F/Q	F/R	F/S
Local events	G	G/A	G/B	G/C	G/D	G/E	G/F	1	G/H	G/I	G/J	G/K	G/L	G/M	G/N	G/O	G/P	G/Q	G/R	G/S
Political Influence	H	H/A	H/B	H/C	H/D	H/E	H/F	H/G	1	H/I	H/J	H/K	H/L	H/M	H/N	H/O	H/P	H/Q	H/R	H/S
Safety	I	I/A	I/B	I/C	I/D	I/E	I/F	I/G	I/H	1	I/J	I/K	I/L	I/M	I/N	I/O	I/P	I/Q	I/R	I/S
Public Opinion/ Opposition from Public	J	J/A	J/B	J/C	J/D	J/E	J/F	J/G	J/H	J/I	1	J/K	J/L	J/M	J/N	J/O	J/P	J/Q	J/R	J/S
Expertise/ confidence in AHBC	K	K/A	K/B	K/C	K/D	K/E	K/F	K/G	K/H	K/I	K/J	1	K/L	K/M	K/N	K/O	K/P	K/Q	K/R	K/S
Right of Way Acquisition	L	L/A	L/B	L/C	L/D	L/E	L/F	L/G	L/H	L/I	L/J	L/K	1	L/M	L/N	L/O	L/P	L/Q	L/R	L/S
Regulatory and Statutory Restrictions	M	M/A	M/B	M/C	M/D	M/E	M/F	M/G	M/H	M/I	M/J	M/K	M/L	1	M/N	M/O	M/P	M/Q	M/R	M/S
Accommodation/ Relocation of utilities	N	N/A	N/B	N/C	N/D	N/E	N/F	N/G	N/H	N/I	N/J	N/K	N/L	N/M	1	N/O	N/P	N/Q	N/R	N/S
Impact on Environment	O	O/A	O/B	O/C	O/D	O/E	O/F	O/G	O/H	O/I	O/J	O/K	O/L	O/M	O/N	1	O/P	O/Q	O/R	O/S
Resource Availability	P	P/A	P/B	P/C	P/D	P/E	P/F	P/G	P/H	P/I	P/J	P/K	P/L	P/M	P/N	P/O	1	P/Q	P/R	P/S
Storm or earthquake damage	Q	Q/A	Q/B	Q/C	Q/D	Q/E	Q/F	Q/G	Q/H	Q/I	Q/J	Q/K	Q/L	Q/M	Q/N	Q/O	Q/P	1	Q/R	Q/S
Finance Availability	R	R/A	R/B	R/C	R/D	R/E	R/F	R/G	R/H	R/I	R/J	R/K	R/L	R/M	R/N	R/O	R/P	R/Q	1	R/S
Fulfilling Federal Environmental Requirement	S	S/A	S/B	S/C	S/D	S/E	S/F	S/G	S/H	S/I	S/J	S/K	S/L	S/M	S/N	S/O	S/P	S/Q	S/R	1

Figure 25: Pair-wise Comparison of the Factors

5.1.2.4Obtaining the judgment for preparing the set of matrix

A second survey was prepared and this time it was sent only to the NYSDOT officials to customize the decision making model according to NYSDOT needs. The survey constituted all the factors identified that might affect the decision making process (see Appendix I). The officials were asked to rate the factors on a scale of 1 to 9, so as to reflect these factors' relevance towards selecting Accelerated Bridge Construction over Traditional Construction. Once the score for each factor was obtained, geometric means of the scores were obtained as suggested in Saaty 1982. To find the relative importance of the factors, Ratio of their corresponding importance value to the sum of all the factors' importance values were calculated. For accurate results, the relative weights were kept in decimal rather than rounding off to the nearest whole number. The matrix is shown in Figure 26.

PAIR-WISE COMPARISON MATRIX		7.5	7.5	7.2	6.8	6.2	6.2	5.7	5.3	4.9	4.6	4.6	4.2	4.2	4	3.5	3.4	3.3	3	2.9
Critical infrastructure element	7.5	1	7.5/7.5	7.5/7.2	7.5/6.8	7.5/6.2	7.5/6.2	7.5/5.7	7.5/5.3	7.5/4.9	7.5/4.6	7.5/4.6	7.5/4.2	7.5/4.2	7.5/4	7.5/3.5	7.5/3.4	7.5/3.3	7.5/3	7.5/2.9
Budget Constraints	7.5	7.5/7.5	1	7.5/7.2	7.5/6.8	7.5/6.2	7.5/6.2	7.5/5.7	7.5/5.3	7.5/4.9	7.5/4.6	7.5/4.6	7.5/4.2	7.5/4.2	7.5/4	7.5/3.5	7.5/3.4	7.5/3.3	7.5/3	7.5/2.9
Coordination with Railroad Facilities	7.2	7.2/7.5	7.2/7.5	1	7.2/6.8	7.2/6.2	7.2/6.2	7.2/5.7	7.2/5.3	7.2/4.9	7.2/4.6	7.2/4.6	7.2/4.2	7.2/4.2	7.2/4	7.2/3.5	7.2/3.4	7.2/3.3	7.2/3	7.2/2.9
Impact on the Traffic Flow	6.8	6.8/7.5	6.8/7.5	6.8/7.2	1	6.8/6.2	6.8/6.2	6.8/5.7	6.8/5.3	6.8/4.9	6.8/4.6	6.8/4.6	6.8/4.2	6.8/4.2	6.8/4	6.8/3.5	6.8/3.4	6.8/3.3	6.8/3	6.8/2.9
Impact on Community	6.2	6.2/7.5	6.2/7.5	6.2/7.2	6.2/6.8	1	6.2/6.2	6.2/5.7	6.2/5.3	6.2/4.9	6.2/4.6	6.2/4.6	6.2/4.2	6.2/4.2	6.2/4	6.2/3.5	6.2/3.4	6.2/3.3	6.2/3	6.2/2.9
Impact on local businesses/ large employers	6.2	6.2/7.5	6.2/7.5	6.2/7.2	6.2/6.8	6.2/6.2	1	6.2/5.7	6.2/5.3	6.2/4.9	6.2/4.6	6.2/4.6	6.2/4.2	6.2/4.2	6.2/4	6.2/3.5	6.2/3.4	6.2/3.3	6.2/3	6.2/2.9
Local events	5.7	5.7/7.5	5.7/7.5	5.7/7.2	5.7/6.8	5.7/6.2	5.7/6.2	1	5.7/5.3	5.7/4.9	5.7/4.6	5.7/4.6	5.7/4.2	5.7/4.2	5.7/4	5.7/3.5	5.7/3.4	5.7/3.3	5.7/3	5.7/2.9
Political Influence	5.3	5.3/7.5	5.3/7.5	5.3/7.2	5.3/6.8	5.3/6.2	5.3/6.2	5.3/5.7	1	5.3/4.9	5.3/4.6	5.3/4.6	5.3/4.2	5.3/4.2	5.3/4	5.3/3.5	5.3/3.4	5.3/3.3	5.3/3	5.3/2.9
Safety	4.9	4.9/7.5	4.9/7.5	4.9/7.2	4.9/6.8	4.9/6.2	4.9/6.2	4.9/5.7	4.9/5.3	1	4.9/4.6	4.9/4.6	4.9/4.2	4.9/4.2	4.9/4	4.9/3.5	4.9/3.4	4.9/3.3	4.9/3	4.9/2.9
Public Opinion/ Opposition from Public	4.6	4.6/7.5	4.6/7.5	4.6/7.2	4.6/6.8	4.6/6.2	4.6/6.2	4.6/5.7	4.6/5.3	4.6/4.9	1	4.6/4.6	4.6/4.2	4.6/4.2	4.6/4	4.6/3.5	4.6/3.4	4.6/3.3	4.6/3	4.6/2.9
Expertise/ confidence in AHBC	4.6	4.6/7.5	4.6/7.5	4.6/7.2	4.6/6.8	4.6/6.2	4.6/6.2	4.6/5.7	4.6/5.3	4.6/4.9	4.6/4.6	1	4.6/4.2	4.6/4.2	4.6/4	4.6/3.5	4.6/3.4	4.6/3.3	4.6/3	4.6/2.9
Right of Way Acquisition	4.2	4.2/7.5	4.2/7.5	4.2/7.2	4.2/6.8	4.2/6.2	4.2/6.2	4.2/5.7	4.2/5.3	4.2/4.9	4.2/4.6	4.2/4.6	1	4.2/4.2	4.2/4	4.2/3.5	4.2/3.4	4.2/3.3	4.2/3	4.2/2.9
Regulatory and Statutory Restrictions	4.2	4.2/7.5	4.2/7.5	4.2/7.2	4.2/6.8	4.2/6.2	4.2/6.2	4.2/5.7	4.2/5.3	4.2/4.9	4.2/4.6	4.2/4.6	4.2/4.2	1	4.2/4	4.2/3.5	4.2/3.4	4.2/3.3	4.2/3	4.2/2.9
Accommodation/ Relocation of utilities	4	4/7.5	4/7.5	4/7.2	4/6.8	4/6.2	4/6.2	4/5.7	4/5.3	4/4.9	4/4.6	4/4.6	4/4.2	4/4.2	1	4/3.5	4/3.4	4/3.3	4/3	4/2.9
Impact on Environment	3.5	3.5/7.5	3.5/7.5	3.5/7.2	3.5/6.8	3.5/6.2	3.5/6.2	3.5/5.7	3.5/5.3	3.5/4.9	3.5/4.6	3.5/4.6	3.5/4.2	3.5/4.2	3.5/4	1	3.5/3.4	3.5/3.3	3.5/3	3.5/2.9
Resource Availability	3.4	3.4/7.5	3.4/7.5	3.4/7.2	3.4/6.8	3.4/6.2	3.4/6.2	3.4/5.7	3.4/5.3	3.4/4.9	3.4/4.6	3.4/4.6	3.4/4.2	3.4/4.2	3.4/4	3.4/3.5	1	3.4/3.3	3.4/3	3.4/2.9
Storm or earthquake damage	3.3	3.3/7.5	3.3/7.5	3.3/7.2	3.3/6.8	3.3/6.2	3.3/6.2	3.3/5.7	3.3/5.3	3.3/4.9	3.3/4.6	3.3/4.6	3.3/4.2	3.3/4.2	3.3/4	3.3/3.5	3.3/3.4	1	3.3/3	3.3/2.9
Finance Availability	3	3/7.5	3/7.5	3/7.2	3/6.8	3/6.2	3/6.2	3/5.7	3/5.3	3/4.9	3/4.6	3/4.6	3/4.2	3/4.2	3/4	3/3.5	3/3.4	3/3.3	1	3/2.9
Fulfilling Federal Environmental Requirements	2.9	2.9/7.5	2.9/7.5	2.9/7.2	2.9/6.8	2.9/6.2	2.9/6.2	2.9/5.7	2.9/5.3	2.9/4.9	2.9/4.6	2.9/4.6	2.9/4.2	2.9/4.2	2.9/4	2.9/3.5	2.9/3.4	2.9/3.3	2.9/3	1

Figure 26: Pair-wise comparison of the factors (with scores)

5.1.2.5 Calculate Eigen Values and Eigenvectors to find Relative Weights

The Eigen vectors of the factors were calculated to determine the relative weights of the criteria. The formula for calculating Eigenvector with the principal Eigen Value of a matrix 'A' was as follows:

$$\lim_{k \to \infty} \left(\frac{A^k e}{e^T A^K e} \right) = Cw$$

Where:

e = Column Vector

e^T = Transpose of Column Vector e

C = Constant

w = Eigen Vector

Several approximate methods have been developed by Saaty to calculate the eigenvectors. Among these, Saaty recommended the Average of Normalized Column technique as it gives the most accurate approximation of the Eigen Vectors. The formula used for calculating the Average of Normalized Column was summarized as follows:

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{k=1}^{n} a_{kj}} \quad \textbf{(1)}$$

Where,

n = Number of elements in the row

i = Number of Factors

j= Number of Rows

k= Number of Columns

The steps for calculation are as follows and can be carried out on an excel spreadsheet:

i. Converting the fraction pair-wise comparison numbers to their decimal equivalents.
ii. Addition of each element in the column.
iii. Formation of normalized matrix by dividing each element by its column total.
iv. Adding the elements of rows of the normalized matrix.

v. Finding the average of the normalized columns by dividing the row sum by the number of elements in the row.

