Categorizing ABC projects for Decision Making ETD 001

By Daniel Antonio Linares Garcia
Categorizing Accelerated Bridge Construction Projects for Improving Decision-Making

by

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Abstract

Accelerated Bridge Construction, also known as ABC, is a methodology that seeks to improve project development of bridges by reducing the overall project schedule and the impact on the traveling public by implementing innovative technologies and strategies in any phase of project development. However, ABC may incur additional direct costs for the project and some risks are associated because of the accelerated constraints implied in this methodology. On the positive side, the opportunity costs and reductions of traffic disruptions costs may overcome the additional costs associated with ABC. Decision-making methodologies for assessment of ABC as an alternative to traditional construction are of great interest for project developers.

The topics of research about ABC are diverse but focus mainly on the means and methods, technical aspects, applications, innovations, and decision-making of ABC. Decision-making is of great concern for project developers, especially government organizations, to sustain project goals of serviceability and to validate the additional expenditures in a project. In addition, project developers improve their decisions and project outcomes by reviewing success and failure cases for completed projects in the past.

This study seeks to improve the decision-making processes in ABC by finding a more direct correlation of projects to compare by means of a categorization of these ABC projects. Smaller groups in this categorization will help narrow the scope of the characteristics of the projects to consider and to find more relevant lessons learned from the smaller groups of the categorization.

To develop the categorization in this study, the data source used is the completed ABC projects database from the Federal Highway Administration (FHWA). The statistical categorization methodology for this study is the Agglomerate Hierarchy Clustering which developed a determined number of cluster based on the closeness among data parameters with “n” number of dimensions of analysis. The number of dimensions for the analysis in this study was established as 13 parameters collected from the database and these were considered critical decision-making parameters and consequential parameters to reflect project decisions and consequences of those decisions.

The results of this study rendered 3 categories, and into these categories, 5 sub-categories were distributed according to the same analysis developed. The sub-categories show similarities between the projects according to the parameters established, so the sub-categories help narrow the scope of projects for project developers. As a complement to the categorization, a project matching tool for external projects was also developed to help decision-makers to test their projects according to the analysis in this study and also help developers narrow their review of cases in search for lessons learned.

Uses of this study include the prediction of information of parameters according to the variables and ranges in this categorization, and the narrowing of study cases to review. Stakeholders interested can be government organizations seeking to establish the viability of an ABC project, or to improve their project outcomes at any stage of development. Other stakeholders can be designers and contractors that also need to improve their projects at any stage of development.
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1 Introduction

The development of infrastructure is a need that supports the society’s lifestyle and progress. We need clean water to drink and clean ourselves. We need an energy grid to power our devices and electronics. We need roadways to have our cars cruise to our everyday commuting. And we need bridges between roads, rivers, and ditches to overcome horizontal limitations in our road structures. Hence, there is an increased need for the development and Improvement of Civil Infrastructure of all kinds.

The American Society of Civil Engineers (ASCE) assess the infrastructure status through its American Infrastructure report card. With this report, the ASCE seeks to raise awareness on deteriorating and insufficient infrastructure and promote innovation to quicken the development and increase the quality of infrastructure. In the most recent 2017 report, a D+ score was given to America’s Infrastructure in general, and bridge infrastructure received a C+ score; both scores can be considered calls for improvements (ASCE 2017).

Focusing on bridges, some highlights from the National Bridge Inventory (NBI) shows that the average age of bridges is 43 years old and more important, 9.1% of bridges nationwide are considered structurally deficient (FHWA 2017). Figure 1 shows the percentage of structurally deficient bridges by age according to the NBI data which obviously confirm that bridges age have a proportional relationship to the bridge status.

![Figure 1. Percentage of structurally deficient bridges by age. (FHWA 2017)](image)

In addition, the percentage of bridges older than 50 years, which is the average design life for bridges, is about 39% of the total 239,615 bridges. See Figure 2.
As per intention of the NBI and the ASCE, these facts raise awareness that infrastructure is not everlasting and will need to be retrofitted or replaced. This need exists because of the inevitable passing of time and also because the societal and environmental needs are ceaseless and constantly changing.

