THESIS

DEVELOPMENT OF A FRAMEWORK TO DETERMINE THE RELATIVE WEIGHTS OF CONTEXTUAL FACTORS FOR COMPLEX HIGHWAY PROJECTS

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ABSTRACT

DEVELOPMENT OF A FRAMEWORK TO DETERMINE THE RELATIVE WEIGHTS OF CONTEXTUAL FACTORS FOR COMPLEX HIGHWAY PROJECTS

Traditional project management strategies for highway projects originated with the advent of new construction during the 1950s and 1960s focusing on three dimensions of complexity i.e. cost, schedule and technical (scope). But recently with the major focus shifting towards reconstruction/ rehabilitation projects, the project management strategies also need to shift to include other dimensions rather than perceiving them as risks. A paper by Winter and Smith (2006), "Rethinking Project Management", introduced five new directions to consider while preparing a risk management strategy for complex projects. Following this, a research was conducted by the Second Strategic Highway Research Program, R-10, to study the factors that impact the construction of complex highway projects. The primary outcome of the R-10 study was a five-dimensional approach to project management planning (5DPM) that adds context and financing as two new dimensions to the traditional dimensions of cost, schedule, and technical. Experience during the pilot testing of the 5DPM implementation suggested that the most complicated dimension to assess during the project management planning phase for a complex project is the context dimension which refers to the external factors that have an impact on the project and are difficult to predict and plan for before the start of the project. Currently there is no structured process for evaluating these factors and they are mostly perceived as risks. The R-10 research team identified 8 factor categories which are: stakeholders, project-specific demands, resource availability, environmental, legal and legislative requirements, global and national

events, unusual conditions and localized issues and 26 factors under these categories which can cause complexity.

The research developed a framework to identify the contextual factors relevant to each specific project and determine the relative weights of these contextual factors using a well-structured approach, the Analytical Hierarchy Process (AHP). Two complex projects within the state of Colorado, U.S. 34 Rebuild and I-25 North Expansion project, were chosen to illustrate the implementation of the developed framework. The primary reason for selecting AHP method was the requirement of pairwise comparison of intangibles derived through the judgement of the experts in a structured mathematical method. The Group AHP was further performed to develop the overall ranking of the contextual factors as a group. The major finding of this study was that as a group, the US 34 Rebuild team valued procedural laws and land acquisition as the most important factor followed by work-zone visualization and marketing and public relations. For the I-25 team, the most important factor was procedural laws followed by limitations and constraints and project management capabilities. The most striking difference between the factor weights for both the projects was that the weights were more evenly distributed between factors for US-34, whereas for I-25, few factors had very high weights while few others had exceptionally low weights.

This framework will enable the project management teams of complex highway projects to determine the relevant weights of the factors during the project management planning phase which can help them in making important decisions at the early stages of the project. Through the development of this framework, this study helps transportation agencies identify the contextual factors and prioritize them right from the start in a structured manner rather than perceiving them as risks for their projects.

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CHAPTER 1: INTRODUCTION

This chapter provides a brief background discussion on the current shift in the construction of infrastructure, especially highways and how this change dictates a change in the project management strategies. In addition to that, this chapter introduces the problem definition along with the needs and purpose of the research, and concludes by stating its contribution to the existing body of knowledge and the scope and limitations of the study.

1.1. Background

Transportation forms the backbone of any economy; and an effective transportation system is a determinative factor of the nation's quality of life (USDHS, 2010). Majority of the roads in United States of America were built in the 1950s and 1960s just after the World War II and since then the traffic has increased four-fold which has led in over exerting the roads (Capers Jr. & Valeo, 2010). Also, in this period, the preservation and maintenance of these roads have been underfunded which has made them structurally deficient (Capers Jr. & Valeo, 2010). There has also been a decrease in the funds available to construct new roads or rebuild the existing ones (John et al., 2012). The Federal Highway Trust Fund (HTF) which is the main source providing funds to these projects has been declining as its main source is the fuel tax which has not changed since 1993 (ASCE, 2017; John et al., 2012). In order to improve the existing highways and construct new ones, the American Society of Civil Engineers (ASCE), in 2017 have estimated a backlog of $836 billion in capital needs for the highway and bridges, out of which majority of the investments ($420 billion) is needed for repairing the existing highways (ASCE, 2017). ASCE has also estimated that about 32% of the urban roads are in poor condition which is costing motorists an additional $112 billion a year in extra vehicle repairs and operating costs (ASCE, 2017). The poor condition of roads is not only causing the increase in the expenditures but is also leading to fatal accidents, increased travel times and shipping delays leading to increase in prices of everyday commodities (ASCE, 2017). The Transportation Research Board (TRB) (2015) published an article which estimated that about 30,000 lives were lost each year due to congestion (TRB, 2015). All of these issues have necessitated a sustainable and reliable approach towards developing revenue sources for the road network and using the available resources efficiently (USDHS, 2010).

1.2. Redeveloping Project Management Strategies

The UK-government funded a research, Rethinking Project Management: Developing A New Research Agenda, with an aim to develop a research agenda for improving the existing project management strategies by focusing on seven core areas of concern (Winter & Smith, 2006). These core areas include projectification; managing multiple projects; actuality of the projects; dealing with uncertainties; managing business projects; the profession and; practitioner development (Winter & Smith, 2006). One of the key reasons for commencing this project was the need to integrate academicians and practitioners to solve the real world problems which are complex, unpredictable and multidimensional; and come up with a robust solution (Winter & Smith, 2006). The theory behind the integration was that all the practical action that is carried out is based on some guiding theory or methodologies which have been accumulated in the academic experience in those fields (Winter & Smith, 2006). The primary outcome of this research was a framework of five directions for the future research which are as follows (Winter & Smith, 2006):

1. Theories of complexity of projects and project management: This was directed towards understanding that each project is unique in its complexity and that the models that are in place today to deal with these complexities are not ‘fit-for-all’. The complexity of each

project should be analyzed before deciding on the relevance and the usefulness of the model that is in use for finding the most efficient solution. Thus, it is imperative for the practitioners to work with multiple images and theories before establishing a solution.

2. Projects as social processes: This was directed towards the need to develop models which show the actual complexity of the projects focusing at all levels. This especially includes the complex social interaction of the projects with the existing social practices, stakeholder relations, politics and power.
3. Value creation as the prime focus: This was directed towards the change that is currently undergoing in many organizations of creating a project of value rather than just a 'product-creation'. Creating value signifies the value of the project in terms of maximizing revenue generation and managing the benefits in relation to different stakeholder groups which is primarily driven by the industry needs.
4. Broader conceptualization of projects: This was directed towards the acceptance that every project requires a multidisciplinary approach and cannot be solved by the members involved in single discipline which leads to a narrow conceptualization of the projects. By taking into account the directions that have been mentioned above, the practitioners can have a holistic approach to the projects revealing new insights and new techniques of managing the projects, which otherwise is not apparent to them.
5. Practitioners as reflective practitioners: This was directed towards understanding the crucial role of the leaders and their leadership capabilities such as experience, intuition and pragmatic application of the theory in conducting successful management of the projects. Thus, the focus should be on developing reflective practitioner capabilities as

the people's ability to intellectually engage themselves in the complexity of the projects has proven to be more beneficial than the existing methods and tools.

During the same time as the development of the abovementioned project, in the United States, the Second Strategic Highway Research Program (SHRP-2) was authorized to find breakthrough resolutions in transportation within a short period of time with concentrated resources (Shane et al., 2014a). This program focused primarily on four major areas i.e. safety, renewal, reliability and capacity (Shane et al., 2014a). In 2014, as a part of the renewal program under SHRP-2, the Transportation Research Board (TRB) published the project, R-10, Project Management Strategies for Complex Projects. The main aim of this project was to develop effective strategies and tools to address the challenges of the management of complex projects, which were defined as reconstruction or rehabilitation projects and are significantly different from the traditional projects (Shane et al., 2014a). For this purpose, the research team developed the 5 Dimensional Project Management (5 DPM) strategy and identified several case studies to verify these dimensions and developed tools to manage these factors within the dimensions (Shane et al., 2014a). This multi-step approach along with the development of a complexity map for each of the case studies led to the development of five project development methods and thirteen tools (Shane et al., 2014a). The 5DPM thus developed was based on the conceptual framework developed by the UK-government project mentioned above (Shane et al., 2014a). Traditional project management is rooted in the integration of only three dimensions of cost, schedule and scope to effectively deliver the project (Shane et al., 2014a). However, recently as there has been a substantial shift in the infrastructure needs from building new roads to replacing, renewing or expanding the existing roads, a need arises to change the strategies applied for formulating an efficient project management plan (Shane et al., 2014a). The managers of these complex projects have to optimize the available resources adhering to the technicalities of the projects and deal with the known and unknown constraints (Shane et al., 2014a). Thus, the additional dimensions of financing (known) and context (unknown) were added to the traditional dimensions of cost, schedule and scope (Shane et al., 2014a). After the development of the 5DPM, the research team conducted a three-level structured case study in which they identified a diverse range of projects depending upon the size, type, level of success, location and current phase of each project (Shane et al., 2014a). Based on these criteria, the team identified 18 projects of which 15 projects were within the United States and the other 3 were international projects (Shane et al., 2014a). The research team drafted a guide which included training materials for the project management teams (Shane et al., 2014a). They also conducted several pilot workshops with different Departments of Transportation (DOT) all over the country to test the efficacy of the guide and the training material and for their refinement (Shane et al., 2014a).

1.3. Problem Definition and the Research Need

A diverse range of participants were grouped together to form the project teams for the pilot workshops mentioned above which included construction engineers, project directors, field engineers, geotechnical engineers, project control engineers etc. (Shane et al., 2014a). The R-10 research team used a two-step ranking system in the workshop in which the first step comprised of ranking the five dimensions i.e. cost, schedule, technical, context and financing in the order from most complex to the least complex with respect to the project (Shane et al., 2014a). Following this, in the second step the participants were asked to assign values from 0 to 100 to each of these dimensions based on the impact each had on the project (called the "the dimensional impact rating") (Shane et al., 2014a). The baseline standard for this dimensional impact rating was 55 and so essentially the dimension that scored above 55 was considered to have greater impact than the one that scored below 55 (Shane et al., 2014a). When the results of this pilot workshop was presented, it was noticed that the there was an overlap of the impacts of dimensions on each other i.e. for example the impact of contextual dimension was seen affecting the technical, schedule and cost dimensions as well and if all these four dimensions could not be optimized, there was a severe impact on financing dimension (Shane et al., 2014a).

Although the complexity mapping developed by the research team provided an effective solution, it was not efficient in the sense that it took almost a day and half to complete the entire process which involved conflicting views from the members of the project team (Shane et al., 2014a). And as the results were provided as a team consensus, the views of individual members were not taken into account separately. The research team used a survey-based approach with a wide range from 0 to 100 rather than a structured quantitative approach. Also, under each of these dimension, a range of factor categories and factors have been categorized in the study; and thus a rating of '65' or '45' only specifies that a particular dimension has a greater impact or a lower impact than the average but it does not signify the degree of impact the various factor categories and the factors have.

It was also noticed that the most difficult dimension to predict and plan for while drafting the project management plan was the context dimension which refers to the external factors (Shane et al., 2014a). The context dimension itself included eight factor categories and twenty-six factors under it. The impact of these factor categories and factors under each of the dimension need to be accounted for individually in order to formulate a robust risk management strategy. Owing to this, a need was identified to develop a framework that would provide a rating for the factor categories and the factors under the dimension instead of just rating the dimension by using a structured approach. Being the most difficult dimension to assess and owning to the scope of the project, the assessment of context dimension was chosen for this research.

1.4. Purpose of the Research

To address the abovementioned need, the ultimate purpose of this study is to develop a decision-making framework using Analytic Hierarchy Process (AHP) to determine the relative weights of the various contextual factor categories and factors, first individually by each member of the project management team and then as an overall group. AHP is a multi-criteria decision making tool designed to help individuals in using intuition and rational thinking to select the best option from a number of alternatives based on multiple criteria (Saaty & Vargas, 2012). It uses a multi-level hierarchical structure of objectives, criteria, sub criteria and alternatives to obtain weights of importance of the decision criteria and the relative performance measures of the alternatives in terms of each individual decision criterion (Saaty & Vargas, 2012).

Additionally, after obtaining the relative weights of the factors from the members of the project management team individually, the combined relative weights of the factors as a group of project management team will also be presented in the study. This information is valuable because it will assess the factors and derive their weights as a group which will enable in having group consensus while drafting a project management plan.

This two-step method in identifying the weights assigned to the factors by the group is efficient as it can be done by the individual members in their own time without having opposing views from the other members and without the need to discuss to reach to consensus as a group. Since the project management team is comprised of people from various disciplines, one can identify which factor is riskier than other for different team members. This decision-making framework can be modified as per the specific needs of each complex project.

To show the implementation examples, this framework will be implemented on two complex highway projects in the state of Colorado which are US-34 Rebuild project and I-25 North Expansion project. The US-34 rebuild project consists of building a 21-mile section of the US-34 highway between Estes Park and Loveland which was heavily damaged in the 2013 floods (CDOT, 2013). The permanent repairs will include removing and replacing the temporary asphalt, embankment fill and temporary channel protection along with repairing bridges and retaining walls and replacing guardrails (CDOT, 2013). The Colorado Department of Transportation (CDOT) completed an Environmental Impact Statement (EIS) in 2011 to address regional and inter-regional movement of people and goods along I-25 and evaluate the multi-modal transportation improvements from Fort Collins-Wellington area to Denver, approximately a 60-mile section (CDOT, 2011). The entire project entails general purpose lanes in each direction between SH 66 and SH 14, tolled express lanes between 84^{th} avenue north to SH14, upgrading of 13 I-25 interchanges, 13 express bus stations, commuter rail service with nine stations connecting Fort Collins to Longmont, commuter bus service with 8 stations connecting Greely to downtown Denver and congestion management (CDOT, 2011). The project is divided into phases and 8 segments in order to provide funding flexibility and is expected to get completed by 2075 (CDOT). The I-25 North Expansion is the 8^{th} segment of the project which includes improvements in sections between Prospect Boulevard and SH 14, Prospect Boulevard Interchange, section between Prospect Boulevard and Harmony Road, and Harmony Road and SH 392.

1.5. Research Questions and Contribution to the Body of Knowledge

In reaching the above mentioned purpose, the following questions have been addressed in the study:

- What is the appropriate relative weight of each of the contextual factor category and factors identified in the SHRP-2 R-10 study?
- How can different relative weights from different members be combined into one final weight for each of the factor category and factors?

This framework will enable the project management teams of complex highway projects to determine the relevant weights of the contextual factors during the project management planning phase which can help them in making important decisions at the early stages of the project. Thus, with the help of this framework the relative weights of each of the factor can be obtained. This study contributes to the construction engineering and management body of knowledge by providing a user-friendly decision-making framework which relies on the experience of the members of the project management teams. One of the ways in which the results can be used is to formulate a risk management strategy to allocate the resources effectively based on the prioritization of the contextual factors and form a realistic schedule.