5.1.2.6 Check consistency of the Matrices

The reliability of judgment of the decision makers needs to be checked at various stages to find the consistency of the matrices. For a positive reciprocal matrix to be consistent, the largest Eigen value should be equal to the order of the matrix (n). The positive reciprocal matrix is said to be inconsistent if the Eigen value is greater than the order of the matrix. Consistency of the matrix can be measured by the consistency index (CI), which can be calculated using the Equation 2 (Saaty 1980)

$$\textbf{Consistency Index} = (\lambda max - n)/ (n-1) \qquad \textbf{(2)}$$

Where,

λmax = Maximum Eigen Value

n = Order of the matrix

If the matrix is perfectly consistent then the CI will be zero as the maximum Eigen value will be equal to the order of the matrix. Comparison matrices of quantitative factors are found to be more consistent than that of the matrices of qualitative factors. For example, if criteria A is slightly more important than B (say 2/1) and also more important than criteria C (say 5/1), then theoretically, criteria C should be more important than criteria B, which might not be the case always. However, for AHP, perfectly consistent matrix is not mandatory and the CI can be greater than zero. In ABC vs. Traditional decision-making model, as we have considered exact ratios of the weights, the CI came out to be zero.

Maximum Eigen value to estimate the Consistency Index can be calculated using following steps:

1. Multiplying each column in the original matrix by the Eigen vector associated with the criteria of the column.
2. Summing the rows of the new matrix
3. Dividing sum of each rows by the corresponding value of the weight vector
4. Summing and averaging the column containing the summed rows will give an approximate estimate of the maximum Eigen value (McIntyre 1996)

The consistency of the judgment can be quantified by Consistency Ratio (CR), which is calculated using the following equation:

Consistency Ratio = Consistency Index/ Random Index **(3)**

Saaty created 500 positive reciprocal matrices of different orders from 1x1 to 15x15 and calculated the Consistency Index of each matrix. Saaty then estimated random Index after studying the probability distribution of the CIs calculated. The values are presented in Table 8.

Table 8: Random Index for Matrix Size 1 to 15 (Saaty 1980)

Matrix Size	Random Index
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

Alonso and Lamata (2006) conducted some further simulations to find the RI for the matrices of order to 16 to 39. The values are listed in Table 9

Table 9: Random Index for Matrix Size 16 to 39 (Alonso and Lamata 2006)

Matrix Size	Random Index
16	1.59
17	1.61
18	1.62
19	1.63
20	1.63
21	1.64
22	1.65
23	1.65
24	1.66
25	1.66
26	1.67
27	1.67
29	1.68
30	1.68
31	1.68
32	1.69
33	1.69
34	1.69

Matrix Size	Random Index
35	1.69
36	1.70
37	1.70
38	1.70
39	1.70

While making a large number of comparisons it should be kept in mind that minimizing consistency ratio does not necessarily mean having a better judgment. Although good decisions are mostly based on consistent judgment, but the vice-versa is not always true. Generally the permissible upper limit for CR is considered to be 0.10 (Saaty 1980). If the CR is found to be above 0.10 then the pair-wise comparison values should be revised till CR comes below 0.10.

5.1.2.7Final Evaluation of the Alternatives for Decision Making

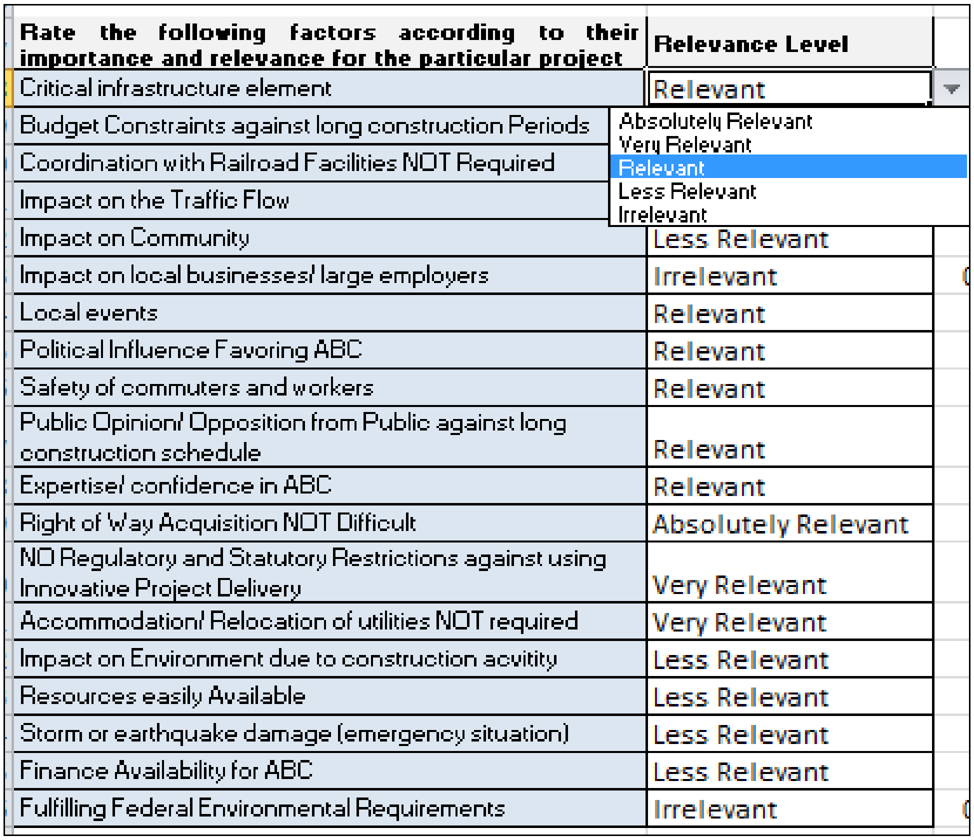
The factors having an impact on the ABC decision-making process will have different preferences in different projects. It is, therefore, necessary to evaluate these factors, this time in a project specific manner to come up with the most suitable alternative for the project. Thus, each alternative is again compared in a pair-wise manner to understand the level of effectiveness that could be achieved for objective(s) stated in each criterion. Figure 27 shows the comparison matrix of the two alternatives for the factor 'Critical Infrastructure Element' where W_A and W_T are the scores entered by the user.

	ABC	Traditional
ABC	1	W_A/W_T
Traditional	W_T/W_A	1

Figure 27: Pair-wise Comparison for "Critical Infrastructure Element"

All the steps from sections 5.1.2.2 to 5.1.2.6 were repeated.

In this step, a scale was prepared to evaluate the importance of each criterion or factor for the project under consideration. These were the same set of factors, identified in the initial stages of AHP and affecting the ABC decision-making process. The model provides the user with a dropdown menu of options (as shown in Figure 28) to select the level of relevance of each criterion to the particular project. The number of options were limited to five as suggested by FHWA officials and also as observed in some other studies such as Pan (2008).



Rate the following factors according to their importance and relevance for the particular project	Relevance Level
Critical infrastructure element	Relevant
Budget Constraints against long construction Periods	Absolutely Relevant Very Relevant
Coordination with Railroad Facilities NOT Required	Relevant
Impact on the Traffic Flow	Less Relevant Irrelevant
Impact on Community	Less Relevant
Impact on local businesses/ large employers	Irrelevant
Local events	Relevant
Political Influence Favoring ABC	Relevant
Safety of commuters and workers	Relevant
Public Opinion/ Opposition from Public against long construction schedule	Relevant
Expertise/ confidence in ABC	Relevant
Right of Way Acquisition NOT Difficult	Absolutely Relevant
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	Very Relevant
Accommodation/ Relocation of utilities NOT required	Very Relevant
Impact on Environment due to construction acvitity	Less Relevant
Resources easily Available	Less Relevant
Storm or earthquake damage (emergency situation)	Less Relevant
Finance Availability for ABC	Less Relevant
Fulfilling Federal Environmental Requirements	Irrelevant

Figure 28: User Interface to Enter Relevance of the Factors for a Particular Project

The options with its corresponding values are listed in Table 10. The scores corresponding to the options selected by the user were used for the pair-wise comparison of the alternatives for each criterion as mentioned earlier in this section.

Table 10: Relevance Level Score

Relevance Level	Score
Absolutely Relevant	9
Very Relevant	5
Relevant	1
Less Relevant	1/5
Irrelevant	1/9

Eigen vectors representing the relevance of the criteria to the project were then obtained. The final score for each alternative was calculated by using the equation 3:

$$\lambda = \sum_{i=1}^{n} (\lambda_{Fi} * \lambda_{Ai}) \qquad (3)$$

Where,

λ = The overall score of the alternative

i = The number of factors/ criteria

λ_{Fi} = Eigen Vector/ Weight obtained from pair-wise comparison of factors

λ_{Ai} = Eigen Vector/ Weight obtained from pair-wise comparison of alternative for each factor

The alternative having the highest score is considered to be most suitable for the project.

5.2 Phase II

In Phase I, once ABC is selected as a viable option for the particular project, Phase II of the model can be used to select the most appropriate construction technique and project delivery. Flowchart models are prepared for this purpose.

5.2.1 ABC Techniques Decision Making Model

The model was prepared using the information obtained from the literature. At first the ABC components were shortlisted based on the scope of the project i.e. whether it was rehabilitation or repair or replacement of existing bridge or construction of new bridge. The techniques to be used for accelerated construction depends mostly on the type of construction i.e. whether the construction is over the water body or wet land or whether the bridge is over roadway with existing traffic or railroad or transit. The complete model is presented in Figure 29.