The rapid development of transportation infrastructure is critical and is highly desired. Such development may bring additional monetary savings to stakeholders but more importantly, the societal cost is reflected as a benefit. For example, bridges support the highway systems that became increasingly complex due to societal progress (FHWA 2012a). New bridge projects are generally the more complex and resource-intensive component of the roadway infrastructure. More problematic, bridge retrofitting or replacement can be very disruptive and logistically challenging to overcoming traffic disturbance, public nuisance, and safety hazards. Accelerated Projects Delivery (APD) practices hold the potential to further reduce time in infrastructure development. These practices when applied to bridges are named Accelerated Bridge Construction (ABC) and is the main topic evaluated in this study.

By focusing on speed of construction, in addition to improved and innovative means and methods, ABC practices have the potential to be solutions to the required infrastructure demands. For these reasons, this study will assess such methodologies in a retrospective and concurrently manner through the statistical analysis of completed ABC projects and the observation of a project in development. The methodology is built upon the evaluation of the parameters of the ABC projects and provide further insight into the benefits and the challenges of these methodologies.
2 Background

The development of bridges is usually a complement to the rest of the highway infrastructure. Bridges usually serve the purpose of overcoming physical obstacles that cannot be addressed by horizontal roadways. For example, the crossing between two roadways is improved when one of the roadways goes over the other. This arrangement is more efficient than a normal intersection with stoplights, so it is preferred. Bridges also open new opportunities to the public and can serve as pushers of development. For example, the Golden Gate Bridge aided the development of the Bay Area in San Francisco and improved the physical conditions by switching from ferries to an automobile crossing.

Bridges incur great economic cost and technical challenges. The assessment of the development of bridges can become critical given that the benefits must surpass the pitfalls and costs. When talking about the rapid development of bridges, the challenges are increased, but ABC is still worthy to consider in terms of quality of infrastructure, quicker schedules and diminishing the disturbances to the traffic and public.

2.1 Key Stakeholders

Decision-makers, planners, designers, contractors, and the public are involved in the development of bridge projects at many levels. Bridge development can be resource and labor intensive so the management of the resources and the continuous interaction of the different parties become crucial.

In the development of Roadway Infrastructure, several government agencies may be involved at various levels, depending on the many characteristics of a project, but ultimately a specific agency or partnership of agencies can champion this kind of infrastructure project. Government agencies not only support project development financially but also, technical and logistical support is included. At the higher level, the United States Department of Transportation (US DOT) has authority over different transportation infrastructure Agencies ¹, and delegate specific infrastructure types to second-level administrative agencies including the Federal Highway Administration (FHWA) for road infrastructure (FHWA 2012b). Among the responsibilities and duties of US DOT and FHWA are: establishing guidelines for infrastructure development per federal policies and support state DOTs to the achievement of their own local policies, provide support to keep the US highways, tunnels and bridges in good condition and encourage innovation into the road infrastructure through research and technical support (US DOT 2015, 2017). Then the State Departments of Transportation (State DOTs) oversees the roadways infrastructure development at the state-level and work with local governments to develop and assess their infrastructure. Finally, the local governments identify the needs of the public in their jurisdiction, assess the infrastructure prospects, and find ways to solve the needs of their target public. Local governments are promoters and beneficiaries of the road infrastructure development.

Other stakeholders are the construction industry and other professional organizations. The construction industry is a collection of organizations, companies, and professionals who have

¹ The USDOT manages not only road infrastructure but many other types of infrastructure including airports, railroads, waterways and others.
interests or are considered participants in the building of infrastructure at various levels. Many professionals and organizations exist in the United States to support the development of the construction industry; some of them focus on professional development like the American Society of Civil Engineers (ASCE) and American Institute of Architects (AIA). Other organizations are conglomerates of companies and institutions that pursue goals of contributing to the development of the construction industry as a whole or to a fraction of companies; these organizations usually support research in the construction field and through these organizations research knowledge is tested and transferred, the Construction Industry Institute (CII) is an example. Construction Companies are the doers in the realization of projects in the construction industry, as consulting companies, they support the planning, design, and building of projects through experience and expertise; then the contractors and subcontractors physically build what is planned to complete the projects. Nowadays, inclusivity of different stakeholders is present in project development and for example, general contractor and subcontractors can make contributions to the project in the design phases.