1.6. Scope and Limitations

As mentioned earlier, the decision-making tool developed is based on the findings of the R-10 study conducted under the Renewal program of Second Strategic Highway Research Program. The study had identified five dimensions to consider while drafting a risk management strategy for complex projects. The scope of this research is restricted to the comparison and relevant ranking of factors only under the context dimension; although the framework can be modified to compare the factors under other dimensions in a similar way and the dimensions itself to develop relevant rankings.

One limitation of the study was that some of the factor categories had only one factor, which eventually led to a higher global weight for that factor. However, as the results were in concordance with the views of the members of the project team, it was a strong indication that the framework was accurate.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

The number of transportation projects have increased tremendously with the increase in urbanization; and these projects play an essential role on the society's financial, social and political life and has a long-lasting effect on the community (Shang et al., 2004). In response to the deterioration of highway pavements, the federal and the state transportation agencies have shifted their focus from building new facilities to restoring, resurfacing, rehabilitating and reconstructing the existing ones (Herbsman et al., 1995; Lee & Thomas, 2007). These renewal projects are inherently complex owing to complex logistics, new construction methods or restrictive regulations but now, the complexity has increased manifold with an increasing demand from the public owners to deliver the projects faster and with more control over time and cost (Gransberg et al., 2006; Puerto et al., 2008; Shane et al., 2014a; Sillars, 2009). Thus, the project management strategies required for these transportation renewal projects need to change to incorporate the increasing demands (Shane et al., 2014a). Also, the context in which such projects have to be carried out is much more challenging and complex than the engineering of the project (Shane et al., 2014a). A report published by the National Cooperative Highway Research Program (NCHRP), identified a number of contextual factors that cause cost and schedule issues; some of them being difficulties in obtaining the rights-of-way, utility conflicts, underground conditions, environmental and political issues and concluded that these issues can be solved by using effective project management strategies (Jacobs Engineering Group, 2009; Shane et al., 2014a). As mentioned in Chapter 1, the SHRP-2, R-10 project developed a model based on the directions provided by the research by Winter and Smith (2006). Out of the five directions, one direction suggested that there is a necessity to account for the external contextual factors at the early stages of project development and not perceive them as risks (Shane et al., 2014a; Winter & Smith, 2006). Another direction suggested that each of these complex projects should be analyzed separately with a custom set of performance goals without taking the history or the conformity within the industry into consideration so as to account for the contextual factors relevant to each of them (Shane et al., 2014a; Winter & Smith, 2006). The following sections of this chapter provides a literature review on the various contextual factors identified in the R-10 study and how these factors can affect the project. The chapter concludes by providing a brief description of the contextual challenges in a few projects in the United States.

2.2 Contextual Factors

2.2.1 Stakeholders

Stakeholders factor category consists of all such parties that are directly affected by the project and have the potential to affect the project directly such as public, politician, owner and jurisdiction (Shane et al., 2014a). A report on the management of large infrastructure projects or megaprojects in Europe states that the project success is defined as "the satisfaction of all the stakeholders" and should be categorized by their impact on the project (Hertogh et al., 2008, p. 29; Shane et al., 2014a). Most of the literature has identified public as one of the most important stakeholders and a major factor in the success of the project (Shane et al., 2014a). Public's trust and confidence is not only important in the transportation community's abilities to invest valuable resources but also for the availability of these resources (Capka, 2004). The impact that these megaprojects have on community such as daily commerce, quality of life and environment makes it necessary for keeping these projects as transparent as possible for the public and not withhold the negative impacts (Capka, 2004; Shane et al., 2014a).

Another important stakeholder are the politicians involved as they lead the legislation and define the process when an agency plans the construction process (Shane et al., 2014a). One of the major reasons for delay in the construction of megaprojects is the process for obtaining approvals from the political parties (Booz et al., 2006; Shane et al., 2014a). Shane et al. (2014a) mentions that heavy pressure can come from the political parties to minimize traffic disruption and accelerate the project when the other stakeholders are unsatisfied with congestion, lack of environmental conditions and insufficient financing (Crichton & Llewellyn-Thomas, 2003; Shane et al., 2014a; TAC, 2009).

Another important stakeholder is the owner who is responsible for the determining which project to undertake and how to streamline the needs and the entire process of the project and the flow of communication between all the groups involved (Shane et al., 2014a). Owner is also an important entity in effectively managing the multicultural and multi-ethnicity of the project team (Larson & Gray, 2011; Shane et al., 2014a). The organizational structure is responsible for laying out the procedures for outlining responsibilities and lines of communication; and if not well-dealt with, can create a lot of barriers throughout the project's life-cycle (Larson & Gray, 2011; Shane et al., 2014a).

Jurisdiction is another stakeholder that might get involved in the project and the time taken for the jurisdictional review affects the length of the project (Shane et al., 2014a). Jurisdictions are also becoming important because of the new environmental regulations and the involvement of external agencies which either lack staff or are unable to provide meaningful input (Miller & Lantz Jr, 2009; Shane et al., 2014a). Hertogh et al. (2008) mentioned in their report that multiple border projects can cause loss in the value of the project as priorities and commitments of the different jurisdictions may vary (Hertogh et al., 2008; Shane et al., 2014a).

2.2.2 Project Specific Demands

The project specific demands are factors such as maintaining capacity, work-zone visualization and intermodal requirements that relate directly to the work done for a given project (Shane et al., 2014a). Martin and Does (2005) concluded that a critical factor in the success of any project is its ability to minimize the impacts and inconvenience to the traffic operations in terms of delays and safety during the entire construction process (Martin & Does, 2005). Chiu and Teft (2006) mentioned in their paper “Redevelopment of Canada’s Second Busiest Border Crossing”, that while developing the Blue Water Bridge Canadian Master Plan, the team had to develop almost twenty alternatives to obtain an optimum balance between the stakeholders and the users to minimize inconvenience to the travelling public (Chiu & Teft, 2006). The alternative that was ultimately selected included a phasing and a construction staging plan with a key challenge to maintain operation and traffic for 24 hours on all 7 days (Chiu & Teft, 2006; Shane et al., 2014a). Lee et al. (2000) mentioned that the California Department of Transportation (Caltrans) used a constructability analysis tool to determine the most efficient construction strategies to minimize the traffic delay and maximize the production (Lee et al., 2000). They found that the concurrent-construction working method was proved to be more efficient than the sequential-construction working method as continuous closures were deemed more successful providing lesser inconvenience to the public (Lee et al., 2000). Also, it was seen that there was an adverse effect on the production capability of the crew based on the number of lanes that had to be paved (Lee et al., 2000). Tom Sorel (2004) mentioned that the T-REX project in Denver was able to gain public trust only because there was minimal inconvenience to the travelling public as the traffic flowed in good shape through the corridor throughout the duration of the project (Sorel, 2004).

In an article “From Highways to Skyways and Seaways- The Intermodal Challenge”, Broadhurst (2004) mentions that the highway agencies should incorporate new design and construction innovations to comply with the accessibility requirements at train stations and parking lots (Broadhurst, 2004). The intermodal transportation projects may require relocating existing utilities which might be an issue for the budget and therefore for the multiple groups involved in the project (Broadhurst, 2004; Crichton & Llewellyn-Thomas, 2003; Shane et al., 2014a). Along with these issues, safety of workers should also be accounted for by ascertaining that the work zones are distinguished; work-zone visualization tools should be used during the planning stages; and coordination of relocations for intermodal projects should be maintained between the multiple groups involved (Broadhurst, 2004; Martin & Does, 2005; Shane et al., 2014a).

2.2.3 Localized Issues

Local issues consists of a wide range of factors including social equity, demographics, public services, land use, growth inducement, land acquisition, marketing, cultural, workforce and utilities (Shane et al., 2014a). This was found to be one of the most important category through literature as it relates to the factors affecting the most important stakeholder of any complex transportation project i.e. the public (Shane et al., 2014a). Barnes and Langworthy (2004) concluded that a number of independent dimensions can sometimes lead to failure in reaching a resolution between the agency and the public (Barnes & Langworthy, 2004). They also mentioned that there have been disputes regarding the local impacts where the locals believed that the outsiders benefitted more from the project than those who were directly affected which lead to issues of social inequity (Barnes & Langworthy, 2004; Shane et al., 2014a). Another issue that has been noted in causing social inequity is the toll infrastructure pay systems (Shane et al., 2014a; TAC, 2009).

Davies and Binsted (2007) studied the environmental equity on two projects which had performed Equality Impact Assessment and how this assessment helped in examining the spatially specific and non-spatially specific positive and negative impacts on the groups of people surrounding the project (Davies & Binsted, 2007). One of the main findings of Hertogh et al. (2008) for project purpose was the essential need to assess and prioritize the project in relation to its contribution to the economic and social problems they cause (Hertogh et al., 2008). These issues also give rise to issues such as causing problems in the demographics of the population, business losses and growth inducement which leads to impacts on park and environment (Barnes & Erickson, 2006; Shane et al., 2014a).

Although there has not been significant research, one other important factor to consider while constructing megaprojects is their impact on the emergency routes for the existing public services (Shane et al., 2014a). Heiner and Kockelman (2005) claim that hedonic price models and large sample data analysis should be done to accurately estimate the Right of way(ROW)-related procedures for the timely completion of the projects (Heiner & Kockelman, 2005). Both Tennessee DOT and Colorado DOT (CDOT) have found that the current procedures for acquiring ROW create barrier and can be a critical factor in the success of the projects (Broadhurst, 2004; Brown & Marston, 1999; Shane et al., 2014a). Chiu and Teft (2006) mentioned that these processes become more difficult when the land is held by the historic and tribal agencies causing further complexities (Chiu & Teft, 2006; Shane et al., 2014a).

The effects that these projects have on the local economy is also identified as one of the major criteria in assessing if the project is successful or not even though the literature remains scarce on this topic (Ashley et al., 1987; Shane et al., 2014a). The general framework provided by the Project Management Plan Guidance by the FHWA enlists project communications through media and public information plan as an essential component of the framework (FHWA, 2009). The marketing strategies to effectively communicate the information of the project status to all the project stakeholders, especially the public, should be incorporated during the pre-planning phase of the projects (FHWA, 2009; Shane et al., 2014a; Sorel, 2004).

Miller et al. (2000) published a paper on seeking the advantages of having a multiethnic and multicultural project team which they inferred could be superior to homogeneous teams (Miller et al., 2000). At the same time, this can also lead to much worse situations if not handled properly because of communication problems and the lack of cohesiveness between the members of the group (Miller et al., 2000). Some of the techniques that the project managers can apply to take advantages of diversity can be utilizing the common bond of technical knowledge and common elements; promoting communication by understanding team members' personality traits and by being more mindful of the culture differences while dealing with projects abroad (Larson & Gray, 2011; Miller et al., 2000; Shane et al., 2014a).

As most of these projects are located in the congested metropolitan areas, another factor to consider is the adjustment of utilities to make provisions for the new or expanded facilities (Chou et al., 2009). These are also claimed to be one of the most cited reasons for delay and cost overruns owing to the involvement of so many groups (Chou et al., 2009; Ellis, 2003; Pickering, 1999). Kraus et al. (2008) analyzed the specific utility conflict data flows with the data needs of the stakeholders to develop a prototype system for managing the utility data while Chou et al. (2009) analyzed the strategy "Combined Transportation and Utility Construction" (CUTC) to help alleviate the complications and risks of utility adjustments (Chou et al., 2009; Kraus et al., 2008).

Another major issue was identified in the report by SHRP-2, R-10 study, which should be considered as a local issue, the ability of the workforce available for the required job, but thus far no literature has been published on this topic (Shane et al., 2014a).

2.2.4 Resource Availability

While the ability of the available workforce was accounted for in the local issues, resource availability deals with the project's accessibility to the required workforce (Shane et al., 2014a). Hertogh et al. (2008) identified a lack of suitable training for sponsor and project team's working skills on large complex projects and they found that the focus was only on the development of project team's management skills (Hertogh et al., 2008; Shane et al., 2014a). Resources such as construction laborers, material delivery and equipment can also lead to potential delays in construction if they are not effectively handled; and the goal should be to maximize the production capability (Crichton & Llewellyn-Thomas, 2003; Lee et al., 2002; Shane et al., 2014a).

2.2.5 Environmental Conditions

Environmental conditions deal with the environmental sustainability issues that are faced by the project team and how these issues can lead to limitations and changes in carrying out the project (Shane et al., 2014a). Vanegas (2003) developed an initial set of principles to implement built environment sustainability needs to relieve the environmental effects of construction and promote sustainable development (Vanegas, 2003). One of the framework principles states that the engineers should design and produce new materials which are harmless to the human health and environment (Vanegas, 2003). Hendrickson and Horvath (2000) estimated the environmental emissions and wastes for four major U.S. construction sectors, one of which was highway and bridges; and found that the total toxic releases just for highway and bridges contributed to 0.7 % as a percentage of U.S. total (Hendrickson & Horvath, 2000). As highway construction is one of the major consumers of non-renewable energy and a significant polluter, it is imperative to attain sustainability measures for materials and structures (El-Assaly & Ellis, 2000; Shane et al., 2014a). The project managers need to decide on the best course of action by using different renewable options and utilizing the recycled materials that are available (El-Assaly & Ellis, 2000; Shane et al., 2014a). Horvath (2004) concluded that most of the literature focuses on the use-phase of these structures rather than the construction-phase which is also an important issue and the environmental analysis should extend to other stages too including raw material extraction and processing, materials manufacturing and maintenance (Horvath, 2004). End-of-life options such as deconstruction and demolition should also be studied to find the environmentally and economically feasible options to alter the environmental degradation (Horvath, 2004).

Another important factor to consider is the limitations provided by the external environmental factors which dictates the coordination and planning of the project (Shane et al., 2014a). While planning I-70 through the Glenwood Canyon, the designers examined several elements such as terraced roadway, cantilevered roadways, retaining walls and revegetation program to develop an environmentally sensitive design solution (Trapani & Beal, 1983). Another project in Canada studied the relationship among grizzly bears and their habitat that dominated a major transportation corridor and the highway system (Chruszcz et al., 2003). To prevent the loss of habitat connectivity and develop environmentally sustainable solutions, the design team studied the bears' spatial response to roads, road-crossing behavior, crossing location attributes and temporal patterns of cross-road movements (Chruszcz et al., 2003). Thus, it is necessary to identify and mitigate the environmental impacts by assessing the methods for integrating transportation planning with environmental limitations (McLeod, 1996; Shane et al., 2014a).

2.2.6 Legal and Legislative Requirements

Hertogh et al. (2008) observed that the effects on the project need to be carefully assessed when two countries are involved in the project because of the different nature of standards and consent procedures in both the countries (Hertogh et al., 2008). They found that these legislative issues have the ability to influence the progression of a project and are one of the major causes of increase in project scope (Hertogh et al., 2008; Shane et al., 2014a). It is necessary for the project team to understand all the legal procedures and laws so that they can make the right decisions (Shane et al., 2014a). Tennessee DOT faced barriers while procuring the land owing to the land acquisition legislation (Brown & Marston, 1999; Shane et al., 2014a). Gransberg and Molenaar (2008) studied the effects design-build (DB) project delivery method had on the staff of the public agencies and found that using DB had no negative impact on the number of engineering jobs in the public agencies and that using this method performed better than the Design-Bid-Build (DBB) Method in terms of cost and schedule (Gransberg & Molenaar, 2008). However, some states still have procedural laws in place which makes it difficult for the owner to use an alternative project delivery method (Shane et al., 2014a). Not only the acceptance of alternative project delivery according to the procedural laws is important but also the willingness and ability of local firms to participate in such methods is also significant (Shane et al., 2014a). However, literature summarizing the adverse effects of procedural laws on alternative delivery methods is limited at this point (Shane et al., 2014a).