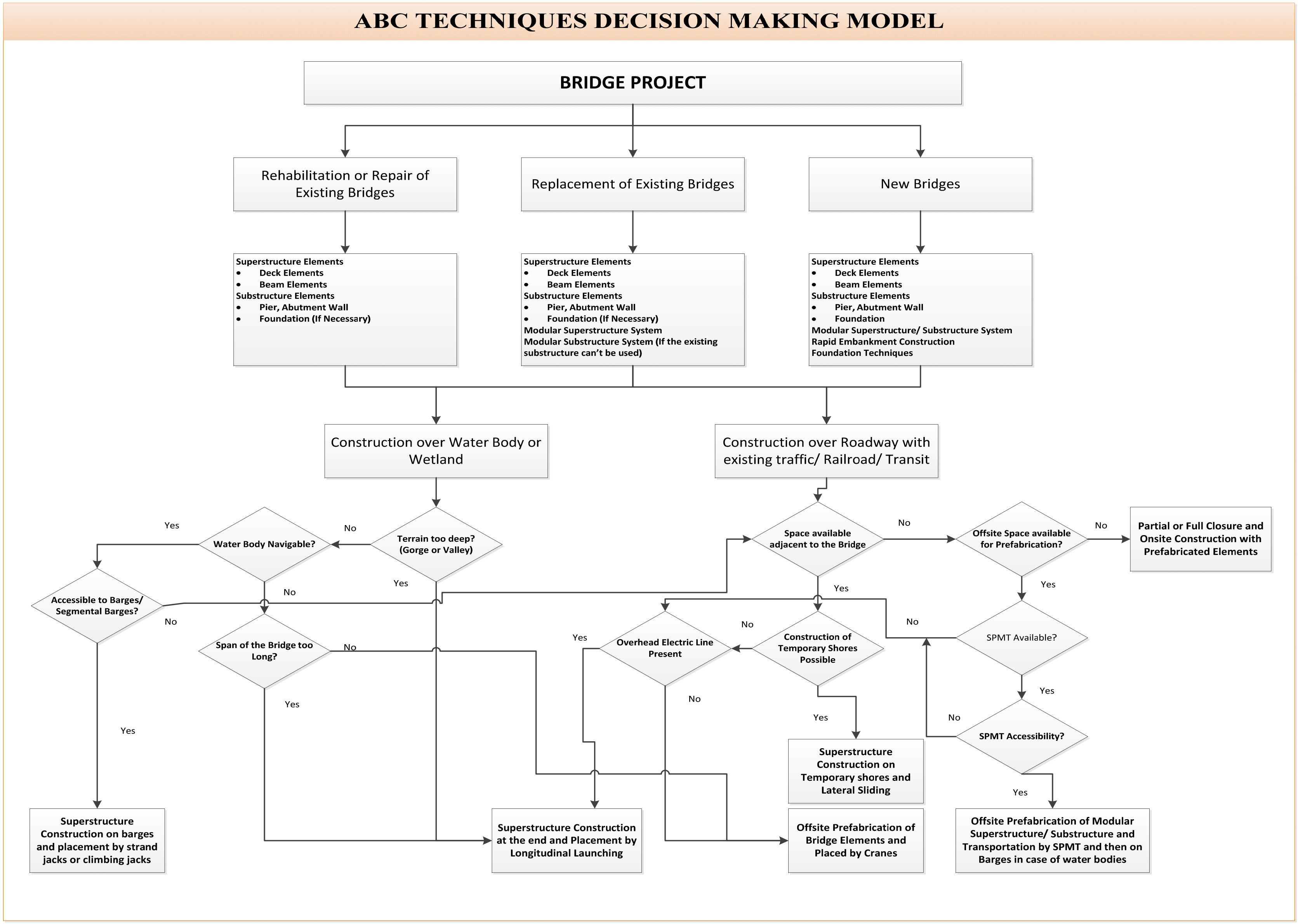


Figure 29: ABC Techniques Decision Making Model

5.2.2 Project Delivery System Decision Making Model

A flowchart model was also prepared for selecting the suitable project delivery system. The project deliveries to choose from are Design Bid Build (DBB), Construction Management at Risk (CMR), Construction Management as Agency (CMA) and Design Build (DB). It has been observed from the literature that contracting provisions like A+B Contracting, Incentive/ Disincentive (I/D), Advanced Purchasing and Phased Construction can be used with any PDS or can be used on their own depending on the project requirements. For example, CalTrans used A+B with I/D for I-40 bridge replacement in Mojave Desert to emphasize on the importance of time (NCHRP 2009b). Alabama DOT used DBB with I/D for replacing the I-65/ I-59 interchange bridge that was damaged by a fire caused due to the crash of a gasoline filled tanker truck. The I-10 bridge over Escambia Bay in Pensacola, Florida, damaged by Hurricane Ivan, was repaired under a DB contract with A+B and I/D provisions (NCHRP 2009b). The Queen Isabella Causeway to South Padre Island, Texas was replaced using a negotiated lumpsum emergency contract with I/D. Although the contract resembled a DB delivery, it was actually a DBB contract with I/D.

The PDS decision-making model is presented in Figure 30.

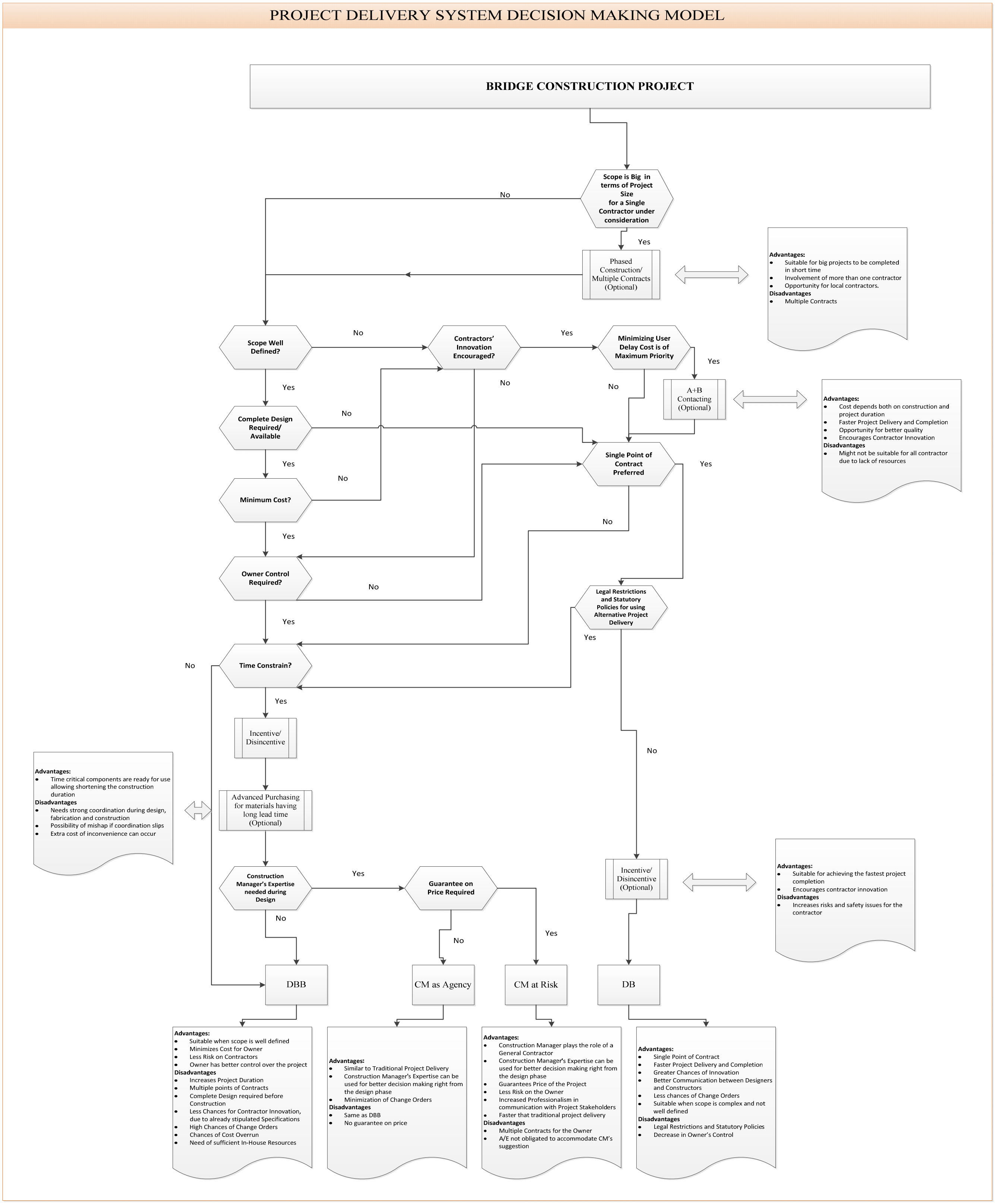


Figure 30: Project Delivery System Decision Making Model

6 Case Studies

The AHP model prepared to assist the selection between ABC and Traditional construction was implemented in several ABC projects in the state of New York. As very few projects were in the construction phase, the model had to be implemented on already constructed bridge projects using the ABC method to determine the validity of the model. The necessary information for the model was obtained from the NYSDOT official involved in the project. In most cases, the results obtained from the model matched with the decision of the NYSDOT official regarding the selection of the ABC option. The Case Studies considered are listed below.

6.1 Cross Bay over North Channel 87 viaduct:

The bridge is 2842 feet long, and consists of 34 spans, and has 3 lanes. Some of the elements used for the project are Cylinder Piles, Precast Pier Caps forms, Pre-stressed I beams, Diaphragm forms, Partial depth precast deck panels. One of the issues faced was cracking tendency of the deck joints. Although the project was already completed, the ABC vs. Traditional decision-making model was validated by entering the inputs from the NYSDOT officials. The model suggested use of ABC for the project. The model inputs and the results are presented in Tables 11 and 12. Table 12 shows the interface where the user is asked to select how relevant or important each factor was for this particular project. Depending on these inputs, points for both ABC and Traditional construction alternative is obtained for each factor. The alternative with higher point is considered to be more suitable for the project. For better visualization of the importance the factors for each alternative, the ABC model also provides a graphical representation of the results as shown in Figure 31.