Research institutions and academia usually have the function to improve the development methodologies, to improve the means and methods in all the project phases, and to update the myriad processes in the development of infrastructure, these goals are accomplished by academic research in the field. Academia also prepares the professionals that will perform the functions and improvements of the processes and applications in the construction industry. Typically, research institutions and academia conduct research under the demand of sponsors which can be organizations, companies, and government.

After a broad examination of the stakeholders in the construction industry, a level of complexity is added by outside constraints which include funding for the projects, political environment, environmental issues and more. Ultimately, the public is being the final beneficiary of the infrastructure development and they are seen as the social investment for which road infrastructure is aimed.

2.2 Project Delivery Methodology

Project developers make use of Design-Bid-Build, Design-Build and Construction Manager/General Contractor to align stakeholders and make a concurrent use of the resources in the project lifecycle.

Design-Bid-Build (DBB) establishes the owner as the centerpiece of the interaction between the other main stakeholders, mainly the design and the builder. The awarding of the designed project to a construction company is also a feature of DBB (Carpenter and Bausman 2016; Yu et al. 2017).

Design-Build (DB) is a more straightforward methodology of contracting in which the owner establishes a relationship with a single party that will serve as designer and builder. In this arrangement, the contracted party can be a sole company, but usually, partnerships are created between a design firm and a contractor, who have a very close working relationship (Gransberg et al. 2006). This simple shortcut in the procurement phases allows a project to add simultaneity between design and construction and more significantly collaboration between designer and builder.
Construction Management/General Contractor (CMGC), also known as CM at Risk, is another contracting methodology that differentiates from the DB in which the owner contracts the designer and the builder independently. A higher collaboration is defined between the parties and the risk allocation is also considered. In CMGC, the designer works on the design to reach a point at which the builder can make economic proposals and start construction of the building. A level of risk or contingency is allocated in case the scope of the project changes so the design evolves to its final state. The designer and the builder work simultaneously until the design is completed and the project continues until completion (Gransberg and Shane 2015). The concurrency between design and construction is a similarity between GMGC and DB; however, the way the contract is managed is different between the two, as GMGC has different contracts for the designer and the builder.

Public Partner Partnership (PPP) is a methodology that is gaining momentum in the development of infrastructure because it helps surpass the limitations of limited public funds to the development of infrastructure projects. PPP establishes a relationship between a government agency and a private party, which are linked by a contract that establishes the duration of the partnership, how the asset is managed, how the revenues are divided, and quality of the created asset and services offered. The government entity becomes the owner of the asset and the regulator for the private party. In exchange, the private party receives a financial benefit defined in the agreement (Levy 2011).

The selection of the project delivery method for public infrastructure projects is not something defined, but something that must be evaluated on a case by case basis. In 2017, Park and Kwak evaluated the trends about project delivery selection on public-sector infrastructure projects and the impact of the project delivery methodology selected in a recent study. Their study reaffirms the scheduling advantages of DB over DBB in large-scale projects but the costs benefits remain unclear (Park and Kwak 2017).
3 Review of Literature

Quick project delivery is a desirable outcome in construction projects. Accelerated Project Delivery (APD) is a common methodology used to generalize the quick development of infrastructure of any type including residential, commercial or government. Reasons to adopt APD for projects can include reaching seasonal dates, getting into a particular market in the desired time, or emergency rehabilitation in case of catastrophes. In 2013, Gransberg addressed this later topic by evaluating different emergency projects in different states. In these situations, quick completion of projects is unquestionable, coordination and early engagement of stakeholders are imperative, and quicken procurement is the strategies for a successfully delivery of emergency projects (Gransberg 2013).