2.2.7 Global and National Conditions

A lot of research revolves around how transportation projects impact the economy of any place but there is scarcity of literature on how the transportation projects are impacted by a change in global or national economy (Shane et al., 2014a). Damnjanovic et al. (2009) identified that cost of materials and oil-based fuels significantly increase the impact on the bid items because of limited capacity to produce materials and price of energy (Damnjanovic et al., 2009). Some materials like asphalt and structural steel which are directly related to the oil-based fuels have experienced a great increase in cost since 2003 (Damnjanovic et al., 2009). The highway material costs have risen over 20% from 2007 to 2009 and are continuing to increase and that is why it is essential for the project managers to consider the global and national economies while planning a project (Damnjanovic et al., 2009; Shane et al., 2014a). A workshop conducted by the Florida DOT concluded that the rise in fuel and steel costs were adversely affecting the bidding market (Larson & Gray, 2011; Shane et al., 2014a).

2.2.8 Unusual Conditions

Unusual conditions include all such events which are difficult to plan for proactively such as anomalous weather and force majeure but have the possibility to affect transportation projects tremendously (Shane et al., 2014a). Mentis (2015) concluded that even though the control of such events is beyond the managers, effective threat assessment should be performed and integrated into the overall project decision-making and execution (Mentis, 2015). The weather conditions might also be unusual where the project is located; for example, a bridge demolition project in Canada was affected by unexpected weather and the construction had to be altered (Martin & Does, 2005; Shane et al., 2014a).

2.3 Contextually Challenging Projects

2.3.1. James River Bridge/ I-95 Richmond Project

This project is a restoration of 0.75 mile long James River Bridge on I-95 that runs through the central business district of Richmond, Virginia, along with improvements to widen Route 1, Jefferson Davis Highway, enhance signalization and install high mast lighting system (Shane et al., 2014b). The bridge has six lanes and was built in 1958 and since then the traffic has increased three fold on this bridge (Shane et al., 2014b). The bridge was rebuilt in 2002 and the contractor suggested the use of pre-constructed composite units (PCUs) and crew set the new prefabricated unit in one day (Kukreja, 2004; Shane et al., 2014b).

Owing to the contextual complexity in this project, the schedule of the project had to be split into two components, with one component focusing on work without disrupting traffic and the other component requiring some traffic control (Shane et al., 2014b). These schedule decisions were made before the design was complete with a lot of assumptions and thus the design team had to validate before marketing the project to the public (Shane et al., 2014b). The Virginia DOT primarily focused on public opinion and procurement constraints in the project planning and procurement phase (Shane et al., 2014b). As the public relations was very important for the VDOT, it advanced a full-scale information campaign as soon as the project was approved (Shane et al., 2014b). The planning process continued for three years and VDOT ensured that residents and business leaders were involved throughout the process to develop the most suitable solution (Shane et al., 2014b). VDOT had taken measures to employ various message boards throughout the corridor one year in advance to modify traveler's behavior and influence them to self-detour which eventually reduced the average hourly weekday traffic from 4,800 to 3000 vehicles per hour (Kozel, 2003; Shane et al., 2014b). VDOT developed three construction options and with the advice from Community Advisor group which consisted of Downtown Chamber of Commerce and other concerned citizens, finalized the option which best met the traffic demands, caused least inconvenience, had the shortest construction period and which also ensured a lane for public services and emergency vehicle route (Kukreja, 2004; Shane et al., 2014b). These relationships with the community were maintained and kept positive even during the project execution phase and the VDOT and contractor made minor adjustments to the schedule to help downtown business with specific needs (Shane et al., 2014b). The construction team used removable barricades to efficiently shift evening traffic and a wrecker service to remove disabled vehicles from construction work zone and maintain flow of traffic during construction hours (Shane et al., 2014b). Shane et al. (2014b) identified that the use of construction-manager-at-risk would have been a better delivery method for this project as the contractor had to make design changes after the project had started and so its initial input would have been valuable (Shane et al., 2014b). They also concluded that the greatest challenge in this project was addressing the political sensitivity, maintaining traffic flow that did not adversely affects the business and encouraging innovative construction means and methods by implementing different contracting schemes (Shane et al., 2014b).

2.3.2. New Mississippi River Bridge Project

This project consisted of building a new 1,500 feet main long-span and cable-stayed bridge over the Mississippi river along with new North I-70 interchange roadway connection between existing I-70 and the new bridge (Shane et al., 2014b). The contextual difficulties were already high in this project as the crash incidence near the existing bridge was three times more than the national average and the congestion on this bridge was ranked among the 10 worst congested corridors in the U.S. (Shane et al., 2014b). Severe traffic conditions such as capacity and mobility of the traffic made the schedule a priority and thus the redesign and expansion was a critical process (Shane et al., 2014b).

The contextual difficulty in this project was not related to the support for the project from the stakeholders but a desire for input from a lot of them in the process (Shane et al., 2014b). There were some design changes which needed to be communicated to the public in the right manner to keep the project financially viable as the public was opposed to the tolling option (Shane et al., 2014b). One of the key reasons to gain public's support was the federal appropriation which dictated having the bridge as designed or not having the bridge at all (Shane et al., 2014b). The project team used the Grant Anticipation Revenue Vehicle (GARVEE) bonds on the Missouri side for which it needed the approval of local and statewide jurisdictions (Shane et al., 2014b). Furthermore, other aspects of the project required compliance with dual state and FHWA regulations and coordination between multiple jurisdictions, state historic preservation offices (SHPO) and the Environmental Protection Agency (EPA) (Shane et al., 2014b). The Intelligent Transportation System (ITS) was integrated with the work zone plans to coordinate closures and peak-hour restrictions during the construction (Shane et al., 2014b). Meetings were held with the service providers for emergency services; and the project team held security workshop to make the team aware of the fact that that major bridges are high-potential targets for terrorist attack (Shane et al., 2014b). During the risk analysis process, some issues were identified related to the railroad ROW and taking of easements which eventually led to a lawsuit to determine if the economic loss must be applied to the easement agreements (Shane et al., 2014b). The positive impact on the local employment proved to be advantageous for the project in helping it to move fast and so maintenance of access to the local businesses was critical (Shane et al., 2014b). Some of the other context issues were the involvement of SHPO owing to the archeological sites and the labor union influx (Shane et al., 2014b).

As many utilities were involved and the span crossed a major railroad which included several set of tracks, the project team dedicatedly managed the utility and railroad coordination facilitated by the risk management process (Shane et al., 2014b). There were some minor complications in the environmental issues such as incorporation of solar panels in the main span design and the use of soil caps to resolve the issue of lead contamination (Shane et al., 2014b). The issue of global and national conditions proved to be beneficial for the project as the steel prices went down helping in contingencies and the overall budget of the project (Shane et al., 2014b). There were issues with the unusual conditions as the contractor was required to pull the equipment barges off the river when the water level was within 2 feet of flood stage (Shane et al., 2014b).

2.3.3. Transportation Expansion (T-REX) SE I-25/I-225 Project

This project consists of 17 miles of highway expansion and improvements and 19 miles of light rail developments along the I-25 from Logan Street to Lincoln Avenue and I-225 from Parker road to newly configured I-225 interchange (Emerson et al., 2016; Shane et al., 2014b). The main contextual complexity was to continue the flow of traffic throughout the project and the subsequent challenging work environment it posed (Shane et al., 2014b). Also, the political parties were worried that they would lose elections if the project were to fail (Shane et al., 2014b). Some other contextual issues that were handled by the CDOT and the Regional Transportation District (RTD) were legislative changes to allow design-build and best-value selection (as this was the first design build project in the state of Colorado), public outreach, utilities, and ROW (Shane et al., 2014b).

CDOT and RTD had established at the very beginning that completing the project on time and budget was not enough; and that keeping the public content throughout the project was very essential due to the lack of alternative routes between Denver downtown and southeast business district (Shane et al., 2014b). Owing to this, the DB method was chosen over the traditional DBB; and the then-governor singed a legislation to allow design-build and best value selection in Colorado (Shane et al., 2014b). The project team developed a public involvement program for allowing the public to participate in the environmental planning process and hired a marketing consultant to prepare an assertive marketing campaign (Shane et al., 2014b). Another major issue was the relocation of utilities in the existing corridor for which the CDOT and RTD had to work with 45 utility companies responsible for 800 separate utilities and develop agreements before procurement phase, reducing the risk to the contractor (Emerson et al., 2016; Shane et al., 2014b). This project required 30 total ROW purchases and 172 partial ROW purchases; and so the relocation experts worked with the homeowners and tenants to assist them with housing and tenants' rights and financing and relocating housing (Emerson et al., 2016; Shane et al., 2014b). The global and national events created a major setback for the project team since the notice to proceed was awarded before 9/11 and thus the project team faced decreased labor availability and increased inflation in the execution phase (Shane et al., 2014b). For this project, the owner and the contractor communicated to the public the daily progress and maintained a website containing real-time maps which showed traffic conditions, closures, and actual travel times (Shane et al., 2014b). The project team even gave hotel vouchers to the public that were directly affected by the construction noise in the nighttime (Shane et al., 2014b). As mentioned earlier, since there was no alternative route, the CDOT developed an emergency services task force and informed them about the closures and the detours (Shane et al., 2014b). Based on the interviews with the project personnel, the R-10 study team concluded that the success of the project was attributed to the minimization of inconvenience to the public, selection of design-build project delivery method, public outreach, and the utility agreements (Shane et al., 2014b).

2.3.4. Detroit River International Crossing Project

This project involves building a new Detroit River Crossing between Detroit, Michigan and Windsor, Canada which separates the United States and Canada at Ambassador Bridge (Shane et al., 2014b). This bridge provides a freeway-to-freeway connection between I-75 Detroit and Hwy 401 Windsor and will complement an existing bridge and an existing tunnel which currently poses limitations on the commercial vehicles usage (Shane et al., 2014b). The main purpose of the bridge is to provide safe and efficient movement of people and goods across the US- Canadian border as its one of the busiest crossing in North America and is central to the economies of both the countries (Shane et al., 2014b; Sutcliffe, 2008).

As per the complexity rating of this project in R-10 study, it was rated highly for contextual and financing dimension primarily because multiple stakeholder agencies were involved in this project such as the Michigan DOT and FHWA in the United States and Ontario Province and Transport Canada in Canada (Shane et al., 2014b). Owing to this, separate documents were prepared for multiple stakeholders involved in each country (Shane et al., 2014b). As there were four organizations involved, it was determined that individuals and resources would be assigned according to the specific stages of development of the project (Shane et al., 2014b). A lot of other contextual factors were also causing difficulties in this project such as various political issues, authorization of Public-Private Partnership (PPP), and competing interest with the private owner of Ambassador Bridge (Shane et al., 2014b). Although, the core working group was comprised of project managers and technical staff from the above mentioned four agencies, more than seven other federal agencies and more than eight state and local agencies were also involved with the project (Shane et al., 2014b). Another important design issue that was affected by the context was that the bridge would be connected to the U.S. side to a plaza which will directly connect to the freeway via a Y-style interchange and the ramps will be elevated over the existing rail lines and a local street (Shane et al., 2014b). Some of the specific contextual issues that were critical to the project are as follows (Shane et al., 2014b):

- Protecting community and neighborhood characteristics
- Maintaining consistency with local planning and protecting cultural resources
- Protecting natural environment and maintaining the air quality
- Improving regional mobility through constructability

2.3.5. I-40 Cross Town Project

This project involves relocating about 4.5 miles of I-40 Crosstown from May Avenue to I-35 interchange in Oklahoma City, Oklahoma and includes 23 separate work packages in the construction phase (Shane et al., 2014b). This project consists of 10 lanes which carry 173,000 vehicles per day and was rated at a level of 100 for the context dimension in the R-10 study (Shane et al., 2014b). The project was already challenging because of the lack of capabilities of local design and construction industry and this issue was further exacerbated because of contextual factors such as availability of funding and stakeholder impacts coupled with the railroad and ROW issues (Shane et al., 2014b).

The main contextual issues were noise and vibration, ROW acquisition and relocation, public opinion and procurement restraints (FHWA, 2004; Shane et al., 2014b). The design for the new I-40 crosstown heavily contributed to the noise and vibration issues; and since this corridor was adjacent to the Riverside neighborhood, the noise levels had to stay below that of FHWA noise abetment criteria, which was not the case (FHWA, 2004; Shane et al., 2014b). Also, because of the public's concern, the Oklahoma Department of Transportation (ODOT) committed to perform structural surveys for all the buildings along the Alternate D route (FHWA, 2004; Shane et al., 2014b). Several of the utilities such as water lines, sanitary lines, and storm sewer lines required adjustment as the alignment of the road was changed (Bowman, 2011). The relocation of these utilities were included in the construction contract; and a corridor wide utility relocation master plan was developed in order to account for the number of conflicts and minimizing the impacts to travelling public (Bowman, 2011). The corridor also led to the relocation of minority and low-income residences which had greater impact than the businesses owing to the landscaped pedestrian bridge over I-40 which was to act as a buffer between the Riverside neighborhood and the new alignment of I-40 (Shane et al., 2014b). This corridor was being built in an existing railroad corridor; and hence the Oklahoma DOT (ODOT) had to work extensively with the Burlington Northern Santa Fe Railroad and the Union Pacific railroad to maintain the relationship and have acceptable solutions for all the parties involved (ODOT, 2015; Shane et al., 2014b). The new alignment of the corridor also posed problems for the phasing and sequencing of the construction because of the existing rail tracks; and the proximity to the Oklahoma River reduced the number of alternative routes available for use by the public which ultimately affected the number and duration of street closures at any given time (Bowman, 2011). All of this led the ODOT to approach phased construction with multiple construction contracts (Bowman, 2011). The ODOT had made conscious efforts to involve the residents, leaders and various organizations of the Oklahoma City to create the most suitable solution for the project (ODOT, 2015; Shane et al., 2014b).

2.3.6. Lewis and Clark Bridge Project

The Lewis and Clark bridge is a 5,478 feet long bridge with 34 spans that carry almost 21,000 vehicles every day and runs over the Columbia river between Washington and Oregon (Ahn et al., 2011). The project consisted of replacing the deck by a full-depth precast deck to increase its life expectancy by 25 years (Ahn et al., 2011). Although the original planning had started in 1993, the project was not approved until 2002 as it took nine years to get the public consent (Ahn et al., 2011). The bridge was to completely shut down during the construction and thus outstanding funds were used for services such as ferry operations and Medical Emergency Helicopter so as to address the needs of the public (Ahn et al., 2011).