Table 11: ABC vs. Traditional Decision Making Model Inputs for Cross Bay over North Channel 87 viaduct, NY

Rate the following factors according to their importance and relevance for the particular project	Relevance Level
Critical infrastructure element	Relevant
Budget Constraints against long construction Periods	Less Relevant
Coordination with Railroad Facilities NOT Required	Relevant
Impact on the Traffic Flow	Relevant
Impact on Community	Absolutely Relevant
Impact on local businesses/ large employers	Absolutely Relevant
Local events	Relevant
Political Influence Favoring ABC	Very Relevant
Safety of commuters and workers	Very Relevant

Rate the following factors according to their importance and relevance for the particular project	Relevance Level
Public Opinion/ Opposition from Public against long construction schedule	Very Relevant
Expertise/ confidence in ABC	Relevant
Right of Way Acquisition NOT Difficult	Absolutely Relevant
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	Relevant
Accommodation/ Relocation of utilities NOT required	Less Relevant
Impact on Environment due to construction activity	Irrelevant
Resources easily Available	Irrelevant
Storm or earthquake damage (emergency situation)	Less Relevant
Finance Availability for ABC	Relevant
Fulfilling Federal Environmental Requirements	Relevant

Table 12: ABC Model Results for Cross Bay over North Channel 87 viaduct, NY

Factors Favoring ABC	Weights	Traditional	ABC	Weighted Traditional	Weighted ABC
Critical infrastructure element	0.079	0.500	0.500	0.040	0.040
Budget Constraints against long construction Periods	0.079	0.833	0.167	0.066	0.013
Coordination with Railroad Facilities NOT Required	0.076	0.500	0.500	0.038	0.038
Impact on the Traffic Flow	0.072	0.500	0.500	0.036	0.036
Impact on Community	0.065	0.100	0.900	0.007	0.059
Impact on local businesses/ large employers	0.065	0.100	0.900	0.007	0.059
Local events	0.060	0.500	0.500	0.030	0.030
Political Influence Favoring ABC	0.056	0.167	0.833	0.009	0.047
Safety of commuters and workers	0.052	0.167	0.833	0.009	0.043
Public Opinion/ Opposition from Public against long construction schedule	0.048	0.167	0.833	0.008	0.040
Expertise/ confidence in ABC	0.048	0.500	0.500	0.024	0.024
Right of Way Acquisition NOT Difficult	0.044	0.100	0.900	0.004	0.040
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	0.044	0.500	0.500	0.022	0.022
Accommodation/ Relocation of utilities NOT required	0.042	0.833	0.167	0.035	0.007
Impact on Environment due to construction activity	0.037	0.900	0.100	0.033	0.004
Resources easily Available	0.036	0.900	0.100	0.032	0.004
Storm or earthquake damage (emergency situation)	0.035	0.833	0.167	0.029	0.006
Finance Availability for ABC	0.032	0.500	0.500	0.016	0.016
Fulfilling Federal Environmental Requirements	0.031	0.500	0.500	0.015	0.015
				0.46	0.54

ABC Score = 0.54

Traditional Construction Score = 0.46

Construction type recommended: **ABC**

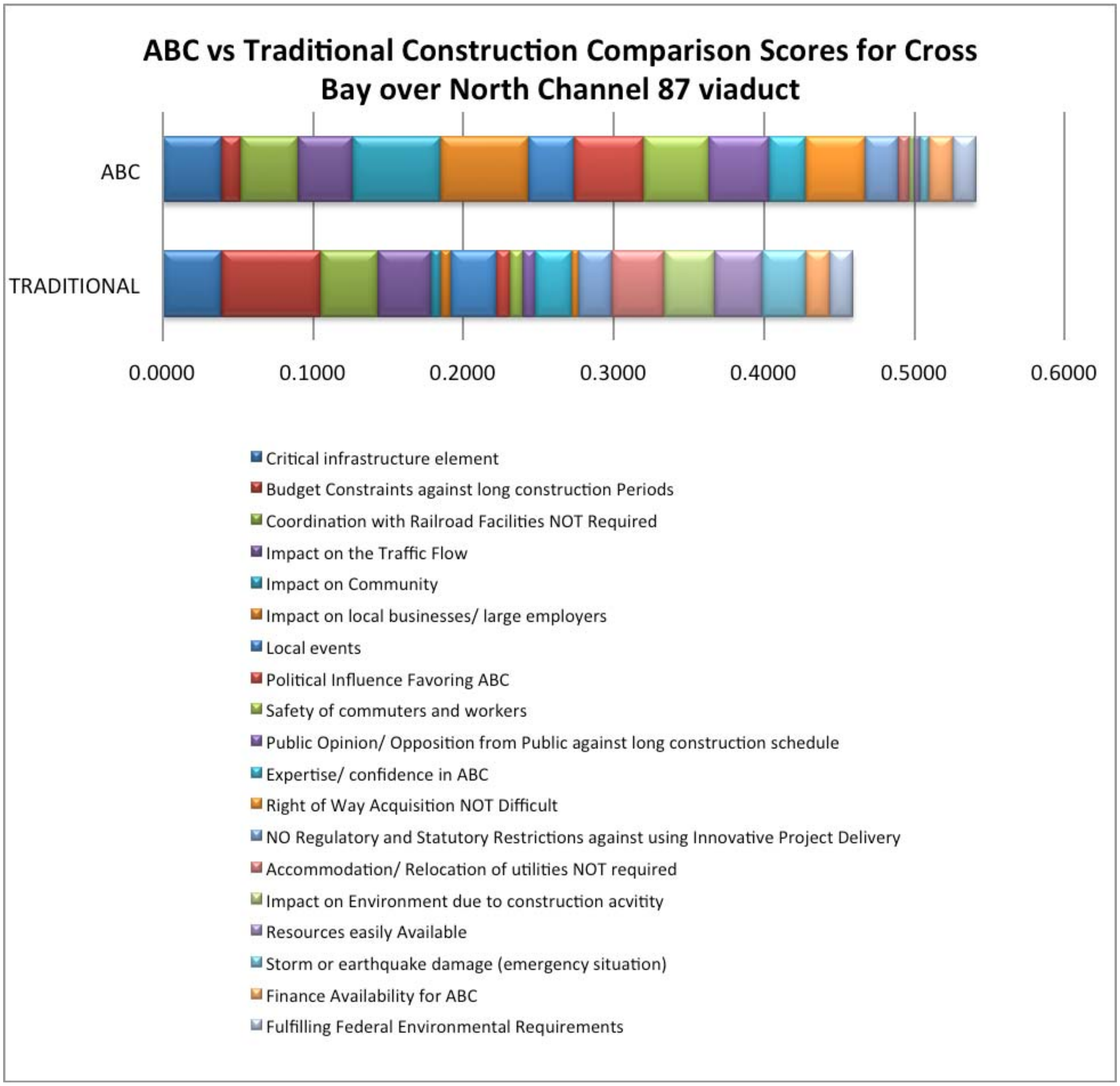


Figure 31: Graphical Representation of the Relative Importance of ABC Decision Making Factors

6.2 Route 31 over Canandaigua Outlet:

The key elements used in the project were Deck Bulb Tee with Ultra High Performance Concrete (UHPC). UHPC joints were used for the first time in the country. Some of the properties of UHPC are extraordinary bond strength, superior durability, high compressive and tensile strength, low drying shrinkage, fast strength gain and its capability of developing a full rebar within a 6-inch wide joint. It was also indicated that the UHPC joints provide a moment connection, whereas, regular grout provide only shear connections. Some of the challenges associated were camber issues, and overlay issues due to difference in levels. Utilizing the ABC vs Traditional decision-making model using the inputs obtained from the NYSDOT officials suggested ABC and provided the following results.

Table 13: ABC vs Traditional Decision Making Model Inputs for Route 31 over Canandaigua Outlet, NY

Rate the following factors according to their importance and relevance for the particular project	Relevance Level
Critical infrastructure element	Relevant
Budget Constraints against long construction Periods	Relevant
Coordination with Railroad Facilities NOT Required	Absolutely Relevant
Impact on the Traffic Flow	Relevant
Impact on Community	Absolutely Relevant
Impact on local businesses/ large employers	Very Relevant
Local events	Relevant
Political Influence Favoring ABC	Less Relevant
Safety of commuters and workers	Relevant
Public Opinion/ Opposition from Public against long construction schedule	Relevant
Expertise/ confidence in ABC	Relevant
Right of Way Acquisition NOT Difficult	Absolutely Relevant
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	Less Relevant
Accommodation/ Relocation of utilities NOT required	Absolutely Relevant
Impact on Environment due to construction activity	Relevant
Resources easily Available	Relevant
Storm or earthquake damage (emergency situation)	Absolutely Relevant
Finance Availability for ABC	Less Relevant
Fulfilling Federal Environmental Requirements	Irrelevant

Table 14: ABC Model Results for Route 31 over Canandaigua Outlet, NY

Factors Favoring ABC	Weights	Traditional	ABC	Weighted Traditional	Weighted ABC
Critical infrastructure element	0.079	0.500	0.500	0.040	0.040
Budget Constraints against long construction Periods	0.079	0.500	0.500	0.040	0.040
Coordination with Railroad Facilities NOT Required	0.076	0.100	0.900	0.008	0.068
Impact on the Traffic Flow	0.072	0.500	0.500	0.036	0.036
Impact on Community	0.065	0.100	0.900	0.007	0.059
Impact on local businesses/ large employers	0.065	0.167	0.833	0.011	0.054
Local events	0.060	0.500	0.500	0.030	0.030
Political Influence Favoring ABC	0.056	0.833	0.167	0.046	0.009
Safety of commuters and workers	0.052	0.500	0.500	0.026	0.026
Public Opinion/ Opposition from Public against long construction schedule	0.048	0.500	0.500	0.024	0.024
Expertise/ confidence in ABC	0.048	0.500	0.500	0.024	0.024
Right of Way Acquisition NOT Difficult	0.044	0.100	0.900	0.004	0.040
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	0.044	0.833	0.167	0.037	0.007
Accommodation/ Relocation of utilities NOT required	0.042	0.100	0.900	0.004	0.038
Impact on Environment due to construction activity	0.037	0.500	0.500	0.018	0.018
Resources easily Available	0.036	0.500	0.500	0.018	0.018
Storm or earthquake damage (emergency situation)	0.035	0.100	0.900	0.004	0.031
Finance Availability for ABC	0.032	0.833	0.167	0.026	0.005
Fulfilling Federal Environmental Requirements	0.031	0.900	0.100	0.028	0.003
				0.43	0.57

ABC Score = 0.57

Traditional Construction Score = 0.43

Construction Type Recommended = **ABC**

6.3 Route 23 Over Otego Creek:

Some of the elements used were precast with Ultra-High Performance Concrete (UHPC) joints, which eliminated the need of any post tensioning thus helps in reducing the thickness of the decks. This project was undertaken on an experimental basis. Integral abutments were also used. Utilizing the ABC decision model resulted in the following results:

Table 15: ABC vs Traditional Decision Making Model Inputs for Route 23 Over Otego Creek, NY

Rate the following factors according to their importance and relevance for the particular project	Relevance Level
Critical infrastructure element	Very Relevant
Budget Constraints against long construction Periods	Relevant
Coordination with Railroad Facilities NOT Required	Relevant
Impact on the Traffic Flow	Less Relevant
Impact on Community	Very Relevant
Impact on local businesses/ large employers	Very Relevant
Local events	Relevant
Political Influence Favoring ABC	Less Relevant
Safety of commuters and workers	Very Relevant
Public Opinion/ Opposition from Public against long construction schedule	Very Relevant
Expertise/ confidence in ABC	Relevant
Right of Way Acquisition NOT Difficult	Absolutely Relevant
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	Relevant
Accommodation/ Relocation of utilities NOT required	Irrelevant
Impact on Environment due to construction activity	Relevant
Resources easily Available	Less Relevant
Storm or earthquake damage (emergency situation)	Relevant
Finance Availability for ABC	Relevant
Fulfilling Federal Environmental Requirements	Irrelevant