For many years, researchers have sought mechanisms to deliver bridge projects quickly. Different terminology has been used to describe the means and methods that support the rapid development of bridges. Researchers have tried to explain the technical knowledge that this kind of project requires, and for example, there are studies that seek to describe the impact on decks, piers, columns, walls or even geotechnical impact in projects that have an accelerated development (Aktan and Attanayake 2015; Garber 2016a; Jabiri 2016). Other researchers have focused on the impacts of the managerial strategies that these accelerated projects imply on scheduling, procurement, and safety (Austin et al. 2015).

Some of the studies have taken a retrospective approach by describing processes and methodologies that have been used by the industry and have gained a connotation to be typical in their use (Garber 2016a). Fewer studies have taken a sequential case study approach to a project development in order to understand the challenges associated with accelerated bridge construction.

For the purpose of this study, it is considered that the term Accelerated Bridge Construction (ABC) represents a clearer and more broadly used concept. Other terminologies relate concepts similar to ABC but refer to more specialized or generalized areas of application. For example, Accelerated Project Delivery (APD) methodologies and Flash Track.

3.1 Accelerated Bridge Construction

Although standard practices for ABC projects have not been completely standardized and defined, bridge projects have employed such practices to a certain degree in the last decades. Researchers have tried to understand and evaluate means and methods in bridge construction that support the development of the set of practices that ABC construction demands (Saeedi et al. 2013). Decision making and technical aspects of ABC projects have been, for the most part, the main focuses of ABC researchers.

In 2016, Orabi and Mostafavidarani presented in their report “Estimating the Construction Cost of Accelerated Bridge Construction (ABC)” the current decision-making tools in ABC projects. Their report suggests qualitative and statistical tools that have been designed to help stakeholders balance the benefits and the risks of ABC projects on its application. The authors suggest that in most cases involving bridge construction, ABC is the best option (Orabi et al. 2016).
Studies also mention the importance of decision-making tools and the targeting of these tools to users such as DOTs at the State and Federal level. These studies also highlight these government organizations as the promoters to standardize ABC methodologies (Culmo 2011). Many studies in ABC projects have been focused on case studies of bridges across the United States. These projects evaluations have been for the most part retrospective but also concurrent analysis has been presented. For the purpose of analyzing ABC projects, databases have been created to ease the retrospective analysis but also to support the concurrent analysis of ABC project (Garber 2016a).

An even greater interest in ABC projects has produced more technical studies. Studies related to a specific evaluation of bridge elements and the impact on the ABC timeframe impact or the elements behavior. For instance, the Michigan DOT and researchers at the Western Michigan University developed a report that evaluates the technical aspects involved in ABC projects in order to set a standard framework at the state level for this kind of projects (Aktan and Attanayake 2015). Figure 3 shows the Hatford bridge replacement bridge project in Vermont, as a case example of Accelerated Bridge Construction using the slide-in deck technique of construction.

Whatever the motivation, it is perceived that the interest in ABC has increased in the last few years and the setting of standards regarding the managerial or technical aspects of Accelerated Bridge Construction has some interest too.

Figure 3. The Hatford bridge replacement bridge project in Vermont is an ABC project that used the Slide-in deck replacement method.
3.2 Flash Track
The Construction Industry Institute (CII) has supported Flash-Track studies to research this methodology to achieve success in project development under reduced timeframes. According to CII, Flash-Track is defined as:

"...as a time-driven project, which by necessity requires a heightened degree of concurrency between engineering, procurement, and construction." (Austin et al. 2015).

The Flash-Track methodology was supported by the development of best practices to address the areas of needed alignment that guide stakeholders in projects. These best practices were formulated taking into consideration experts in the construction industry and making statistical analysis to rate the importance of each of the categories and practices (Austin et al. 2015). Further research was done on Flash-Track research to implement a tool that would aid stakeholders to assess the degree of preparedness for the implementation of such practices (Austin et al. 2016; Pishdad-Bozorgi et al. 2016).