This project was rated 100, which is the highest rating value, in the factor rating footprint in R-10 study primarily because the design was highly dictated by minimizing the impacts on the public and the project team had to prepare several options to manage the public’s needs and expectations (Ahn et al., 2011; Shane et al., 2014b). As mentioned earlier, it took the owner almost nine years to seek solutions to minimize the traffic impacts and get consent from the public stakeholders on the best possible way to construct the bridge (Ahn et al., 2011; Shane et al., 2014b). The project team used a small physical model to explain the process of the construction to the public (Ahn et al., 2011; Shane et al., 2014b). The small local community also posed a huge challenge for the project because of the attention it was drawing and had to be timely notified about the project and its progress (Ahn et al., 2011; Shane et al., 2014b). Even though the owner had to go to great extents to satisfy the public, public’s participation was one of the main reasons for the success of the project (Shane et al., 2014b). The communication plan for maintaining capacity by the owner included a website updated daily, live webcam, local papers with weekly calendars, phone line to public, highway advisory radio and email and text alerts to alert the public of lane closures, detours and time of construction activities (Ahn et al., 2011; Shane et al., 2014b).

CHAPTER 3: METHODOLOGY

The purpose of this chapter is to present the methodology that has been used in this research. As mentioned in chapter one, the ultimate purpose of this study is to develop a decision-making framework using AHP to determine the relative weights of the various contextual factor categories and factors for a given project first by each member of the project management team and then as a group. The framework consists of four main steps:

1. Identification of the initial list of contextual factors to be considered by the project management team of complex highway projects based on a previous study by SHRP-2, R-10.
2. A meeting with the members of the project management team of the transportation agency to vet the factors identified in the step above and then to add any other factors specific to the project which were not a part of the initial list.
3. Development and implementation of a survey instrument based on the AHP methodology in order to assign weights to the contextual factors finalized in step ‘2’.
4. Combining the responses from the team members of the project management team of the transportation agency into one overall ranking for all the factor categories and factors.

3.1. Identification of Contextual Factors from SHRP-2, R-10 Study

The study, R-10, conducted by the SHRP-2 was one of the first studies to provide a comprehensive list of the factors of complexity that should be considered by the project management teams of transportation agencies even though there has been few studies on separate factors with majority focusing on the effective management of stakeholders (Booz et al., 2006; Capka, 2004; Crichton & Llewellyn-Thomas, 2003; El-Gohary et al., 2006; Freeman, 2010; Hertogh et al., 2008; Larson & Gray, 2011; Miller & Lantz Jr, 2009; Olsson, 2006; Sutterfield et al., 2006; TAC, 2009) and a few others focusing on sustainability requirements (Chruszcz et al., 2003; El-Assaly & Ellis, 2000; Hendrickson & Horvath, 2000; Horvath, 2004; McLeod, 1996; Trapani & Beal, 1983; Vanegas, 2003). The R-10 study defines the contextual factors as the external influences that have an impact on the project development and progress (Shane et al., 2014a). This study had reported the results by conducting an exhaustive literature review and identified 8 factor categories and 26 factors. The definitions of these factor categories and factors are given below (Shane et al., 2014a):

1. **Stakeholders**: It includes everyone who is directly or indirectly associated with the project and is going to get affected by the project in some or the other way including public, politician, owner and the jurisdictions.
    1.1. **Public** is the most important stakeholder as the success of the project is defined by how it is perceived by the public at large.
    1.2. **Politicians** are especially important in convincing the public that the project is needed and also for financing the project.
    1.3. **Owner** is the most affected stakeholder by the success or failure of the project.
    1.4. **Jurisdiction** refers to the outside parties like Federal Highway Administration (FHWA) or State Historical Preservation Office (SHPO) who may be responsible for directing the regulations and limitations for the project.
2. **Project-Specific Demands**: This category includes all those factors that are directly related to the project such as maintaining capacity, work-zone visualization and intermodal requirements.
    2.1. **Maintaining capacity** refers to how well the site is being maintained with respect to lane closures, detours, and time of activities.

2.2. **Work-zone visualization** refers to how well the public is informed about these activities through signage.

2.3. **Intermodal requirements** state that other modes of transportation should be considered while planning the construction to increase capacity or when the construction affects an existing mode of transportation.

3. **Resource Availability:** This category includes all types of resources that may be required for the project and the capability of the project management team to gather all the resources in time.

3.1. **Availability of direct resources** includes the availability of resources in terms of labor, material and equipment.

3.2. **Project management capabilities** refers to the capability of the different parties associated with the project to gather these resources.

4. **Environmental:** This category includes factors that impact the environment as a whole.

4.1. **Sustainability** refers to the use of sustainable materials and methods for construction.

4.2. **Limitations** relates to the environmental study or research that needs to be carried so that the project can be built by sustainable means and methods.

5. **Legal and Legislative Requirements:** This category relates to the legal and legislative requirements required when many parties are involved or when there are some legal restriction as per the existing laws to complete the project.

5.1. **Procedural laws** include the laws relating to issues such as permitting, zoning, land acquisition, and use of a different project delivery method such as Design-Build or Construction Manager at Risk.

5.2. **Local acceptance (jurisdiction)** refers to the acceptance and willingness of using these project delivery types if allowed by the procedural laws.

6. **Global and National Events:** This category includes factors which affect the project owing to financial or political instabilities at the global or national level.

   6.1. **Global and national economic factors** such as growth, interest rates, and unemployment.

   6.2. **Global and national incidents** such as political unrest, instability, and uncertainty.

7. **Unusual Conditions:** This category includes factors related to the conditions that are abnormal and unforeseen.

   7.1. **Weather** is something that cannot be planned for whereas climate is something that is already accounted for during the planning stage.

   7.2. **Force majeure** includes factors like catastrophic events or terrorism.

8. **Localized Issues:** This category includes factors that affects the public and businesses in the area where the construction is being carried out.

   8.1. **Social equity** refers to the aspect that the construction of any project should be beneficial for all the classes of the society and should not harm the lower class.

   8.2. **Integration of land use planning, growth inducement and economic impacts** are all related to each other and relates to the fact that land use gets affected by the location of the project which might lead to growth inducement causing impacts to the local economy.

   8.3. **Demographics** relates to the population and how it reacts to the construction of new highways.

8.4. **Land acquisition** relates to acquiring the land for construction which might be difficult due to some external factors other than cost.

8.5. **Public emergency services** refer to fire and medical personnel and their change of course due to the lane closures for construction.

8.6. **Workforce issues** relates to the availability of labor in the given area or the increase or decrease in labor jobs in an area by implementation of a project. It also relates to the level of skill of the local labor force.

8.7. **Utilities** are gas, electricity, water or waste water lines as well as the railroads that need to be moved due to the new construction and should be preplanned.

8.8. **Cultural** factor relates somewhat to demographics and population's acceptance of the project in terms of its culture.

8.9.**Marketing** relates to how well the project is marketed to the public.

3.2. Meeting Protocol

After the identification of the contextual factors through the literature, it is necessary to vet all these factors with the different transportation agency. Most of the factors identified above will be specific to the project and will change according to the requirements of each specific project. To have an efficient vetting process, it is essential for the members of the project team to be on the same page with respect to the definitions of the factors. For this purpose, a need exists to identify the project management teams of such transportation agency who are in the early stages of a complex highway project (rebuild/reconstruction). After the identification of the projects, an email should be sent to each member of the project team informing them about the background and the definitions of the contextual factors that have been identified from the previous step. This step is conducted to familiarize project management team with the factor categories and factors in advance which will aid in shortening the duration of the meeting and thus keeping it to the point. After this, a meeting with the project team is scheduled to the carry out the second step of the framework i.e. to vet the contextual factors and subsequently add any other factors specific to the project.

The meeting should start with a brief review of SHRP-2 and an introduction of R-10 study. After that, the team members should be questioned about the email that was sent previously and if they have any questions, it needs to be addressed now before proceeding any further. The next step is to hand out the factor rating sheet which contains all the 8 factor categories and the 26 factors. This rating sheet uses a 0-2 scale with 0 being least important and 2 being very important and is used only for the purpose of vetting the factors. A scale of 0-2 is selected to keep the process short and quickly eliminate the factors so that majority of the time could be dedicated for important discussions. The factor rating sheet used is shown below:

1. **Stakeholders**:

0…1…2 The public
0…1…2 Individuals and groups with political influence
0…1…2 The owner agency (DOT, tolling authority, PPP concessionaire)
0…1…2 Jurisdiction of government units (FHWA, County, Municipality, etc.)

2. **Project-Specific Demands**:

0…1…2 Maintaining capacity
0…1…2 Work-zone visualization
0…1…2 Intermodal requirements

3. **Resource Availability**

0…1…2 Availability of direct resources
0…1…2 Project management capabilities

4. **Environmental Category:**

0…1…2 Sustainability
0…1…2 Limitations and constraints

5. **Legal and Legislative Requirements:**

0…1…2 Procedural laws
0…1…2 Local acceptance (jurisdiction)

6. **Global and National Events:**

0…1…2 Global and national economic factors
0…1…2 Global and national incidents

7. **Unusual Conditions:**

0…1…2 Likelihood and impact of extreme weather events
0…1…2 Forces majeure

8. **Localized Issues:**

0…1…2 Social equity
0…1…2 Integration of land use planning, growth inducement and economic impacts
0…1…2 Demographics of the population
0…1…2 Land acquisition
0…1…2 Public emergency services
0…1…2 Workforce issues
0…1…2 Utilities and railroad issues
0…1…2 Cultural factors
0…1…2 Marketing and public relations issues

Figure 3. 1: Factor Rating Sheet

After the completion of ratings by each individual team member, an average of the rating should be taken for each of the factors. Any factor that receives an average score of 0.5 and less should be eliminated and any factor with an average of 1.5 and greater should be retained in the list. The next part of the meeting should be dedicated to conducting a guided and detailed discussion of factors that received an average between 0.5 and 1.5. After each factor is discussed and decided to be kept or discarded based on that discussion, the project management team should be questioned if there would be any other factor category and/or factor that should be added to the existing list. This lends in having an exhaustive list of the factor categories and factors that are specific to the project. In the last part of the meeting, the next steps that will be taken to complete the framework should be explained and an introductory presentation on the AHP methodology should be presented.

3.3. Development and Implementation of a Survey Instrument Based on the AHP Methodology

3.3.1. Introduction to Multicriteria Decision Making (MCDM)

Decision making in the real world is primarily behavioral in nature and is more than just choosing the right option or choice (Belton & Stewart, 2002). Most decision making involves problems that are “ill-structured” i.e. for most of them the data is uncertain with conflicting and non-commensurate objectives, which can also have different units (Belton & Stewart, 2002). Also, since these involve human preferences, disagreements about appropriate assumptions are a common occurrence (Belton & Stewart, 2002). Owing to these difficulties, the best approach to deal with such ill-structured problems is to use a Multicriteria Decision Making (MCDM) method that provides a systematic and transparent approach which enhances objectivity and generates results which can be trusted with satisfaction (Janssen, 2001; Macharis et al., 2004b;

Zardari et al., 2015). MCDM can be defined as the "The study of methods and procedures by which multiple and conflicting criteria can be incorporated into the decision process" (Zardari et al., 2015, p. 9). For executing any decision making, there are eight steps that need to be followed which are as follows (Zardari et al., 2015):

a. In the first step, the decision maker needs to clearly define the problem.
b. Then if there are any important requirements to the problem which might aid in finding the solution, they should be added.
c. After the problem is well-defined, the next step is to establish the objectives/goals of the problem
d. Based on the objectives/goals that have been identified above, the decision maker should formulate the list of alternatives
e. Then the evaluation criteria need to be defined on the basis of which the alternatives will be selected.
f. Depending on the number and type of alternatives and the evaluation criteria, the correct decision making tool needs to be selected.
g. After the selection of the right tool, the decision maker will perform the selected MCDM analysis and deduce the results.

In the following section a review of the more common MCDM methods is performed to understand the different assumptions of each method and determine the appropriate MCDM method for the framework presented in this research.

3.3.2. Different Multicriteria Decision Making Methods

Multicriteria decision making methods can be broadly classified into the following three categories (Roy & Vanderpooten, 1996; Zardari et al., 2015):

a. Unique synthesis criterion approach
b. Outranking synthesis approach
c. Interactive local judgement approach

The unique synthesis criterion approach consists of aggregating the different viewpoints of the decision maker into one unique function which is optimized; the outranking synthesis approach consists of developing a outranking relationship based on the decision-makers preferences; and the interactive local judgement approach involves alternates between calculation steps and the dialog steps which gives successive compromised solutions to the decision maker's problems (Zardari et al., 2015). The selection of the right MCDM method depends on the type of information available, results required, transparency and the computation i.e. quantitative or qualitative and quantitative (Zardari et al., 2015). Although there is not one MCDM method that is more superior to others in all circumstances, some of the more potentially useful ones are Compromise Programming (CP) which is an interactive local judgment approach ; multiattribute utility theory (MAUT) and analytical hierarchy process (AHP) which fall under the unique synthesis criterion approach; and ELECTRE I-IV and PROMETHEE I-II which fall under the outranking synthesis approach (Abrishamchi et al., 2005).

Interactive local judgment approach forms one of the best methods to carry out an MCDM as it not only provides solutions to the problem but also an opportunity for the decision makers to become more aware of their preferences (Buchanan, 1994). However, this requires constant interaction with the decision makers which is not a feasible approach for the framework developed in this research. The next type i.e. the outranking synthesis approach methods consists of ELECTRE and PROMOTHEE and indicates the dominance of one alternative over the other (Kangas et al., 2001). The main advantage of ELECTRE is that it accounts for uncertainty and vagueness in terms of “zone of hesitation” which is a common occurrence in any real world decision making; however, the process and the outcomes are hard to explain in layman terms (Velasquez & Hester, 2013). It eventually leads to the formation of concordance and discordance matrices which in turn alters recognition of the strengths and weaknesses of the alternatives and impacts the results and analysis of trade-offs (Roy, 2013). This matrix is then evaluated for making the final credibility matrix from which the project qualification is performed to further complete the descending and ascending distillation (Roy, 2013). The results are also very sensitive to the level of thresholds which are used to define the concordance and the discordance index (Zardari et al., 2015). PROMETHEE I, another outranking method, leads to partial ranking of the alternatives and needs to be combined with PROMETHEE II in order to obtain the complete ranking of the alternatives (Brans et al., 1986). In this method, the analyst either assigns arbitrary weights to each of the alternatives and assumes the choices of the decision maker or has to work extensively with the decision maker to assign the appropriate preference relations and the weights (Brans et al., 1986; Macharis et al., 2004a). In both the above mentioned method, it is not possible to convert the individual judgements into group judgements and furthermore, the process becomes cumbersome as the number of alternatives increase.

Given all of these, the unique synthesis criterion approach was chosen to be the most appropriate MCDM approach based on the requirements of this research. The ranking of alternatives in the MAUT is based on the expected utility theory which states that if an appropriate utility (value) is assigned to each possible consequence and the expected utility (value) of each alternative is calculated, then the preferred decision is assumed to have the expected utility of highest value (Chen et al., 2010; Keeney & Raiffa, 1993). The main disadvantage of MAUT is that it is extremely data intensive which might not be available for the many decision-making problems (Velasquez & Hester, 2013). Another disadvantage is that it requires the decision maker to be very precise while assigning weights to the alternatives and have strong assumptions; and thus it has wide application in economics, financial, actuarial, energy management and agricultural problems (Velasquez & Hester, 2013). Out of all the methods used in the unique synthesis criterion approach, the one which is used widely in academia is AHP owing to its easy use (Vaidya & Kumar, 2004).