Table 16: ABC Model Results for Route 23 Over Otego Creek, NY

Factors Favoring ABC	Weights	Traditional	ABC	Weighted Traditional	Weighted ABC
Critical infrastructure element	0.079	0.167	0.833	0.013	0.066
Budget Constraints against long construction Periods	0.079	0.500	0.500	0.040	0.040
Coordination with Railroad Facilities NOT Required	0.076	0.500	0.500	0.038	0.038
Impact on the Traffic Flow	0.072	0.833	0.167	0.060	0.012
Impact on Community	0.065	0.167	0.833	0.011	0.054
Impact on local businesses/ large employers	0.065	0.167	0.833	0.011	0.054
Local events	0.060	0.500	0.500	0.030	0.030
Political Influence Favoring ABC	0.056	0.833	0.167	0.047	0.009
Safety of commuters and workers	0.052	0.167	0.833	0.009	0.043
Public Opinion/ Opposition from Public against long construction schedule	0.048	0.167	0.833	0.008	0.040
Expertise/ confidence in ABC	0.048	0.500	0.500	0.024	0.024
Right of Way Acquisition NOT Difficult	0.044	0.100	0.900	0.004	0.040
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	0.044	0.500	0.500	0.022	0.022

Factors Favoring ABC	Weights	Traditional	ABC	Weighted Traditional	Weighted ABC
Accommodation/ Relocation of utilities NOT required	0.042	0.900	0.100	0.038	0.004
Impact on Environment due to construction activity	0.037	0.500	0.500	0.018	0.018
Resources easily Available	0.036	0.833	0.167	0.030	0.006
Storm or earthquake damage (emergency situation)	0.035	0.500	0.500	0.017	0.017
Finance Availability for ABC	0.032	0.500	0.500	0.016	0.016
Fulfilling Federal Environmental Requirements	0.031	0.900	0.100	0.028	0.003
				0.464	0.536

ABC Score = 0.54

Traditional Construction Score = 0.46

Construction Type Recommended = **ABC**

6.4 Route 9 W over Cedar Pond Brook:

Advanced purchasing was used for this project, which saved 50% of the construction time. With this method, materials might be purchased before hand and then stored in the agency warehouse, and if there is not enough space available then residency areas can be rented temporarily for storage. Arrangements may be made with the vendors to deliver the materials to site on specified date and time. For this project date of completion was fixed, and the contractor, if failed to finish it on time, would be subjected to liquidated damages. The input and the results of the model are presented below.

Table 17: ABC vs Traditional Decision Making Model Inputs for Route 9 W over Cedar pond Brook, NY

Rate the following factors according to their importance and relevance for the particular project	Relevance Level
Critical infrastructure element	Very Relevant
Budget Constraints against long construction Periods	Irrelevant
Coordination with Railroad Facilities NOT Required	Very Relevant
Impact on the Traffic Flow	Relevant
Impact on Community	Less Relevant
Impact on local businesses/ large employers	Relevant
Local events	Relevant
Political Influence Favoring ABC	Relevant
Safety of commuters and workers	Relevant
Public Opinion/ Opposition from Public against long construction schedule	Relevant
Expertise/ confidence in ABC	Relevant
Right of Way Acquisition NOT Difficult	Absolutely Relevant

Rate the following factors according to their importance and relevance for the particular project	Relevance Level
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	Less Relevant
Accommodation/ Relocation of utilities NOT required	Very Relevant
Impact on Environment due to construction activity	Less Relevant
Resources easily Available	Very Relevant
Storm or earthquake damage (emergency situation)	Very Relevant
Finance Availability for ABC	Very Relevant
Fulfilling Federal Environmental Requirements	Irrelevant

Table 18: ABC Model Results for Route 9 W over Cedar pond Brook, NY

Factors Favoring ABC	Weights	Traditional	ABC	Weighted Traditional	Weighted ABC
Critical infrastructure element	0.079	0.167	0.833	0.013	0.066
Budget Constraints against long construction Periods	0.079	0.900	0.100	0.071	0.008
Coordination with Railroad Facilities NOT Required	0.076	0.167	0.833	0.013	0.063
Impact on the Traffic Flow	0.072	0.500	0.500	0.036	0.036
Impact on Community	0.065	0.833	0.167	0.054	0.011
Impact on local businesses/ large employers	0.065	0.500	0.500	0.033	0.033
Local events	0.060	0.500	0.500	0.030	0.030
Political Influence Favoring ABC	0.056	0.500	0.500	0.028	0.028
Safety of commuters and workers	0.052	0.500	0.500	0.026	0.026
Public Opinion/ Opposition from Public against long construction schedule	0.048	0.500	0.500	0.024	0.024
Expertise/ confidence in ABC	0.048	0.500	0.500	0.024	0.024
Right of Way Acquisition NOT Difficult	0.044	0.100	0.900	0.004	0.040
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	0.044	0.833	0.167	0.037	0.007
Accommodation/ Relocation of utilities NOT required	0.042	0.167	0.833	0.007	0.035
Impact on Environment due to construction activity	0.037	0.833	0.167	0.031	0.006
Resources easily Available	0.036	0.167	0.833	0.006	0.030
Storm or earthquake damage (emergency situation)	0.035	0.167	0.833	0.006	0.029
Finance Availability for ABC	0.032	0.167	0.833	0.005	0.026
Fulfilling Federal Environmental Requirements	0.031	0.900	0.100	0.028	0.003
				0.48	0.52

ABC Score = 0.52

Traditional Construction Score = 0.48

Construction Type Recommended = **ABC**

6.5 Route 32 over Katerskill Creek:

The bridge was originally built in 1941. It was decided to rebuild the structure. Integral abutments were used in the new design. An existing span, which was salvaged from another bridge (9P over I87 – Exit 14 of Northway), was installed on site. The elements used were adjacent box beams. Steel was bought in advance. The input and the results of the project are as follows.

Table 19: ABC vs Traditional Decision Making Model Inputs for Route 32 over Katerskill Creek, NY

Rate the following factors according to their importance and relevance for the particular project	Relevance Level
Critical infrastructure element	Relevant
Budget Constraints against long construction Periods	Relevant
Coordination with Railroad Facilities NOT Required	Absolutely Relevant
Impact on the Traffic Flow	Relevant
Impact on Community	Absolutely Relevant
Impact on local businesses/ large employers	Very Relevant
Local events	Relevant
Political Influence Favoring ABC	Less Relevant
Safety of commuters and workers	Relevant
Public Opinion/ Opposition from Public against long construction schedule	Relevant
Expertise/ confidence in ABC	Relevant
Right of Way Acquisition NOT Difficult	Absolutely Relevant
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	Relevant
Accommodation/ Relocation of utilities NOT required	Absolutely Relevant
Impact on Environment due to construction activity	Less Relevant
Resources easily Available	Relevant
Storm or earthquake damage (emergency situation)	Absolutely Relevant
Finance Availability for ABC	Less Relevant
Fulfilling Federal Environmental Requirements	Irrelevant

Table 20: ABC Model Results for Route 32 over Katerskill Creek, NY

Factors Favoring ABC	Weights	Traditional	ABC	Weighted Traditional	Weighted ABC
Critical infrastructure element	0.079	0.500	0.500	0.040	0.040
Budget Constraints against long construction Periods	0.079	0.500	0.500	0.040	0.040
Coordination with Railroad Facilities NOT Required	0.076	0.100	0.900	0.008	0.069
Impact on the Traffic Flow	0.072	0.500	0.500	0.036	0.036
Impact on Community	0.065	0.100	0.900	0.007	0.059
Impact on local businesses/ large employers	0.065	0.167	0.833	0.011	0.054

Factors Favoring ABC	Weights	Traditional	ABC	Weighted Traditional	Weighted ABC
Local events	0.060	0.500	0.500	0.030	0.030
Political Influence Favoring ABC	0.056	0.833	0.167	0.047	0.009
Safety of commuters and workers	0.052	0.500	0.500	0.026	0.026
Public Opinion/ Opposition from Public against long construction schedule	0.048	0.500	0.500	0.024	0.024
Expertise/ confidence in ABC	0.048	0.500	0.500	0.024	0.024
Right of Way Acquisition NOT Difficult	0.044	0.100	0.900	0.004	0.040
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	0.044	0.500	0.500	0.022	0.022
Accommodation/ Relocation of utilities NOT required	0.042	0.100	0.900	0.004	0.038
Impact on Environment due to construction activity	0.037	0.833	0.167	0.031	0.006
Resources easily Available	0.036	0.500	0.500	0.018	0.018
Storm or earthquake damage (emergency situation)	0.035	0.100	0.900	0.004	0.031
Finance Availability for ABC	0.032	0.833	0.167	0.026	0.005
Fulfilling Federal Environmental Requirements	0.031	0.900	0.100	0.028	0.003
				0.43	0.57

ABC Score = 0.57

Traditional Construction Score = 0.43

Construction Type Recommended = **ABC**

6.6 Seven Lake Drive/ Ramapo River:

This project involved construction of a large number of temporary bridges in order to provide access in and out of the villages in the area. Failures in spread footing caused formation of cracks in the superstructures. Foundations were undermined. Some of the bridges included utility lines. Coordination with utility companies represented one of the hardest tasks in this project. Public involvement was another important factor in accelerating the construction. It was indicated that the agency sometimes avoided ABC, if the bridge was located over utilities or railroads due to difficulties faced in coordination.

Table 21: ABC vs Traditional Decision Making Model Inputs for Route 981 G over Ramapo River

Rate the following factors according to their importance and relevance for the particular project	Relevance Level
Critical infrastructure element	Absolutely Relevant
Budget Constraints against long construction Periods	Very Relevant
Coordination with Railroad Facilities NOT Required	Absolutely Relevant
Impact on the Traffic Flow	Absolutely Relevant
Impact on Community	Absolutely Relevant
Impact on local businesses/ large employers	Absolutely Relevant
Local events	Very Relevant
Political Influence Favoring ABC	Relevant
Safety of commuters and workers	Very Relevant
Public Opinion/ Opposition from Public against long construction schedule	Absolutely Relevant
Expertise/ confidence in ABC	Relevant
Right of Way Acquisition NOT Difficult	Less Relevant
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	Relevant
Accommodation/ Relocation of utilities NOT required	Irrelevant
Impact on Environment due to construction activity	Relevant
Resources easily Available	Relevant
Storm or earthquake damage (emergency situation)	Absolutely Relevant
Finance Availability for ABC	Less Relevant
Fulfilling Federal Environmental Requirements	Irrelevant

Table 22: ABC Model Results for Cross Bay over Route 981 G over Ramapo River

Factors Favoring ABC	Weights	Traditional	ABC	Weighted Traditional	Weighted ABC
Critical infrastructure element	0.079	0.100	0.900	0.008	0.071
Budget Constraints against long construction Periods	0.079	0.167	0.833	0.013	0.066
Coordination with Railroad Facilities NOT Required	0.076	0.100	0.900	0.008	0.068
Impact on the Traffic Flow	0.072	0.100	0.900	0.007	0.064
Impact on Community	0.065	0.100	0.900	0.007	0.059
Impact on local businesses/ large employers	0.065	0.100	0.900	0.007	0.059
Local events	0.060	0.167	0.833	0.010	0.050
Political Influence Favoring ABC	0.056	0.500	0.500	0.028	0.028
Safety of commuters and workers	0.052	0.167	0.833	0.009	0.043
Public Opinion/ Opposition from Public against long construction schedule	0.048	0.100	0.900	0.005	0.044
Expertise/ confidence in ABC	0.048	0.500	0.500	0.024	0.024
Right of Way Acquisition NOT Difficult	0.044	0.833	0.167	0.037	0.007
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	0.044	0.500	0.500	0.022	0.022

Factors Favoring ABC	Weights	Traditional	ABC	Weighted Traditional	Weighted ABC
Accommodation/ Relocation of utilities NOT required	0.042	0.900	0.100	0.038	0.004
Impact on Environment due to construction activity	0.037	0.500	0.500	0.018	0.018
Resources easily Available	0.036	0.500	0.500	0.018	0.018
Storm or earthquake damage (emergency situation)	0.035	0.100	0.900	0.004	0.031
Finance Availability for ABC	0.032	0.833	0.167	0.026	0.005
Fulfilling Federal Environmental Requirements	0.031	0.900	0.100	0.028	0.003
				0.32	**0.68**

ABC Score = 0.68

Traditional Construction Score = 0.32

Construction Type Recommended = **ABC**

6.7 A Hypothetical Traditional Construction Project:

As information could not be obtained from NYSDOT regarding a traditional bridge construction project, a hypothetical scenario for a conventional bridge construction was created and then ABC vs Traditional Decision making model was implemented to validate the model. The inputs and the results are presented below.

Table 23: ABC vs Traditional Decision Making Model Inputs for a Hypothetical Traditional Bridge Construction Project

Rate the following factors according to their importance and relevance for the particular project	Relevance Level
Critical infrastructure element	Relevant
Budget Constraints against long construction Periods	Less Relevant
Coordination with Railroad Facilities NOT Required	Relevant
Impact on the Traffic Flow	Relevant
Impact on Community	Less Relevant
Impact on local businesses/ large employers	Irrelevant
Local events	Relevant
Political Influence Favoring ABC	Relevant
Safety of commuters and workers	Relevant
Public Opinion/ Opposition from Public against long construction schedule	Relevant
Expertise/ confidence in ABC	Relevant
Right of Way Acquisition NOT Difficult	Absolutely Relevant
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	Very Relevant

Rate the following factors according to their importance and relevance for the particular project	Relevance Level
Accommodation/ Relocation of utilities NOT required	Very Relevant
Impact on Environment due to construction activity	Less Relevant
Resources easily Available	Less Relevant
Storm or earthquake damage (emergency situation)	Less Relevant
Finance Availability for ABC	Less Relevant
Fulfilling Federal Environmental Requirements	Irrelevant

Table24: ABC Model Results for a Hypothetical Traditional Bridge Construction Project

Factors Favoring ABC	Weights	Traditional	ABC	Weighted Traditional	Weighted ABC
Critical infrastructure element	0.079	0.500	0.500	0.040	0.040
Budget Constraints against long construction Periods	0.079	0.833	0.167	0.066	0.013
Coordination with Railroad Facilities NOT Required	0.076	0.500	0.500	0.038	0.038
Impact on the Traffic Flow	0.072	0.500	0.500	0.036	0.036
Impact on Community	0.065	0.833	0.167	0.054	0.011
Impact on local businesses/ large employers	0.065	0.900	0.100	0.059	0.007
Local events	0.060	0.500	0.500	0.030	0.030
Political Influence Favoring ABC	0.056	0.500	0.500	0.028	0.028
Safety of commuters and workers	0.052	0.500	0.500	0.026	0.026
Public Opinion/ Opposition from Public against long construction schedule	0.048	0.500	0.500	0.024	0.024
Expertise/ confidence in ABC	0.048	0.500	0.500	0.024	0.024
Right of Way Acquisition NOT Difficult	0.044	0.100	0.900	0.004	0.040
NO Regulatory and Statutory Restrictions against using Innovative Project Delivery	0.044	0.167	0.833	0.007	0.037
Accommodation/ Relocation of utilities NOT required	0.042	0.167	0.833	0.007	0.035
Impact on Environment due to construction activity	0.037	0.833	0.167	0.031	0.006
Resources easily Available	0.036	0.833	0.167	0.030	0.006
Storm or earthquake damage (emergency situation)	0.035	0.833	0.167	0.027	0.006
Finance Availability for ABC	0.032	0.833	0.167	0.026	0.005
Fulfilling Federal Environmental Requirements	0.031	0.900	0.100	0.028	0.003
				0.59	0.41

ABC Score = 0.41

Traditional Construction Score = 0.59

Construction Type Recommended = **Traditional**

7 Conclusion

It is becoming increasingly evident that traditional methods for repair and upgrade of highway bridges are giving rise to major inconveniencies for daily commuters and businesses. It is expected that, in the near future, the decision making process for selection of repair, rehabilitation and construction methods will become more complex due to increasing restrictions on available funds and resources, as well as increasing demands and expectation placed by users. Thus, given the high demands on aging highway infrastructure networks, agencies are now urged to investigate opportunities to expedite construction activities.

The AHP based ABC vs. Traditional decision making model; ABC Techniques Decision Making Model and the Project Delivery System Decision Making Model together provide a solid decision support framework which can assist DOT officials to select the correct strategy for accelerated construction. A properly selected accelerated construction strategy provides an opportunity to reduce the life cycle costs, user costs, traffic disruptions, and environmental impacts; thereby, helps in sustainable development of infrastructure. All the models were prepared after a comprehensive literature review on the accelerated construction techniques, various innovative contracting techniques, existing ABC decision making models and the mathematical techniques generally used to generate models that consider factors with uncertainty. Several important qualitative and quantitative factors influencing the selection procedure of construction alternative and project delivery systems were also identified, which were later modeled using the mathematical techniques studied during the literature review.

In addition to general Economic, Social and Environmental aspects, the factors took into consideration the importance of the infrastructure to the surrounding community in terms of access routes to emergency services, schools and businesses. These also incorporate the opinion of the people affected or dependent on the infrastructure and negotiation challenges between various sector of transportation, such as railroad and waterways, mostly when utilities are involved. The effects of many of these factors are highly difficult to be quantified. Therefore, a national survey was conducted, which involved several experienced bridge engineers and project managers all over the United States to determine the importance of these factors. As the information obtained could be used to generate a representation of experts' opinion on the relative importance of one factor over the other. Analytical hierarchy process was deemed to be a suitable method to develop a decision support tool as it allows users to consider the relative priorities of the attributes in a system to select the best alternative among the potential candidates for a given goal. Analytical hierarchy process is known for its ability to model a wide range of unstructured problems in an easily understood way integrating the deductive and system approaches. It also allows interdependence of elements in a system without insisting on linear thinking.

The AHP model developed assists the users in the higher level decision making, where the responsible party selects priorities for the factors as it appears for a particular project and then get an idea of the suitable mode of construction (i.e. ABC or traditional) in a quantitative format. If ABC is selected as the option, it is again important to select appropriate construction techniques as well as proper contracting alternatives. The flow chart based ABC Techniques Decision-Making Model and the Project Delivery System Decision-Making Model provides a strategic framework to the DOT officials to shortlist the most suitable and feasible alternatives.

In other words, the decision support framework developed in this study, will provide a systematic procedure for comparing various upgrades and repair strategies. The models are anticipated to make the decision process for the selection of appropriate upgrade/repair methods and contracting approaches more objective and justifiable. The study has the potential to lead to the development of more efficient management strategies for highway bridges by reducing the negative impacts associated with bridge upgrade and repair activities.

8 Recommendations

Although the AHP model prepared in this study is technically sound, it is prepared based on a relatively small data set (thirty) due to lack of information obtained from the State DOTs. More information can be fed into the model in the future to achieve a higher level of accuracy. The model can be customized according to the needs of different DOTs.

The study presented in this report focuses mainly on economic and social aspects of accelerated construction. Only generalized factors were considered for the higher-level decision-making. One of the potential areas of future research is to perform a detailed benefit/cost (BC) analysis. As money plays an important role in any kind of construction activity, BC can be performed to precisely determine the technical and economic feasibility of each ABC alternative, and this allows decision-making to be based on more accurate quantitative evaluation.

Detailed studies can also be done on the environmental impacts of the repair and maintenance of transportation systems and investigations on how to use accelerated construction techniques to minimize those impacts will also be beneficial.

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Appendix I: Questionnaire Survey

QUESTIONNAIRE

Accelerated Highway Bridge Construction (AHBC)

The Civil and Environmental Engineering Department at Syracuse University is conducting a research study that is funded by the US DOT and Region II University Transportation Center to explore possible Accelerated Highway Bridge Construction (AHBC) Approaches. AHBC is any project delivery approach that involves construction techniques and/or contracting procurement methods that result in reducing the negative impacts of highway bridge construction activities on: traffic safety and mobility, user costs, local businesses, and the environment. In other words, AHBC refers to any highway bridge project that is completed or is planned to be completed in substantially less time compared to traditional construction methods. The following questionnaire is intended to provide the research team with understating of the current state of practice at State DOTs in relation to AHBC. The summary and analysis of this survey will be documented and made available to interested State DOTs. There are 10 questions in this survey and we estimate that it will take 20-25 minutes to complete.

If you have additional comments please feel free to add them in the space provided at the end of the survey indicating the question number referred to.

We would like to thank you in advance for your participation in this survey.

Respondent's Contact Information:

Name:

Title:

Agency:

Address:

Phone Number:

Email:

May we contact you with follow up questions? Yes No

1. In the last five years, has your agency used accelerated construction as a strategy to reduce construction project delivery time?

    a. Yes b. No

If "Yes", please indicate below the percentage of AHBC projects to overall construction projects executed:

If "No", please explain why it has not been used so far.