AHP has seen extensive use in fields such as planning, selecting the best alternative, resource allocations, resolving conflicts, optimization etc. which is similar to the requirements of the stated research (Vaidya & Kumar, 2004; Vargas, 1990; Zahedi, 1986). Al-Harbi (2001) used AHP to select the best contractor from a list of 5 contractors based on the criteria of experience, financial stability, quality performance, manpower resources, equipment resources and current workload (Al-Harbi, 2001; Vaidya & Kumar, 2004). A research was conducted by Topcu (2004) and Abudayyeh et al. (2007) to establish ranking in order to prequalify the contractors (Abudayyeh et al., 2007; Jato-Espino et al., 2014; Topcu, 2004). Al Khalil (2002) used AHP to select the most appropriate project delivery method from DBB, DB and CM based on various criteria as key success factors (Al Khalil, 2002; Vaidya & Kumar, 2004). Skibniewski (1988) discussed the benefits of using AHP in technical and economic evaluations while Ei-Mikawi and Mosallam (1996) used AHP to evaluate the utilization of composite materials in civil engineering application (Ei-Mikawi & Mosallam, 1996; Jato-Espino et al., 2014; Skibniewski, 1988). The factors required for developing the Life Cycle Cost benefit assessment of composite material was evaluated by Hastak and Halpin (2000) and based on the set of four criteria, five different alternatives were evaluated for the selection of highway alignment using AHP method (Hastak & Halpin, 2000). Shapira and Goldenberg (2005) used AHP to build a model for equipment selection in construction projects whereas, Lai et al. (2008) approached AHP to administer construction project budgets (Jato-Espino et al., 2014; Lai et al., 2008; Shapira & Goldenberg, 2005). Zayed et al. (2008) used AHP to build an evaluation model which was aimed at reducing the risks and uncertainties of the highway construction projects by determining a risk index (Zayed et al., 2008). AHP has also seen application in assessing the environmental impacts of construction such as to weigh the environmental impact associated with sustainable analysis of different flooring system by Bahareh et al. (2011) and development of a model which provides integration of Life Cycle Cost and Life Cycle Assessment in civil structures by Kim et al. (2013) (Jato-Espino et al., 2014; Kim et al., 2013; Reza et al., 2011). As seen from the examples above, AHP method can has been widely used in the construction industry owing to its simplicity and flexibility. Also, the previously mentioned MCDM methods had some drawbacks with respect to the purpose of this research to develop an overall ranking and thus, AHP was selected as the most appropriate method.

3.3.3. The Analytical Hierarchy Process

Analytical Hierarchy Process (AHP) was developed by Saaty in 1980 and is a multi-criteria decision making model which uses relative measurement on absolute scales of both tangible and intangible criteria based on the judgment of expert people (Saaty, 2008; Zardari et al., 2015). It uses multi-level hierarchical structure of alternatives in which the decision maker performs a simple pairwise comparison to generate the priorities (relative weights) of those alternatives (Saaty & Vargas, 2012). It is based on three principles which are 1) construction of a hierarchy; 2) priority setting and; 3) logical consistency (C. Macharis et al., 2004). To make the decision-making process easier and relevant, Saaty developed three levels of hierarchy i.e. goal, criteria and alternatives (Saaty & Vargas, 2012). Thus, the factors affecting the decision are organized in gradual steps from the general in upper level to the more specific in the lower levels (Saaty & Vargas, 2012). This also helps the human mind to deal with diversity and compare the importance of the elements in the same level (Saaty & Vargas, 2012). The process of the AHP methodology, based on the three principles above, are discussed in the following paragraphs (Bhushan & Rai, 2007):

a. In the first step, the goal is broken down into a hierarchy of criteria, sub-criteria and alternatives. This helps in establishing the relationship between the elements of all the levels in a networked manner. A generic hierarchy structure is shown below:

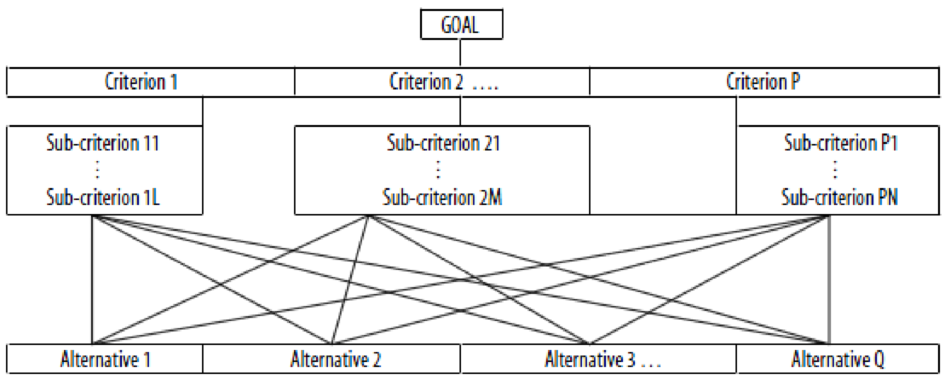

Figure 3. 2: Generic Hierarchy Structure of AHP

b. In the second step, a pairwise comparison is performed to determine the relative priority (weight) of each element in the hierarchy. The pairwise comparison mechanism uses a 1-9 scale and is shown in Table 3.1:

Table 3. 1: The Fundamental Scale of Absolute Numbers in AHP (Saaty, 2008)

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate Importance	Experience and judgement slightly favor one activity over another

4	Moderate Plus	
5	Strong Importance	Experience and judgement strongly favor one activity over another
6	Strong Plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity i has one of the above non-zero numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	A reasonable assumption

c. These pairwise comparisons are then organized in a square matrix which forms the third step of the process. The diagonal elements of this matrix are 1 since it is the comparison of the same element with itself which equals to 1. The number value in the matrix relates to the importance of the criteria. For example if the value in the (a_{ij}) cell is greater than 1 then the factor in the i^{th} row is more important than the factor in the j^{th} and if the value is less than 1 then the factor in the i^{th} row has a lower importance. If the value is less than 1 then the element (a_{ij}) is the reciprocal of the element in (a_{ji}).

d. After the data from the decision-makers are entered into the matrix, the principal eigenvalues and the eigenvectors are calculated in the fourth step. These eigenvectors are the relative priority (weights) for each alternative.

e. In the next step, the consistency of the matrix is evaluated. The pairwise comparison completed by the decision-maker in the second step is subjective which can lead to inconsistencies in the results. Saaty has defined a certain level of consistency and if the consistency ratio (CR) calculated is above the defined value then the decision-maker needs to go back to re-evaluate the comparisons (Saaty & Vargas, 2012)

f. For calculating the consistency ratio, we first need to calculate the consistency index (CI). The method for the calculation of the consistency index is as follows:

$$CI = (\lambda_{max} – n) / (n – 1)$$

where,

λ_{max} – the maximum eigenvalue from the matrix above

The ratio of the CI is taken with random index (RI) which gives the consistency ratio (CR). For the matrix to be consistent, the CR should be less than 0.1 (Saaty & Vargas, 2012).

g. In the last and final step, the weights of the alternatives are multiplied by the weights of the criteria to get the total global weights of each factor. This gives the final relative priority of all the factors.

An example is demonstrated below to explain the mechanism of the AHP process. The tool used for the formulation of the AHP-based survey for this research was Microsoft Excel spreadsheet, although there are numerous AHP software packages available to use (Belton & Stewart, 2002; Zardari et al., 2015).

Suppose John, a recent graduate student, has job offers from three companies in three different locations which have the same reputation and have offered him a similar range of salary. Owing to this, it has become difficult for him to decide on which company to choose and so he develops a list of four other criteria to help him decide where he would relocate based on the features of each location. Even having those four criteria has not made his decision easier as he does not know which criteria he prefers more than the other. The four criteria are:

i. Cost of living
ii. Climate
iii. Availability of Arts and Recreation Options
iv. Commuting Time

The AHP method will now be used to demonstrate how he can solve this problem and make a decision. The four criteria considered will be represented in a table format and each criteria will be compared pairwise with the other three as shown below in Table 3.2:

Table 3. 2 Pairwise Comparison Table for Criteria

Criterion A	Criterion B	More Important Criterion	Degree of Importance
Cost of Living	Climate	A	7
Cost of Living	Arts and Recreation	A	5
Cost of Living	Commuting time	B	3
Climate	Arts and Recreation	B	3
Climate	Commuting time	B	9
Arts and Recreation	Commuting time	B	5

The first two columns indicate the criteria that John wants to consider while selecting the location and subsequently the company. As mentioned earlier, each criterion is compared with the other resulting in six comparisons in total. The third column which is the “More Important Criterion” indicates which of the two criteria compared is more important based on the preferences of the decision-maker i.e. Criterion A or Criterion B. And finally, in the last column, “Degree of Importance”, the importance of the selected criterion is mentioned based on the fundamental scale shown in Table 3.1.

After this table has been completed by the decision-maker, the AHP calculations are performed. A pairwise comparison matrix is formulated alongside the table. The Excel sheet should be formulated in such a manner that as soon as the decision maker chooses the option and the degree of importance, the corresponding cell in the matrix should be populated. For example, when cost of living is selected over climate with a degree of importance of 7, the value 7 should appear in the cell ($a_{\text{cost of living},\text{climate}}$) and the cell ($a_{\text{climate},\text{cost of living}}$) should be populated with a numerical value of 1/7. Thus, in this way all the cells in the matrix should be populated simultaneously as the table is filled by the decision maker. The cells which are highlighted in yellow are directly linked to the table and are automatically filled based on the pairwise comparison by the decision maker i.e. if the decision maker's decision is A with a value of 7 then the cell is populated with 7 and if it is B with a value of 3 then the cell is populated with a value of 1/3. The other half of the matrix is the reciprocals of the values in the corresponding yellow cells. The final matrix is shown in Table 3.3.

Table 3. 3: Comparison Matrix for Criteria

Criteria	Cost of Living	Climate	Arts and Recreation	Commuting time
Cost of Living	1	7	5	0.333
Climate	0.143	1	0.333	0.111
Arts and Recreation	0.2	3	1	0.2
Commuting time	3	9	5	1

Now when both the table and the matrix has been populated, a series of calculations need to be performed to generate the final relative weights of the criteria. In the first step, the geometric mean of the values of all the criteria from the matrix is calculated and are then summed together. After this, the eigenvector i.e. the relative weight of each criterion is calculated. To calculate the eigenvector, the geomean of each criterion is divided by the total sum of all the geomean. All the eigenvectors added together should give a value of 1. The calculations are shown in Table 3.4:

Table 3. 4: The Eigenvector Calculation

Criteria	Geomean	Eigenvector
Cost of Living	1.848	0.30
Climate	0.270	0.04
Arts and Recreation	0.589	0.10
Commuting time	3.409	0.56
	6.115	1

Thus, the relative weights (i.e., priority) of each criterion can be interpreted from the table as follow:

Cost of Living: 30%

Climate: 4%

Arts and Recreation: 10%

Commuting Time: 56%

After the eigenvector calculation, another important calculation is the consistency ratio. This calculation signifies how consistent the decision maker has been while selecting the more important criterion, or in other words if he/she has taken transitivity into account. Going back to the example above, if John chooses commuting time over cost of living and cost of living over climate then he needs to select commuting time over climate with a much higher number from the absolute scale. As mentioned earlier, the consistency ratio of 0.1 or less indicates that the decision maker was consistent while selecting the "more important criterion" and the "degree of importance". However, when the number of criteria increase, it may not be easy to attain this threshold given that the decision maker is making a large number of comparisons. The issue of consistency ratio can also be dealt with an extension of the AHP method i.e. Group AHP which is discussed in the next section of this chapter.

The first step to calculate the consistency ratio is to calculate the consistency index. The consistency index is calculated by the formula:

$$CI = (\lambda_{max} - n) / (n - 1)$$

The λ is calculated by performing a matrix multiplication between the degree of importance of the factors and the eigenvectors respectively. To find the λ_{max}, first the λ value of each factor is divided by the eigenvector of the corresponding factor and then the average of all these fractions is calculated. This average is the λ_{max} which is shown in Table 3.5:

Table 3. 5: Calculation of Consistency Ratio (CR):

Criteria	**Geomean**	**Eigenvector**	**λ**	**λ/Eigenvector**	**CI**	**RI**	**CR**
Cost of Living	1.85	0.30	1.28	4.23	0.06	0.89	0.07
Climate	0.27	0.04	0.18	4.11			
Arts and Recreation	0.59	0.10	0.40	4.16			
Commuting time	3.41	0.56	2.34	4.20			
	6.12	1.00		$\boldsymbol{\lambda_{max}}$ = 4.176			

The final step in the process is to take the RI number as per Saaty's random index table developed for the matrices of different sizes as shown in Table 3.6:

Table 3. 6: Random Consistency Index Table (Saaty & Vargas, 2012)

N	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
Random Index	0.00	0.00	0.52	0.89	1.11	1.25	1.35	1.40	1.45	1.49

Thus, the CI for this example is:

CI = (4.176-4)/3

$= 0.06$

RI = 0.89 from the table above

CR = CI÷RI

$= 0.06 \div 0.89$

$= 0.07 = 7\%$

Based on the AHP analysis, it can be concluded that John has been consistent in his pairwise comparison of the criteria and that his preferred criteria in selecting the place to relocate would be commuting time followed by cost of living, arts and recreation and climate as his least preferred criterion.

3.3.4. Group AHP

Many of the organizational decisions being inherently complex and uncertain, requires group decision-making which should be quick and efficient with the lowest possible disagreements (Saaty, 1989, 2008). There are two types of approach that can be used while trying to find a consensus in a group with the AHP methodology. In the first approach, all the criteria can be discussed one by one with all the members of the group at the same time to complete one pairwise comparison (Saaty, 1989). In the second approach, each member can complete the pairwise comparison individually and then those individual judgements would be combined together to generate the group consensus (Saaty, 1989). In this research, the second approach is applied to obtain the group consensus. In order to combine the individual decisions into group decisions, the geometric mean of the individual decision is used to acquire the group decision for each pairwise comparison which aids in retaining the reciprocal property of the combined pairwise comparison matrix (Saaty, 1989). After this, the consistency should be measured to check if the group decision corresponds to the individual decisions (Saaty, 1989). The equations for these operations are shown below:

	Individual Decision maker		
	1	2	N
Judgements	a_{12}^{1}	a_{12}^{2}	a_{12}^{n}

Combined Judgements

$a_{12} = [\, a_{12}^{1} \text{ x } a_{12}^{2} \text{ x } \ldots\ldots \text{ x } a_{12}^{n} \,]^{1/n}$

The consistency ratio is computed in the same way by taking the ratio of the consistency index to the random index. However, the equation for the consistency index for group AHP results is given by:

C.I. = $(\lambda_{max} - n) / (n)$

And similar to the individual AHP, if the C.R. for the group results is less than 0.1 then the group judgement is consistent (Saaty, 1989). It should be noted that the implementation of this framework does not require a minimum number of participants. However, for more accurate results, it is advisable that the entire project team should participate in completing this framework as then the results would exhibit a representation of the viewpoints of every member of the project management team.

CHAPTER 4: FRAMEWORK IMPLEMENTATION AND RESULTS

In the previous chapter, the four-step framework that is being developed to fulfill the purpose of this study was explained. This chapter presents the findings of the implementation of the four-step framework by applying it to two complex highway projects. As mentioned in Chapter 1, the framework was applied to US-34 Rebuild Project and the I-25 North Expansion Project; and the results are documented herein. The first step of the framework was to identify the generalized contextual factor categories and the factors which formed the basis for the meetings conducted in the next step. The definitions of these factor categories and factors have been presented in Section 3.1 of the previous chapter and what follows is the implementation of the framework from the second step onwards for the two projects mentioned above.

4.1. US-34 Rebuild Project Implementation

4.1.1. Step 2

In the second step, the researchers conducted a meeting with the members of the project team to vet the factors identified from the SHRP-2, R-10 study, remove the factors that were not specific to US-34 Rebuild project and add the ones which were specific but was not identified in the literature.

The meeting started with a brief background on the SHRP-2, R-10 study, to familiarize the participants with the foundation of the present research. This was followed by a brief background presentation on the use of AHP in several of the CDOT projects and its potential benefits. The participants for the interview included Mr. James Usher and Mr. Benjamin Rowles from the Colorado Department of Transportation and Mr. Steven Humphrey from the Muller Engineering Company who is a consultant on the US 34 Rebuild project and one other individual who chose her/his information not to be published. The members of the project team provided information about the background of the project and mentioned that it was an untraditional project with CM/GC project delivery method. Mr. James is related more to the construction phase whereas Mr. Steven is related more to the design and preconstruction phase. The project is divided into 4 phases and currently, Phase 1 is under construction. As mentioned in the methodology, the participants were sent a document containing the definitions of the contextual factors a week prior to the meeting so that the participants could concur with the parameters of the factors to be discussed. After all the background discussions, the participants were asked to complete the factor-rating sheet for all the 26 factors and the results were then populated into Excel spreadsheet to calculate the average of all of the respondents for all the 26 factors. The factors which scored an average equal to or more than 1.5 were automatically included as a complexity factor and the factors that scored between 0.5-1.5 were discussed. In this case, none of the factors scored below 0.5 which was the criteria for automatically eliminating the factors. Out of the 26 factors, 14 were included and 12 were discussed.

A detailed discussion was carried out on each of these factors and out of the 12 factors, 9 were excluded and 3 were included. Intermodal requirements was excluded as the participants reasoned that this factor was more relevant in an urban context where there is severe disruption to the public for daily transport. The entire factor category of Resource Availability was eliminated on the grounds that this could have been a factor upfront in causing complexity but was not anymore. Local Acceptance factor under the Legal and Legislative category was discussed for a long time. The participants went back and forth discussing the exact definitions of this factor. The participants mentioned that this project was seen more as an opportunity to use a different project delivery method like CM/GC and there was not much competition as there were only 2 construction firms with CM/GC experience in the state of Colorado. They further added that after going through the bid process and the cost estimation, the contractor was automatically chosen as it had gained the goodwill of the people and so local jurisdiction was not a factor to cause complexity in the project. The participants did not feel that this would be a difficult issue with the other phases as well and thus it was removed. The next factor category in the discussion was the Global and National Events and although initially they did not contemplate that this factor could cause complexity, after the discussion it was established that there should be stability at the Federal government level so as to provide emergency funding for this project. Also, given that there could be other incidents competing for emergency funding like this one across the US, this factor category was retained on the list. The participants also mentioned that the funding provided to them was eligible only for fixing things that were destroyed by the flood and not for new construction. Force majeure factor was eliminated without any debate. Social Equity was another factor in the discussion for a long time. The participants mentioned that none of the residents were relocated and temporary easements were constructed for the permanent residents. However, they mentioned that there is a slight rift between the seasonal and the permanent population. Also, the Estes park residents were more open to the permanent closing of the corridor for construction than the population in the Canyon. Owing to all this discussion, social equity factor was eliminated but demographics of the population which is the next factor was retained and its definition was changed to include a broader perspective. The next factor of integration of land use planning, growth inducement and economic impacts was also eliminated as the major work consists of realignment of roadways rather than new construction. The last two factors in discussion was the workforce issues and the relocation of utilities. Although few business in Estes Park had some issues because the people working there would have to commute few extra miles, the project management team did not have problem in getting their workforce so these concerns were included under the demographics factor. Again as there is no new construction, utilities was not viewed as a factor for causing complexity. The participants mentioned that the owner of the utilities have been very responsive. The final list of factor categories and factors as identified for US-34 is given in table 4.1 below.

Table 4. 1: Final list of Factor Categories and Factors Identified for the US-34 Rebuild Project

Factor Categories	Factors	Average Score	Selected (Yes/No)
Stakeholders	Public	1.75	Yes
	Politician	2	Yes
	Owner	2	Yes
	Jurisdiction	2	Yes
Project-Specific Demands	Maintaining Capacity	2	Yes
	Work-zone visualization	1.75	Yes
	Intermodal requirements	0.75	No
Resource Availability	Direct Resources	1.25	No
	Project Management capabilities	1	No
Environmental	Sustainability	1.5	Yes
	Limitations and Constraints	1.5	Yes
Legal and Legislative	Procedural Laws	1.5	Yes
	Local jurisdiction	1	No
Global and National Events	Economic factors	1	Yes
	Incidents	0.75	Yes
Unusual conditions	Weather	1.5	Yes
	Force majeure	0.75	No

Localized issues	Social equity	1.25	No
	Land use planning, growth inducement and economics	1	No
	Demographics	0.75	Yes
	Land acquisition	2	Yes
	Public emergency services	2	Yes
	Workforce issues	0.5	No
	Utilities	0.75	No
	Cultural factors	1.75	Yes
	Marketing	2	Yes

One important thing to note is that had this process of retaining and eliminating the factors specific to the project been conducted before the start of Phase-1, some of the now eliminated factors would have been retained. Also, if the same process is conducted for rest of the three phases, it might yield different results. At the end of the vetting process, the participants were asked if they felt a need to add any other factor that was specific to the project but was not included in the list provided by literature; but no additional factor was added. At the end of the meeting, the participants were informed about the next steps of the study and were given a brief presentation on the AHP methodology.

4.1.2. Step 3

As mentioned in the previous chapter, the third step of the framework was to develop and implement the survey instrument based on the AHP methodology, first individually and then combined as a group. Based on the finalization of the factor categories and factors from the second step, each participant was sent an Excel spreadsheet with the pairwise comparisons (see

Appendix A). This allowed the participants to make the comparisons individually using their own judgement. The setup of the Excel spreadsheet was the same as illustrated in the example in section 3.2.2., Table 3.2. As an example, the results of each of the factors and factor categories by one participant is shown below in tables 4.2 to 4.7.

Table 4. 2: Relative Weights of Factors under Stakeholders category:

Factor Category	Factors	Relative Weights
Stakeholders	Public	0.17
	Politician	0.27
	Owner	0.49
	Jurisdiction	0.07
	Total	1.00

Table 4. 3: Relative Weights of Factors under Project-Specific Demands category:

Factor Category	Factors	Relative Weights
Project-Specific Demands	Maintaining Capacity	0.75
	Work-Zone Visualization	0.25
	Total	1.00

Table 4. 4: Relative Weights of Factors under Environmental category:

Factor Category	Factors	Relative Weights
Environmental	Sustainability	0.75
	Limitations and Constraints	0.25
	Total	1.00

Table 4. 5: Relative Weights of Factors under Global and National Events category:

Factor Category	Factors	Relative Weights
Global and National Events	Economic Factors	0.75
	Incidents	0.25
	Total	1.00

Table 4. 6: Relative Weights of Factors under Localized Issues category:

Factor Category	Factors	Relative Weights
Localized Issues	Demographics of Population	0.38
	Land Acquisition	0.11

	Public Emergency Services	0.16
	Cultural Factors	0.05
	Marketing and Public Relation issues	0.30
	Total	1.00

Table 4. 7: Relative Weights of Factor Categories:

Factor Categories	Relative Weights
Stakeholders	0.20
Project-Specific Demands	0.14
Environmental	0.23
Global and National Events	0.03
Localized Issues	0.30
Legal and Legislative Requirements	0.05
Unusual Conditions	0.05
Total	1.00

As mentioned earlier, an important part of the AHP survey is to check the consistency of the judgements of participants while making the pairwise comparisons. The consistency ratio of 0.1 or less indicates that the participant was consistent (Saaty & Vargas, 2012). Table 4.8 indicates the consistency of the above-mentioned participant for each category of the pairwise comparison which had 3 or more factors. It should be noted that the consistency ratio cannot be calculated for less than 3 factors as the RI for 2 factors is 0.

Table 4. 8: Consistency Ratios

Factor Categories	Consistency Ratio
Stakeholders	0.13
Localized Issues	0.05

The consistency ratio for factor categories was 0.10. The consistency ratio for this participant was a little over 0.1 for Stakeholders factor category.

4.1.3. Step 4

After the ranking was obtained from each individual member, the Group AHP was carried out in order to develop one overall ranking for all the factors and factor categories and as a side benefit, the Group AHP also resulted in much lower consistency ratios. The results from the Group AHP methodology for US-34 rebuild project is presented in the tables below:

Table 4. 9: Relative Weights of Factors under Stakeholders category:

Factor Category	Factors	Relative Weights	CR
Stakeholders	Public	0.21	0.02
	Politician	0.22	
	Owner	0.29	
	Jurisdiction	0.28	
	Total	1.00	

Table 4. 10: Relative Weights of Factors under Project-Specific Demands category:

Factor Category	Factors	Relative Weights
Project-Specific Demands	Maintaining Capacity	0.36
	Work-Zone Visualization	0.64
	Total	1.00

Table 4. 11: Relative Weights of Factors under Environmental category:

Factor Category	Factors	Relative Weights
Environmental	Sustainability	0.40
	Limitations and Constraints	0.60
	Total	1.00

Table 4. 12: Relative Weights of Factors under Global and National category:

Factor Category	Factors	Relative Weights
Global and National Events	Economic Factors	0.43
	Incidents	0.57
	Total	1.00

Table 4. 13: Relative Weights of Factors under Localized Issues category:

Factor Category	Factors	Relative Weights	CR
Localized Issues	Demographics of Population	0.21	0.03
	Land Acquisition	0.33	

	Public Emergency Services	0.14	
	Cultural Factors	0.07	
	Marketing and Public Relation issues	0.25	
	Total	1.00	

Table 4. 14: Relative Weights of Factor Categories:

Factor Categories	Relative Weights	CR
Stakeholders	0.22	0.01
Project-Specific Demands	0.14	
Environmental	0.11	
Global and National Events	0.06	
Localized Issues	0.30	
Legal and Legislative Requirements	0.10	
Unusual Conditions	0.07	
Total	1.00	

After all the results from each individual member was combined into a group, the relative weights revealed that the highest ranked category was the Localized Issues (30%), followed by Stakeholders (22%) and both these factors represented over 50% of the total relative weights. Within the local issues, the highest ranked factors were land acquisition (33%), marketing and public relations issues (25%), and demographics of the population impacted by the project (21%). Within the Stakeholders category, the project owner (29%) and local jurisdiction (28%) issues were ranked similarly, and were higher than the more general stakeholder groups of politicians (22%) and the general public (21%). Project specific demands factor category was the third highest ranked category (14%), followed by environmental factor category (11%) and legal and legislative requirements (10%). The categories of unusual condition and the global and national events were ranked as the least important factor categories with 7% and 6% relative weights. These local priority vectors of each factor is multiplied with the local priority vector of the respective factor category to obtain the global vectors. The global vectors of each factor is shown in the Table 4.15.

Table 4. 15: Global Vector (Final Weights) for Each Factor for US-34 Rebuild Project

Factors	Local Priority Vector for Factors	Local Priority Vector for Factor Categories	Global Vector (Final Weight for Each Factor)
Stakeholders			
Public	0.21	0.22	0.05
Politician	0.22	0.22	0.05
Owner	0.29	0.22	0.06
Jurisdiction	0.28	0.22	0.06
Project Specific Demands			
Maintaining Capacity	0.36	0.14	0.05
Work-zone Visualization	0.64	0.14	0.09
Environmental			
Sustainability	0.40	0.11	0.04
Limitations and Constraints	0.60	0.11	0.07
Global and National Events			
Economic Factors	0.43	0.06	0.03
Incidents	0.57	0.06	0.03
Localized Issues			
Demographics of Population	0.21	0.30	0.06
Land Acquisition	0.33	0.30	0.10
Public Emergency Services	0.14	0.30	0.04
Cultural Factors	0.07	0.30	0.02
Marketing and public relations issues	0.25	0.30	0.08
Legal and Legislative Requirements (Procedural Laws**)**	1	0.10	0.10
Unusual Conditions (Extreme Weather**)**	1	0.07	0.07

Total	**1**

As per the results of the global vectors, the top five factors (based on the weights assigned) are:

i. Procedural Laws and Land Acquisition

ii. Work Zone Visualization

iii. Marketing and Public Relations

iv. Limitations and Constraints and Extreme Weather

4.2. I-25 North Expansion Project Implementation

4.2.1. Step 2

Similar to the US-34 Rebuild project, the researchers conducted a meeting with the members of the I-25 North Expansion project team to vet the factors identified from the SHRP-2, R-10 study, remove the factors that are not specific to the project and add the ones which were not identified in the literature. The project team consisted of six members with one member from FHWA and other five members from CDOT.

This meeting also started with a brief background on the SHRP-2 project R-10, to familiarize the participants with the foundation of the present research. After the background, the participants were asked to complete the factor-rating sheet which was on the scale of 0-2. The results from this survey was populated into an Excel spreadsheet to calculate the average of all of the responses for all the 26 factors and the same protocol was followed for retaining and removing the factors i.e. factors with an average equal to or more than 1.5 were automatically included and the factors with an average of 0.5-1.5 were discussed. Out of the 26 factors, only one factor, cultural, got a score below 0.5 and was directly eliminated from the list. Out of the remaining 25 factors, 14 were included and 11 were discussed. The 11 factors were Availability of direct resources, Sustainability, Local jurisdiction, Global and National Economic factors, Global and National Economic Incidents, Likelihood and impact of extreme weathers, Forces majeure, Social equity, Integration of land use planning, growth inducement and economic impacts, Demographics of the population and Workforce issues. Detailed discussion was carried out on each of these factors and out of the 11 factors, 6 were excluded and 5 were included.