If answered "Yes" to Question 1, please proceed with rest of the survey

2. Please specify the percentage of AHBC projects completed:
    a. On or ahead of schedule [ ]
    b. Within or below budget [ ]
    c. With acceptable quality and workmanship [ ]
    d. With no accidents [ ]

3. Please select one or more construction method(s) that are utilized during your agency's AHBC projects. Please specify inside the brackets, the number of AHBC project(s) for which the method was utilized.
    a. Prefabricated Components of Bridges [ ]
    b. Heavy Cranes/Transporters to Bridges [ ]
    c. Stay -in-place steel forms [ ]
    d. Concrete filled steel grid decks [ ]
    e. Fast Setting Hydraulic Cement Concrete [ ]
    f. Rapid Strength Concrete [ ]
    g. Cast-in-place/ post-tensioned (CIP/PS) box girder with transverse girders and large edge beams spanning column support [ ]
    h. Precast sub structure units [ ]
    i. High performance and fast setting concrete [ ]
    j. "Deck less" bridges (Adjacent box or bulb "T" beam) [ ]
    h. FRP modular bridge decks [ ]

i. Self Propelled Modular Transporter [ ]

j. Others (Please add the other techniques used with the number of project(s) in which it was utilized)

4. Please specify the number of AHBC projects performed under each of the following contracting procurement techniques, with or without an Incentive/Disincentive (I/D) clause. Also, please identify the factors (using the list of factors provided in Appendix 1) affecting the decision making process for the project delivery, under each project delivery checked.

	With I/D	Without I/D	Factors
a. Design Bid Build (DBB)	[ ]	[ ]	[ ]
b. Design Build	[ ]	[ ]	[ ]
c. A+B	[ ]	[ ]	[ ]
d. Lane Rental	[ ]	[ ]	[ ]
e. Construction Management at Risk	[ ]	[ ]	[ ]
f. Construction Management Agency	[ ]	[ ]	[ ]
g. More than one contracting technique (Please Specify)	[ ]	[ ]	[ ]
h. Other (Please Specify)	[ ]	[ ]	[ ]

5. Please specify the number of AHBC Projects performed using Phased Construction under each of the contracting methods. In phased construction the project is divided into different contracts, which can be carried out separately at the same time to accelerate the construction process. The contracts may also be handed over to different contractors. Please state in the space provided below factors other than time, considered (if any) for selecting phased construction:

	Number of Projects	Factors
a. Design Bid Build (DBB)	[ ]	[ ]
b. Design Build	[ ]	[ ]
c. A+B	[ ]	[ ]
d. Lane Rental	[ ]	[ ]
e. Construction Management at Risk	[ ]	[ ]
f. Construction Management Agency	[ ]	[ ]
g. Other (Please Specify)	[ ]	[ ]

6. Please rate the impact of the following factors on the decision making process of AHBC projects (i.e. to accelerate vs. not to accelerate), on a scale of 1 to 9, where 1 represents no impact and 9 represents maximum impact.

Factors		Rating
a.	Critical infrastructure element (e.g. the only bridge or access to a particular area)	1 2 3 4 5 6 7 8 9
b.	Impact on the Traffic Flow	1 2 3 4 5 6 7 8 9
c.	Finance Availability (How fast is the financing available?)	1 2 3 4 5 6 7 8 9
d.	Safety (Motorist, Construction Worker, and Pedestrian)	1 2 3 4 5 6 7 8 9
e.	Political Influence	1 2 3 4 5 6 7 8 9
f.	Public Opinion	1 2 3 4 5 6 7 8 9
g.	Budget Constraints (How much money is available?)	1 2 3 4 5 6 7 8 9
h.	Impact on Community (e.g. reduced access, detours, emergency services, etc)	1 2 3 4 5 6 7 8 9
i.	Impact on local businesses and large employers (e.g. airports, postal, package service companies, etc.)	1 2 3 4 5 6 7 8 9
j.	Impact on Environment (Ecosystems, Air Pollution and Noise Pollution etc.)	1 2 3 4 5 6 7 8 9
k.	Fulfilling Federal Environmental Requirements (e.g. National Environmental Policy Act (NEPA) process)	1 2 3 4 5 6 7 8 9
l.	Right of Way Acquisition	1 2 3 4 5 6 7 8 9
m.	Local events (e.g. project to be completed before school begins, sport events, festivals etc)	1 2 3 4 5 6 7 8 9
n.	Resource Availability (Labor, Material and Equipment)	1 2 3 4 5 6 7 8 9
o.	The level of expertise and confidence the agency has in AHBC	1 2 3 4 5 6 7 8 9
p.	Regulatory and Statutory Restrictions	1 2 3 4 5 6 7 8 9
q.	Storm or earthquake damage	1 2 3 4 5 6 7 8 9
r.	Others (Please Specify in the space provided below)	1 2 3 4 5 6 7 8 9

7. Please rate the impact of following challenges/ constraints (on a scale of 1 to 9) which may hinder or delay the AHBC process, where 1 represents "Not Challenging" and 9 represents "Most Challenging"

	Factors	Rating
a.	Accommodation or Relocation of existing surface or sub-surface utilities	1 2 3 4 5 6 7 8 9
b.	Coordination with Railroad Facilities while working on or around Railroad properties	1 2 3 4 5 6 7 8 9
c.	Communication, Coordination and Collaboration with different State and Federal Regulatory Agencies (i.e. FHWA, Environmental Protection Agency, U.S. Coast Guard, Historic Preservation Agencies etc.)	1 2 3 4 5 6 7 8 9
d.	Lack of historical traffic or construction data (e.g. Temporal Traffic Volume, Crash Data, Bridge Inspection Reports, Bridge Performance, ROW acquisition time etc.)	1 2 3 4 5 6 7 8 9
e.	Opposition from public	1 2 3 4 5 6 7 8 9
f.	Availability of producers/precasters/fabricators within reasonable distance to construction site	1 2 3 4 5 6 7 8 9
g.	Access road to transport precast/prefabricated members	1 2 3 4 5 6 7 8 9
h.	Availability of alternate routes for detours	1 2 3 4 5 6 7 8 9
i.	Site condition	1 2 3 4 5 6 7 8 9
j.	Others (Please Specify in the space provided below)	1 2 3 4 5 6 7 8 9

8. Among AHBC projects, please indicate the percentage of projects performed under each of the following categories.

	Percentage
a. Emergency AHBC	[ ]
b. Planned AHBC	[ ]

9. Please specify the type of cost(s) considered by your agency for selecting AHBC alternatives. Please rank them on a scale of 1 - 9 depending on their importance for the decision making process (where, 1 represents no importance and 9 represents maximum importance).

a. Emergency AHBC — Importance

		Importance
i.	Initial Cost (Construction Cost)	[1 2 3 4 5 6 7 8 9]
ii.	Life Cycle Costs (Future maintenance and repair costs)	[1 2 3 4 5 6 7 8 9]
iii.	User Costs (Delays, traffic accidents, etc.)	[1 2 3 4 5 6 7 8 9]
iv.	All of the above	[1 2 3 4 5 6 7 8 9]
v.	None of the above	[1 2 3 4 5 6 7 8 9]

b. Planned AHBC — Importance

		Importance
i.	Initial Cost (Construction Cost)	[1 2 3 4 5 6 7 8 9]
ii.	Life Cycle Costs (Future maintenance and repair costs)	[1 2 3 4 5 6 7 8 9]
iii.	User Costs (Delays, traffic accidents, etc.)	[1 2 3 4 5 6 7 8 9]
iv.	All of the above	[1 2 3 4 5 6 7 8 9]
v.	None of the above	[1 2 3 4 5 6 7 8 9]

10. Please prioritize factors considered for calculating user costs on a scale of 1 to 9 (where 1 represents no priority and 9 represents highest priority)

		Priority
a.	Delayed and increased traffic	[1 2 3 4 5 6 7 8 9]
b.	Increased travel time due to detours	[1 2 3 4 5 6 7 8 9]
c.	Safety	[1 2 3 4 5 6 7 8 9]
d.	Disruption of local businesses due to closure / detours	[1 2 3 4 5 6 7 8 9]
e.	Others (Please Specify)	[1 2 3 4 5 6 7 8 9]

f.

Appendix 1:

List of factors that may affect the decision making process of AHBC project delivery:

I. Time constraints
II. Budget constraints
III. Time for bid preparation
IV. Precise cost estimate during the bidding phase
V. Scope of the project (size and complexity)
VI. Owner's involvement and control over design
VII. Owner's understanding of project scope
VIII. Owner's benefit from cost saving
IX. Quality of design
X. Quality of construction
XI. Clarity of scope (Any chances of substantial design changes during the construction?)
XII. Flexibility of redesign after the contract is awarded on a negotiated budget
XIII. Value engineering (effectiveness and constructability of design)
XIV. Familiarity with scope
XV. Contractor's involvement during design
XVI. Coordination and communication among the project stakeholders (Owner, Contractor and Designer)
XVII. Risk allocation (Owner's effort to minimize risk on its part)
XVIII. Competitive bidding
XIX. Owner's preference of the contractor and negotiation
XX. Legal restrictions for using alternative project delivery
XXI. Project financing (Money available for project initiation, mobilizing and construction)
XXII. Experience of the constructor
XXIII. Potential for claims and disputes

Appendix 2:

Glossary:

Design-Bid-Build (DBB): DBB is a traditional way for delivering highway projects where the owner enters into separate contracts with the providers of design and the construction services. At first, qualified engineers design the project and the project cost is estimated on a unit price basis. After the owner reviews the design, the project is bid out in the market and request for proposals from prospective contractors are solicited on a lump sum or unit price basis. This is followed by bid appraisal and handing over the project to the contractor with lowest responsive bid.

Design Build (DB): In Design Build (DB) delivery, the public agency has a single contract with the company that is in charge of both design and construction. There are various types of DB contracts such as Design-Build-Operate-Maintain, Design-Build-Finance-Operate, Design-Build-Operate-Transfer, and Design-Build-Operate-Maintain-Warrant.

A+B (Cost Plus Time): In A+B bidding approach, the agency uses both the initial cost of construction and the time required for completing the project as criteria for selecting the contractor. The time involved is converted into its corresponding dollar value by calculating the user cost, which is obtained by multiplying the user cost rate per day with the number of days of construction.

Lane Rental: In this type of contract the contractor is charged according to the time spent for construction activities in the traffic lanes. The rates depend on the specific time and the amount of traffic volume in the place. Some of the common types of lane rentals used are lane-by-lane rental, continuous site rental and bonus/rental charge method. The lane-by-lane rental charges the contractor on the basis of the number of lanes occupied at a time for construction. Continuous site rental charges the contractor on a day to day basis. Bonus/rental charge considers the cost of construction as well as the cost of time for which the contractor occupies the lane or shoulder.

Construction Management at Risk (CMR): In CMR, the construction manager (CM) is brought in during the design process to assist designers in pre-project planning. The owner has different contracts with designer and CM. In CMR, the contract is generally guaranteed maximum price (GMP) and the CM guarantees cost and schedule.

Construction Management Agency (CMA): CMA is similar to CMR except that the CM neither holds any subcontract nor provides any bonding for the construction project. It only acts as the representative of the owner.

Emergency Accelerated Construction: Accelerated Construction triggered mostly due to unforeseen incidents such as "Act of Nature", accidents and structural failure. Highest degree of acceleration is often needed to restore normal traffic flow, with minimum impact on adjacent traffic.