The discussion started with Local acceptance as that was the starting factor following which most of the factors had fallen in the range of 0.5-1.5. The participants excluded Local acceptance as they mentioned that the population using the I-25 for commute had always wanted an additional lane to decrease the travel time caused by the traffic in peak hours. So local acceptance was not a factor causing complexity on the project and there was no local jurisdictional complication. Global and National Events as a factor category was discussed for a long time. Some participants argued that it was not a big issue while some reasoned that it might become an issue based on the results of the presidential elections. Some of the participants were worried about the fluctuation in the interest rates as this is a debt-financed project and the team had taken a sizeable commercial loan. As the majority of the population are opposed to increase in the tax, they were worried that this category might cause some complexity for the opportunities over the course of the project. Thus, the global and national economic factors was retained in this category whereas the economic and global incidents was eliminated as that related more towards causing complexity in the process of construction owing to political instability and uncertainty. The next factor category, Unusual Conditions, was directly eliminated as there was a common consensus that this factor category was not going to cause any complexity. The next factor discussed was sustainability and the ranking of this factor was confusing as some of the participants rated it at 0 and some rated it at 2. While discussing this, the participants who scored it at 0 said that the team had already taken all the sustainability issues into consideration such as LCCA analysis. The facilitator intervened at this point and mentioned that this factor related more towards to the usage of materials which could lead to deterioration of environment and thus would be an unsustainable approach. They mentioned that no such material was being used but then one of the participant who had scored this at 2 mentioned that the permanent alignment of the highways are going to change in the next 40 years. So according to her, this was an issue as they would have to plan the utilities in a manner that it matches with the future construction which would be social sustainability. So ultimately this factor was also retained in the list. The participants expressed that the first three factors under the Localized issues factor category i.e. social equity, integration of land use planning, growth inducement and economic impacts and demographics of the population, all sounded similar to them. So the facilitator explained how these factors originated based on the case studies of the SHRP-2, R-10 study and how they were identified as three different factors. The participants concluded that social equity need not be considered but integration of land use planning, growth inducement and economic impacts needed to be included as addition of an extra lane would lead to growth and the team was communicating with the developers and the local jurisdictions to accommodate the growth. There was also a discussion that no particular type of demographic was being affected by this project and thus demographics was removed. The last factor in discussion was workforce issues. The team was confused between this factor and the availability of direct resources factor. Again, the facilitator explained them that availability of direct resources relates more to the availability of laborers whereas workforce issues relates to the availability of highly skilled workforce for specialized tasks. At this point there was some discussion on the availability of direct resources factor as well. One of the team member pointed out that there were several big projects coming up in the state of Colorado which could lead some of the projects to have problems in obtaining resources. They mentioned that it would be a good solution if the project management team of these projects get a chance to have a common meeting so that they can discuss about their schedules and devise a solution. So as a result of this discussion, both direct resources factor and workforce issues factor was retained in the list. Thus after all the discussion, the I-25 team identified 19 factors and 7 factor categories which were causing complexity on this project.

After the discussion of the factors identified by us, the participants were asked if there were any other factors which was not in the list but was relevant to the project. One of the participants mentioned that one factor was the phasing and constructability of this project. I-25 being one of the busiest roads, the project team was facing a lot of issues in phasing the construction as no part of the highway could be permanently closed. One of the most important issue was expanding the highway causing minimum delay to the travelling population and so this factor was added under the Project-specific demand factor category as the fourth factor. It was defined as the phasing of the entire project to cause minimum inconvenience or disruption to the moving public. After this discussion, a brief presentation was given on the AHP Survey and the further steps of the research was explained. The final list of 7 factors categories and 20 factors identified for I-25 project is given in the Table 4.16 below:

Table 4. 16: Final list of Factor Categories and Factors Identified for the I-25 North Expansion Project

Factor Categories	Factors	Average Score	Selected (Yes/No)
Stakeholders	Public	2	Yes
	Politician	2	Yes
	Owner	2	Yes
	Jurisdiction	2	Yes

Project-Specific Demands	Maintaining Capacity	2	Yes
	Work-zone visualization	2	Yes
	Intermodal requirements	1.67	Yes
	Phasing and Constructability	-	Yes
Resource Availability	Direct Resources	1.33	Yes
	Project Management capabilities	1.83	Yes
Environmental	Sustainability	1	Yes
	Limitations and Constraints	2	Yes
Legal and Legislative	Procedural Laws	2	Yes
	Local jurisdiction	1.16	No
Global and National Events	Economic factors	1	Yes
	Incidents	0.67	No
Unusual conditions	Weather	1	No
	Force majeure	0.67	No
Localized issues	Social equity	0.83	No
	Land use planning, growth inducement and economics	1.16	Yes
	Demographics	0.5	No
	Land acquisition	1.67	Yes
	Public emergency services	1.67	Yes
	Workforce issues	1.33	Yes
	Utilities	2	Yes
	Cultural factors	0.33	No
	Marketing	2	Yes

4.2.2. Step 3

After this, the third step of the framework was implemented i.e. the survey instrument based on the AHP methodology. Again, this was first done individually and then the individual results were combined into a group. The Excel spreadsheet sent to the I-25 team was the same as sent to US-34 (see Appendix B) and it allowed the team members to make the comparisons using their individual judgements. As an example, the results of the individual AHP of one of the member is shown in tables 4.17 to 4.22.

Table 4. 17: Relative Weights of Factors under Stakeholders Category:

Factor Category	Factors	Relative Weights
Stakeholders	Public	0.50
	Politician	0.08
	Owner	0.28
	Jurisdiction	0.14
	Total	1.00

Table 4. 18: Relative Weights of Factors under Project-Specific Demands Category:

Factor Category	Factors	Relative Weights
Project-Specific Demands	Maintaining Capacity	0.36
	Work-Zone Visualization	0.19
	Intermodal Requirements	0.07
	Phasing and Constructability	0.38
	Total	1.00

Table 4. 19: Relative Weights of Factors under Resource Availability Category:

Factor Category	Factors	Relative Weights
Resource Availability	Availability of Direct Resources	0.25
	Project Management Capabilities	0.75
	Total	1.00

Table 4. 20: Relative Weights of Factors under Environmental Category:

Factor Category	Factors	Relative Weights

Environmental	Sustainability	0.80
	Limitations and Constraints	0.20
	Total	1.00

Table 4. 21: Relative Weights of Factors under the Localized Issue category:

Factor Category	Factors	Relative Weights
Localized Issues	Integration of land use planning, growth inducement and economic impacts	0.07
	Land Acquisition	0.25
	Public Emergency Services	0.16
	Workforce Issues	0.06
	Utilities and railroad issues	0.42
	Marketing and public relations issues	0.04
	Total	1.00

Table 4. 22: Relative Weights of Factor Categories:

Factor Categories	Relative Weights
Stakeholders	0.16
Project-Specific Demands	0.17
Resource Availability	0.05
Environmental Category	0.23
Localized Issues	0.12
Legal and Legislative Requirements	0.24
Global and National Events	0.03
Total	1.00

The consistency ratios of the factor categories which had 3 or more factors have been shown in the table 4.23. As mentioned earlier, the consistency ratio can only be calculated for more than 2 pairwise comparison as the RI for 2 factors is 0.

Table 4. 23: Consistency Ratios:

Factor Categories	Consistency Ratio
Stakeholders	0.20
Project-Specific Demands	0.49

Localized Issues	0.08

The consistency ratio for factor categories was 0.15. As seen from the table, the consistency ratio for project-specific demands factor category was very large for this participant (0.49 >>0.1). The only factor category within the range of consistency ratio was localized issues.

4.2.3. Step 4

The next step was to apply Group AHP to provide the results as one overall group and as a result, also overcome the inconsistencies.

Table 4. 24: Relative Weights of Factors under Stakeholder Category:

Factor Category	Factors	Relative Weights	CR
Stakeholders	Public	0.31	0.05
	Politician	0.14	
	Owner	0.36	
	Jurisdiction	0.19	
	Total	1.00	

Table 4. 25: Relative Weights of Factors under Project-Specific Demands Category:

Factor Category	Factors	Relative Weights	CR
Project-Specific Demands	Maintaining Capacity	0.34	0.05
	Work-Zone Visualization	0.13	
	Intermodal Requirements	0.09	
	Phasing and Constructability	0.44	
	Total	1.00	

Table 4. 26: Relative Weights of factors under Resource Availability Category:

Factor Category	Factors	Relative Weights
Resource Availability	Availability of Direct Resources	0.39
	Project Management Capabilities	0.61
	Total	1.00

Table 4. 27: Relative Weights of Factors under Environmental Category:

Factor Category	Factors	Relative Weights
Environmental	Sustainability	0.27
	Limitations and Constraints	0.73
	Total	1.00

Table 4. 28: Relative Weights of Factors under Localized issues Category:

Factor Category	Factors	Relative Weights	CR
Localized Issues	Integration of land use planning, growth inducement and economic impacts	0.06	0.14
	Land Acquisition	0.26	
	Public Emergency Services	0.13	
	Workforce Issues	0.13	
	Utilities and railroad issues	0.33	
	Marketing and public relations issues	0.09	
	Total	1.00	

Table 4. 29: Relative Weights of Factor Categories:

Factor Categories	Relative Weights
Stakeholders	0.16
Project-Specific Demands	0.16
Resource Availability	0.13
Environmental	0.21
Localized Issues	0.11
Legal and Legislative Requirements	0.18
Global and National Events	0.05
Total	1.00

After the results from each individual member is combined into a group, the relative weights revealed that the highest rank category was the Environmental category (21%). The Legal and Legislative Requirements (18%) was the next priority followed closely by Stakeholders and

Project-Specific Demands, both having a relative weight of 16%. Unlike US-34 project, in this case the relative weights of all the factor categories were tightly distributed between 21%-11%. Global and National Events was the only factor category that had a relative weight of 5% which was much lower than the range specified above. Within the local issues, the highest ranked factors were utilities and railroads (33%), land acquisition (26%) and public emergency services and workforce issues with equal relative weights of 13%. Within the Environmental category, limitations and constraints was ranked with a much higher relative weight of 73%. Under Stakeholder factor category, owner and public were ranked with 36% and 31% relative weights respectively and under the project-specific demands, phasing and constructability and maintaining capacity ranked the highest with 44% and 34% relative weights respectively. These local priority vectors of each factor is multiplied with the local priority vector of the respective factor category to obtain the global vectors. The global vectors of each factor is shown in the Table 4.30.

Table 4. 30: Global Vector (Final Weights) for Each Factor for I-25 North Expansion Project

Factors	Priority Vector for Factors	Priority Vector for Factor Categories	Global Vector (Final Weight for Each Factor)
Stakeholders			
Public	0.31	0.16	0.05
Politician	0.14	0.16	0.02
Owner	0.36	0.16	0.06
Jurisdiction	0.19	0.16	0.03
Project Specific Demands			
Maintaining Capacity	0.34	0.16	0.05
Work-zone Visualization	0.13	0.16	0.02
Intermodal Requirements	0.09	0.16	0.01

Phasing and Constructability	0.44	0.16	0.07
Resource Availability			
Availability of Direct Resources	0.39	0.13	0.05
Project Management Capabilities	0.61	0.13	0.08
Environmental			
Sustainability	0.27	0.21	0.06
Limitations and Constraints	0.73	0.21	0.15
Localized Issues			
Integration of land use planning, growth inducement and economic impacts	0.06	0.11	0.01
Land Acquisition	0.26	0.11	0.03
Public Emergency Services	0.13	0.11	0.02
Workforce Issues	0.13	0.11	0.02
Utilities and railroad issues	0.33	0.11	0.04
Marketing and public relations issues	0.09	0.11	0.01
Legal and Legislative Requirements (Procedural Laws**)**	1	0.18	0.18
Global and National Events (Global and National Economic Factors**)**	1	0.05	0.05
Total			**1**

According to the results from the Global Vector calculations, the top five factors are:

i. Procedural Laws

ii. Limitations and Constraints

iii. Project Management Capabilities

iv. Phasing and Constructability

v. Sustainability and Owner

CHAPTER 5: CONCLUSION

5.1. Summary of Research

The goal of this research was to develop a framework for the project management teams of various transportation agencies to assess the contextual difficulties for a complex highway project by making better and less-biased decisions. Along the lines of the dimensional impact rating developed by the SHRP-2, R-10 team, a need was identified to rate the factors under those dimensions, instead of just rating the dimension, by using a structured approach. Given the scope and time constraints, the weightings of factors was conducted only for the context dimension. It was identified from the literature that assessing contextual difficulties at the early stages of the project is essential especially to keep the project on schedule and within the budget. Also, gaining public trust and support is one of the most essential factor in the success of any project. To fulfill the purpose of this research, the following steps were taken:

1. The SHRP-2, R-10 study was thoroughly examined to identify the initial list of contextual factors and factor categories. Through this, a total of 26 factors and 8 factor categories were identified.
2. After the identification of the factors, they were vetted by the project management team of the transportation agency to retain the factors specific to the project and remove the ones which were not related. Additional factors were also included at this point which were not identified through literature.
3. The weightings for each factor and factor category was identified individually by each member of the project team using the AHP methodology.

4. After the individual judgements were gathered from each participant, an overall ranking for all the factors and factor category was identified by using the Group AHP methodology.

5.2. Implementation Examples

The framework was implemented for two projects by CDOT; US-34 Rebuild Project and I-25 North Expansion Project. The objective was to determine the relative weights for each factor and factor category individually and then as a group using the framework developed. The implementation of the framework for both the project is summarized below:

Step 1: The initial list of factors was identified through the SHRP-2, R-10 study which included 8 factor categories and 26 factors mentioned below:

i. Stakeholders
   - Public
   - Politician
   - Owner
   - Jurisdiction

ii. Project-Specific Demands
   - Maintaining Capacity
   - Work-zone visualization
   - Intermodal Requirements

iii. Resource Availability
   - Availability of direct resources
   - Project management capabilities

iv. Environmental

- Sustainability
- Limitations

v. Legal and Legislative Requirements

- Procedural Laws
- Local Acceptance

vi. Global and National Events

- Global and National Economics
- Global and National incidents

vii. Unusual Conditions

- Weather
- Force Majeure

viii. Local Issues

- Social Equity
- Demographics
- Public services
- Integration of land use, growth inducement and economic impact
- Land Acquisition
- Marketing
- Cultural
- Workforce
- Utilities

Step 2: After the identification of the initial list of factors from R-10 study, meetings were conducted with the project management teams of each project. The purpose of the meeting was to vet the factors identified from the literature to retain the factors relevant to the project and remove the ones which were not relevant. At the end of the meeting, the team members were also asked to add additional factors which were not identified in the literature but were relevant to the project. The US-34 Rebuild team did not add any additional factors but the I-25 North expansion team added an additional factor under the project-specific demands factor category which was “phasing and constructability”.

Step 3: After the final list was created through the above two steps, an AHP based survey instrument was developed for the members of the project management teams of both the projects. Based on the factors selected by each team, the US-34 project had a total of 40 pairwise comparisons while the I-25 project had 50 pairwise comparisons. These pairwise comparisons were to be made individually by each decision maker, i.e., the members of the project team and were to be returned to the researcher after completion.

Step 4: The final step of the implementation was to combine the individual relative weights of each member for each factor and factor category and obtain the overall ranking of all the factors and factor category for both the projects.

A detailed explanation of the results for each project is provided in Chapter 4 of this research. The following section shows the findings of this research by comparing the overall group findings of both the projects.

5.3. Findings

The comparison between the factors of different categories for both the projects is shown in the tables from Table 5.1 to Table 5.10. It can be seen that even though both the projects are similar in nature in that they both are reconstruction projects and both are in the state of Colorado, there are striking differences between the relative weights of the contextual factors in both the projects. Table 5.1 shows the relative weights of factors in the stakeholder category. It was found that for both the project, owner is the most important factor with a relative weight of 29% in US-34 and 36% in I-25 project. However, for US-34 project all the other factors had relatively similar importance and were tightly bound between 21-28% but for I-25 project, politician had a very low importance of 14% in comparison to the highest weight factor.

Table 5. 1: Relative Weights for Factors in Stakeholder Category:

Factors	US-34 Rebuild Project	I-25 North Expansion project
Public	0.21	0.31
Politician	0.22	0.14
Owner	0.29	0.36
Jurisdiction	0.28	0.19

Table 5.2 shows the relative weights of the factors in the project-specific demands factor category. It was found that for US-34, the most important factor was work-zone visualization with a relative weight of 64% and this could possibly be attributed to the terrain of the place where the project is being constructed. However, phasing and constructability was the most important factor for I-25 with a relative weight of 44% primarily because this is one of the busiest roads; and the project team was not sure how to shut down parts of road for construction. The next important factor for US-34 and I-25 was maintaining capacity with relative weight of 36% and 34% respectively.

Table 5. 2: Relative Weight of Factors for Project-Specific Demands Factor Category:

Factors	US-34 Rebuild Project	I-25 North Expansion project
Maintaining Capacity	0.36	0.34
Work-zone Visualization	0.64	0.13
Intermodal Requirements	NA	0.09
Phasing and Constructability	NA	0.44

Table 5.3, shows the relative weights of factors for environmental category. For both of the projects, the most important factor was limitations and constraints with a relative weight of 60% for US-34 and 73% for I-25. It was found in the meeting with I-25 team that this was one of their major concerns as the alignment of the roads are to change in the future and hence it was causing limitations to the project now in terms of planning.

Table 5. 3: Relative Weights of Factors for Environmental Category:

Factors	US-34 Rebuild Project	I-25 North Expansion project
Sustainability	0.40	0.27
Limitations and Constraints	0.60	0.73

Table 5.4 shows the relative weights of the factors for resource availability category. This category was eliminated by the US-34 rebuild team as they were confident that the resources would be intact till the end of the project. However, the I-25 team mentioned that there were more projects that was being planned in the state of Colorado, which might lead to issues in resources. They ranked project management capabilities as the most important factor with a relative weight of 61%.

Table 5. 4: Relative Weights of Factors in Resource Availability Factor Category:

Factors	US-34 Rebuild Project	I-25 North Expansion project
Availability of Direct Resources	NA	0.39
Project Management Capabilities	NA	0.61

Table 5.5 shows the relative weights of the factors for global and national events. For US-34, the global and national incidents had more importance with a relative weight of 57%. However, as the funding for the project was provided through the Emergency Relief funding, there was not a significant difference in the relative weights of both the factors. I-25 team had excluded the

global and national incidents and thus the relative weight of global and national economic factor was 100%.

Table 5. 5: Relative Weights of Factors for Global and National Events Category:

Factors	US-34 Rebuild Project	I-25 North Expansion project
Economic Factors	0.43	1.00
Incidents	0.57	NA

Table 5.6 shows the relative weights for the factors in the legal and legislative factor category. In both the projects, the factor of local acceptance was eliminated. Thus, the relative weight for procedural laws was 100% for both the projects.

Table 5. 6: Relative weights of Factors for Legal and Legislative Requirements Category:

Factors	US-34 Rebuild Project	I-25 North Expansion project
Local Acceptance	NA	NA
Procedural Laws	1.00	1.00

Table 5.7 shows the relative weights of factors for unusual conditions factor category. This factor category was eliminated by the I-25. However, owing to the location and the time of construction for US-34 project, the weather factor was maintained and since that was the only factor, it had a relative weight of 100%.

Table 5. 7: Relative weights of Factors for Unusual Conditions:

Factors	US-34 Rebuild Project	I-25 North Expansion project
Weather	1.00	NA
Force Majeure	NA	NA

Table 5.8 shows the relative weights for the factors in the localized issues category. It was identified that the most important factor for US-34 was land acquisition with a relative weight of 33% while for I-25 the most important factor was railroad and utilities with a relative weight of 33%. The next important factor for US-34 was marketing and public relations with a relative

weight of 25% because the businesses in Estes Park were being affected due to the project and the project was causing some issues with the public. For I-25, the next most important factor was land acquisition with a relative weight of 27%.

Table 5. 8: Relative weights of Factors for Localized Issues Category:

Factors	US-34 Rebuild Project	I-25 North Expansion project
Demographics of Population	0.21	NA
Land Acquisition	0.33	0.26
Public Emergency Services	0.14	0.13
Cultural Factors	0.07	NA
Marketing and public relations issues	0.25	0.09
Integration of land use planning, growth inducement and economic impacts	NA	0.06
Workforce Issues	NA	0.13
Utilities and railroad issues	NA	0.33

Table 5.9 shows the relative weights of factor categories. It was found that for US-34 project, the most important category was the localized issues with a relative weight of 30% primarily because the entire corridor was being shut down for construction. The US-34 team had mentioned that few residents and businesses were opposed to this. For I-25 the most important issue was the environmental category with a relative weight of 21% because of the fact that the alignments of the roads had to be changed. This was causing a lot of issues not only for social sustainability but also for designing and phasing the construction of the entire project. The next important category for US-34 was stakeholders with a relative weight of 22% and for I-25 was legal and legislative requirements with a relative weight of 18%.

Table 5. 9: Relative Weights of Factor Categories:

Factor Categories	US-34 Rebuild Project	I-25 North Expansion project
Stakeholder	0.22	0.16
Project-Specific Demands	0.14	0.16

Environmental	0.11	0.21
Resource Availability	NA	0.13
Global and National Events	0.06	0.05
Legal and Legislative Requirements	0.10	0.18
Unusual Conditions	0.07	NA
Localized Issues	0.30	0.11

Table 5.10 shows the global weights (global vector) of all the factors. When the global weights were compared, it was found that the most important factor for US-34 was procedural laws and land acquisition and both had a relative weight of 10%. The next important factor for US-34 was work-zone visualization with a relative weight of 9% followed by marketing and public relations with a relative weight of 8%. Similarly for the I-25 team, the procedural laws was the most important factor with a relative weight of 18%. However, the next important factor was limitations and constraints with a relative weight of 15% followed by project management capabilities with the relative weight of 9%. Procedural laws factor was rated so highly for both the projects as the funding is provided by many different parties; and each of these parties wants some control over the design, which is causing issues for the project management teams. The most striking difference between the factor weights for both the projects was that the weights were more evenly distributed between factors for US-34, whereas for I-25, few factors had very high weights such as procedural laws and limitations and constraints while few others had exceptionally low weights such as intermodal requirements, marketing and public relation issues and integration of land use planning, growth inducement and economic impacts.

Table 5. 10: Global Weights for All Factors for both the Projects:

Factors	US-34 Rebuild Project			I-25 North Expansion Project		
	Local Priority	Local priority vector for	Global Vector	Local Priority	Local priority vector for	Global Vector

	Vector for Factors	Factor Categories		Vector for Factors	Factor Categories	
Stakeholders						
Public	0.21	0.22	0.05	0.31	0.16	0.05
Politician	0.22	0.22	0.05	0.14	0.16	0.02
Owner	0.29	0.22	0.06	0.36	0.16	0.06
Jurisdiction	0.28	0.22	0.06	0.19	0.16	0.03
Project Specific Demands						
Maintaining Capacity	0.36	0.14	0.05	0.34	0.16	0.05
Work-zone Visualization	0.64	0.14	0.09	0.13	0.16	0.02
Intermodal Requirements	NA	NA	NA	0.09	0.16	0.01
Phasing and Constructability	NA	NA	NA	0.44	0.16	0.07
Environmental						
Sustainability	0.40	0.11	0.04	0.27	0.21	0.06
Limitations and Constraints	0.60	0.11	0.07	0.73	0.21	0.15
Resource Availability						
Availability of direct resources	NA	NA	NA	0.39	0.13	0.05
Project Management capabilities	NA	NA	NA	0.61	0.13	0.08
Global and National Events						
Economic Factors	0.43	0.06	0.03	1.00	0.05	0.05
Incidents	0.57	0.06	0.03	NA	NA	NA
Legal and Legislative Requirements						
Local Acceptance	NA	NA	NA	NA	NA	NA
Procedural Laws	1.00	0.10	0.10	1.00	0.18	0.18
Unusual Conditions						
Weather	1.00	0.07	0.07	NA	NA	NA
Force Majeure	NA	NA	NA	NA	NA	NA
Localized Issues						
Demographics of Population	0.21	0.30	0.06	NA	NA	NA
Land Acquisition	0.33	0.30	0.10	0.26	0.11	0.03

Public Emergency Services	0.14	0.30	0.04	0.13	0.11	0.02
Cultural Factors	0.07	0.30	0.02	NA	NA	NA
Marketing and public relations issues	0.25	0.30	0.08	0.09	0.11	0.01
Integration of land use planning, growth inducement and economic impacts	NA	NA	NA	0.06	0.11	0.01
Workforce Issues	NA	NA	NA	0.13	0.11	0.02
Utilities and railroad issues	NA	NA	NA	0.33	0.11	0.04
Social Equity	NA	NA	NA	NA	NA	NA
	Total		1	Total		1

Even though the methodology and the calculation process used is accurate, due to the elimination of some factors resulting in only one factor under a category, some of the weights might be higher. If these factors had been placed under another category, these results might have varied.

5.4. Concluding Remarks

In conclusion, the framework developed for assessing the contextual factors by the project management teams can be used by the transportation agencies to provide more accurate relative weights of the factors under the context dimension. As seen from results, these relative weights can help the project team to focus on factors with higher weights. Furthermore, the project team can further discuss and eliminate the factors with a lower weight. Owing to the Group AHP approach used in this research, the consistency ratio was also within the required limit which validates the results obtained. One of the ways in which these weights can be used is to aid in developing the risk management strategies. For the projects it funds, the FHWA require agencies to draft a risk management strategy before the funds can be released; and these weights can aid in establishing initial probabilities of causing such issues in the project. Also, with the help of these weights, the project management team can be more aware of issues that might cause delays and can develop a more realistic budget and schedule.

One limitation of the study was that some of the factor categories had only one factor, which eventually led to a higher global weight for that factor. However, as the results are in concordance with the views presented in meetings with both the project teams, it provides a strong indication that the methodology was accurate and can assist in the assessment of contextual factors.

5.5. Future Research

The SHRP-2, R-10 team had identified two new dimensions that should be considered while developing a project management plan i.e. context and financing along with the existing three dimension of cost, schedule and technical. The team identified similar factors and factor categories in each of these other four dimensions. This framework can be modified and similar methodology can be performed for the other four dimensions as well. Comparisons of all the factors across all the dimensions could lead to valuable results.

Another possible future research could be to use other MCDA techniques such as PROMETHEE I & II and ELECTRE III if overall ranking is not required and the team members only want to know the top most factors. However, the implementation of these methods might require multiple interaction with the team members and is difficult to complete in one interaction. This framework can also be applied to a project that has been completed and the relative weights obtained at the end could be checked with the project management teams to see if the ranking through this process matches to what had been incorporated in the project management plan.

Also, while working through this project, it was identified that some of the factors have overlapping definitions. As a future study, these factors can be reinvestigated to develop fewer factors and factor categories and the definitions could be broadened. This might also aid in solving the issue of having only one factor under a category and yield interesting results.

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APPENDICES

APPENDIX A: Pairwise Comparison Tool for US-34 Rebuild Project

Instructions: Please perform pairwise comparisons between the factors shown below in columns A and B by considering the complexity these factors will cause in the U.S. 34 Rebuild project. To see the explanations of the factors please refer to the "Definitions of Factors" worksheet. In making pairwise comparisons, first you need to identify which factor is more important to consider than the other (in causing complexity) and indicate that selection in the "More Important Factor" column. Then, you need to determine how much more important that factor is over the other one and indicate that selection in the "Degree of Importance" column. Table-1 provides information on the scale to be used for those comparisons. There are 17 factors and 7 factor categories resulting in 40 pairwise comparisons. It is estimated that completing the survey will take approximately 30-35 minutes. If you have any questions with respect to this survey, please contact the graduate student, Akanksha Sinha (akanksha.sinha@colostate.edu).

Table 1:Pairwise Comparison Scale

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate Importance	Experience and judgement slightly favor one activity over another
4	Moderate Plus	
5	Strong Importance	Experience and judgement strongly favor one activity over another
6	Strong Plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Only input data in the yellow fields! The fields should turn green after

Factor Categories	Factors A	Factors B	More Important Factor	Degree of Importance
Stakeholders	Public	Politicians		
	Public	Owner		
	Public	Jurisdictions		
	Politicians	Owner		
	Politicians	Jurisdictions		
	Owner	Jurisdictions		
Project-Specific Context Factors	Maintaining Capacity	Work-Zone Visulaization		
Environmental Category	Sustainability	Limitations and constraints		
Global and National Events	Global and National Economic Factors	Global and National Economic Inciden		
Localized Issues	Demographics of Population	Land Acquisition		
	Demographics of Population	Public Emergency Services		
	Demographics of Population	Cultural Factors		
	Demographics of Population	Marketing and public relations issues		
	Land Acquisition	Public Emergency Services		
	Land Acquisition	Cultural Factors		
	Land Acquisition	Marketing and public relations issues		
	Public Emergency Services	Cultural Factors		
	Public Emergency Services	Marketing and public relations issues		
	Cultural Factors	Marketing and public relations issues		

APPENDIX B: Pairwise Comparison Tool for I-25 North Expansion Project

Instructions: Please perform pairwise comparisons between the factors shown below in columns A and B by considering the complexity these factors will cause in the I-25 Expansion project. To see the explanations of the factors please refer to the "Definitions of Factors" worksheet. In making pairwise comparisons, first you need to identify which factor is more important than the other (in causing complexity) and indicate that selection in the "More Important Factor" column. Then, you need to determine how much more important that factor is over the other one and indicate that selection in the "Degree of Importance" column. Table 1- below provides information on the scale to be used for those comparisons. There are 20 factors and 7 factor categories resulting in 50 pairwise comparisons. It is estimated that completing the survey will take approximately 30-35 minutes. If you have any questions with respect to this survey, please contact the graduate student, Akanksha Sinha (akanksha.sinha@colostate.edu).

Table 1:Pairwise Comparison Scale

Intensity of Importance	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate Importance	Experience and judgement slightly favor one activity over another
4	Moderate Plus	
5	Strong Importance	Experience and judgement strongly favor one activity over another
6	Strong Plus	
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation

Only input data in the yellow fields!
The fields should turn green after the input.

Factor Categories	Factors A	Factors B	More Important Factor	Degree of Importance
Stakeholders	Public	Politicians		
	Public	Owner		
	Public	Jurisdictions		
	Politicians	Owner		
	Politicians	Jurisdictions		
	Owner	Jurisdictions		
Project-Specific Context Factors	Maintaining Capacity	Work-Zone Visulaization		
	Maintaining Capacity	Intermodal Requirements		
	Maintaining Capacity	Phasing and Constructability		
	Work-Zone Visulaization	Intermodal Requirements		
	Work-Zone Visulaization	Phasing and Constructability		
	Intermodal Requirements	Phasing and Constructability		
Resource Availability	Availability of Direct Resources	Project Management Capabilities		
Environmental Category	Sustainability	Limitations and constraints		
	Integration of land use planning, growth inducement and economic	Land Acquisition		