Planned Accelerated Construction: Accelerated Construction performed in a predefined way for a regular project to minimize effect of construction on the daily commuters, businesses and economy. The project deadline may also be governed by some specific events. In this case, the project stakeholders generally have more time during the design phase.

Appendix II: Minutes of the Meeting held on July 2, 2012 at NYSDOT Headquarters, Albany, NY

Accelerating the Construction Process of Highway Bridges
University Transportation Research Center - Region II Project

Minutes of the Meeting held on July 2, 2012 at NYSDOT Headquarters, Albany, NY

Participants:

- Wahid Albert (Email: wahid.albert@dot.ny.gov, Phone: 518-457-4453)
- Mathew Royce (Email: mathew.royce@dot.ny.gov, Phone: 518-485-7256)
- Richard Marchione (Email: richard.marchione@dot.ny.gov, Phone: 518-457-2436)
- Baris Salman (Email: bsalman@syr.edu, Phone: 513-652-7090)
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Highlights of the meeting:

The meeting started with a highly informative presentation on the current state of practice of Accelerated Bridge Construction (ABC) in the State of New York. The summary of this presentation is as follows:

- NYSDOT uses ABC in cases of emergency construction, for repairs and replacements at locations experiencing heavy traffic, in case of a need for a compressed schedule and for constructing in adverse weather conditions (winter construction). To reduce impacts on the existing traffic, NYSDOT opts for nightly closures or weekend closures.
- Some of the contracting methods or techniques implemented by the agency are mandated shorter construction time, incentive/disincentive, value engineering, best value, design build, and advanced purchasing.
    - Value engineering encourages contractors to propose innovative construction methods that are outside the original design and may help in improving the quality of the finished product and/or reducing construction time.
    - Best Value was started recently and is used to optimize the trade-off between price and performance.

- Recently (in November of 2011), NYSDOT has been granted permission to use Design Build delivery for the next three years. DB is not permitted in many states DOTs due to several reasons:
    - DB does not always provide the least-cost delivery.
    - DB presents difficulty for local and small contractors to compete, (DB requires contractors to perform a high amount of engineering design work upfront. If the contractor does not win the award, all these efforts are wasted).
    - The owner has less control over quality assurance and quality control, (QA/QC aspects represent the toughest duties for the agency in this type of contractual arrangement).
    - The finished product may not have the desired quality.
    - Less opportunity for small local contractors,
    - DB projects initially had a tarnished history.
- Advance purchasing is another strategy followed by NYSDOT to buy construction materials (such as steel bearings) ahead of time, so as to prevent further delays due to time consuming purchasing processes. For any kind of delivery it is important to include the material purchase and delivery time into the schedule. In advance purchasing, the burden is on the fabricator. Strong coordination between design, fabrication and construction is required. Accurate planning and scheduling is highly important.
- For emergency ABC, NYSDOT has predetermined a list of contractors for immediate action. These projects are run based on force account. It can be thought of as a design build type project that is run by the agency. The contractor with the lowest bid undertakes the construction work provided that the contractor agrees to finish the project on a certain day. The agency has also conducted emergency projects by accelerating the Design Bid Build process, with expedited design, bidding and best value contractor selection components.

- NYSDOT engages in a case-by-case decision process for selecting ABC over conventional methods for particular projects. Some of the factors considered by the agency are appropriateness of ABC for the project, whether ABC adds any value to the project, experimentation purposes and dealing with emergency situations. Disadvantages associated with ABC are listed as higher cost, durability issues, design complexity, construction complexity, and dealing with uncertainties (ex: presence of more damages than anticipated).

- Details of some of the projects conducted by ABC method are as follows:
    - Cross-Bay over North Channel 87 viaduct: The bridge is 2842 feet long, and consists of 34 spans, and has 3 lanes. Some of the elements used for the project are Cylinder Piles, Precast Pier Caps forms, Pre-stressed I beams, Diaphragm forms, Partial depth precast deck panels. One of the issues faced was cracking tendency of the deck joints.
    - I-287 Cross Weschester Expressway Viaduct: Use of ABC saved 50% of the total project duration for this project, which is about one year. The elements used for the project are precast piers; precast decks (full width), post tension decks, 2 inch concrete overlay, and Open traverse joints. Some issues arose while grouting the connections as the post-tensioning ducts were getting clogged.
    - Route 31 over Canandaigua Outlet: The key elements used in the project were Deck Bulb Tee with Ultra High Performance Concrete (UHPC). UHPC joints were used for the first time in the country. Some of the properties of UHPC are extraordinary bond strength, superior durability, high compressive and tensile strength, low drying shrinkage, fast strength gain and its capability of developing a full rebar within a 6 inch wide joint. It was also indicated that the UHPC joints provide a moment connection, whereas, regular grout provide only shear connections. Some of the challenges associated are camber issues, and overlay issues due to difference in levels.
    - Route 23 Over Otego Creek: Some of the elements used are precast with Ultra-High Performance Concrete (UHPC) joints, which eliminates the need of any post tensioning thus helps in reducing the thickness of the decks. This project was undertaken for an experimental basis. Integral abutments were also used.
    - Route 9 W over Cedar Pond Brook: Advanced purchasing was used for this project, which saved 50% of the construction time. Materials might be purchased before hand and then stored in the agency warehouse, and if there is not enough

space available then residency areas can be rented temporarily for storage. Arrangements may be made with the vendors to deliver the materials to site on specified date and time. For this project a certain date of completion was fixed, and the contractor if failed to finish it on time would be subjected to liquidate damages.

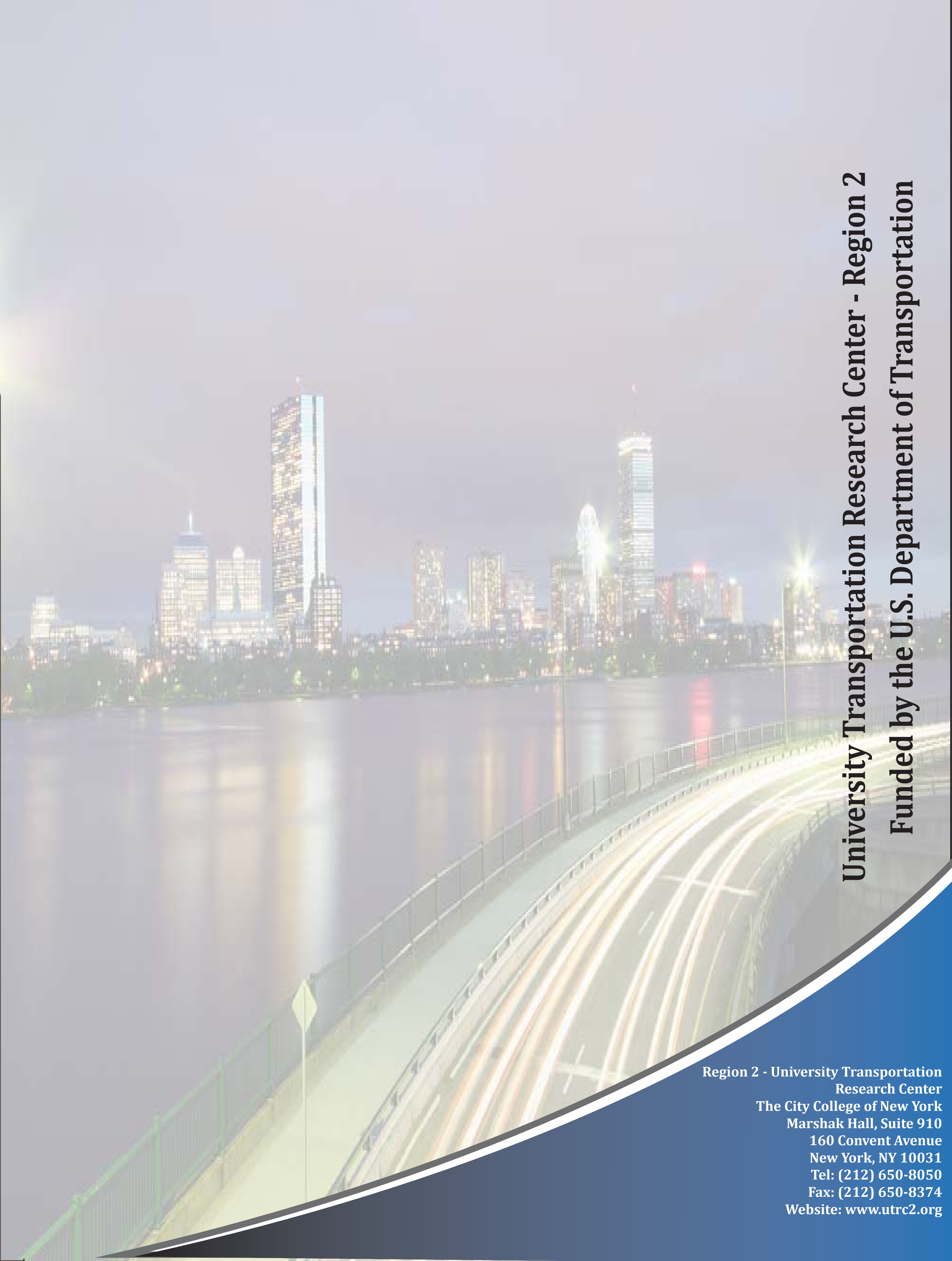
- Route 32 over Katerskill Creek: The bridge was originally built in 1941. It was decided to rebuild the structure. Integral abutments were used in the new design. An existing span, which was salvaged from another bridge (9P over I87 – Exit 14 of Northway), was installed on site. The elements used were adjacent box beams. Steel was bought in advance.
- Seven Lake Dr/ Ramapo River: This project-involved construction of a large number of temporary bridges in order to provide access in and out of the villages in the area. Failures in spread footing caused formation of cracks in the superstructures. Foundations were undermined. Some of the bridges included utility lines. Coordination with utility companies represented one of the hardest tasks in this project. Public involvement was another important factor in accelerating the construction. It is indicated that the agency sometimes avoids ABC if the bridge is located over utilities or railroads due to difficulties faced in coordination.

In the second part of the meeting, the conceptual design of the decision-making framework was presented to NYSDOT. Based on the discussions, it was decided that a double stage decision-making procedure be developed:

- The first stage of decision-making procedures will consider the factors that determine whether ABC should be used for a particular project or not. Analytical Hierarchy Process (AHP) can be used for this first stage decision-making process. Once the decision is made, the user can use the decision making flowchart to select various ABC alternatives that will be shortlisted using three phases of filtering (i.e. Project Type, Project Scope and Requirements for the particular project). Performing a second phase of AHP using the factors listed in the chart can then prioritize the selected techniques and components.

Based on the discussions, the following tasks are anticipated to be completed in the near future:

- Feedback regarding the importance of factors in deciding whether ABC should be employed or not will be sought from NYSDOT.
- Details of the case studies presented on July 2^{nd} will be sought from NYSDOT.
- A new layer of decision-making process will be developed. This layer will assist agency officials in deciding whether ABC should be employed or not.
- The conceptual decision-making framework will be revised based on the previous tasks.



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