3.3 The completed ABC projects database
The completed ABC projects database was created as a result of the efforts made by the AASHTO Technology Implementation Group (TIG), Prefabricated Bridge Elements and Systems (PBES) Lead States Team and the FHWA. Its creation was also supported by the research efforts of the Accelerated Bridge Construction - University Transportation Center (ABC-UTC) which is a conglomerate of research projects by different universities and institutes (Garber 2016b).

The completed ABC project database is the compilation of the bridge projects which have employed any of the acceleration practices available to quicken their completion time or reduction to traffic and public disturbances. This database includes projects from all US and includes projects that date back to 1973 (ABC-UTC and FHWA 2017).

The completed ABC project database has two main components:

The first component is an online website with an interactive interface of the database. The website can be found at the following web address:

http://utcdb.fiu.edu/

This website, provide a centralized access to the information for the ABC projects as well as references to information to each of the ABC projects by means of individual web pages with additional information. The second component is an Excel summary sheet as a summary document for all the projects.

Many parameters were included in the database to characterize the projects, the parameters range from basic information to specific innovative approaches or techniques to achieve acceleration. The database was created to have records of lessons learned and to share the knowledge and practices that previous ABC practitioners faced. At this moment, the database has records of 100 projects. Figure 4 shows a list of some of the parameters included in the database.
In this study, the database will be used as follows:

- The database will be the data source from which our study will depart for the analysis of previous completed ABC projects by statistical analysis.
4 Research Objectives and Goals

The purpose of this study is to provide insight into the status of ABC and how it will perform in the future as a supporting methodology to fulfill the gap between the infrastructure needed and the infrastructure developed. To assess the parameters that define the ABC projects, the following data source will be used:

The existing completed ABC project database from FHWA, which will be analyzed retrospectively. A post-facto analysis of the existing ABC Project Database will be the starting point to set a baseline to understand ABC projects and tentative categorization.

4.1 Objective of this study
1. Make a general categorization of the ABC projects based on the assessment of the parameters in the completed ABC projects database.

4.2 Tasks
1. Analyze the existing Federal Highway Administration (FHWA) ABC completed projects database.
2. Define the statistical analysis to use.
3. Define the relevant parameters that will be used to categorize the ABC projects, according to the database and the selected statistical analysis method.
4. Use a statistical analysis for clustering into categories the projects based on the parameters in the FHWA database.
5. Validation of analysis.
5 Research Design

The research design for this project will utilize a mixed approach to qualitative and quantitative analysis. This study will consist of two components that will be conducted concurrently. The first component includes the analysis of the completed FHWA ABC database and the second component is the collection of the data and then the analysis and comparison of the ongoing case study.

5.1 Analysis of existing database
For the database analysis, a statistical analysis of the parameters of completed ABC projects within the existing databases is intended. The database includes the various aspects of ABC projects like project planning, geotechnical, structural considerations and construction techniques. By clustering, the parameters in categories, another statistical analysis, among the ones considered, will be applied to infer the categorized parameters of the projects and find established intrarelationships between the characteristics of the projects documented in the inventory.

5.2 The Statistical Analysis Methodology
The goals of this study demand a statistical analysis that takes into consideration grouping of the parameters and finds its similarities within same clusters and identifies differences among different clusters. By definition, clustering analysis methodology was considered as the best ways to perform the analysis and because of the categorical goal for this study, Agglomerate Hierarchical Clustering or AHC was the statistical methodology selected for this study.

5.2.1 Agglomerate Hierarchical Clustering (AHC)
AHC is a center-based clustering algorithm where the grouping of the data is clustered from bottom-up. This means that from the beginning the clusters are defined from the most basic unit, which can be the data point itself, and subsequently grouped together by the closeness from other data points which form bigger cluster until the whole population is grouped as the major cluster (Gan et al. 2007).

Figure 5 shows the graphical process for AHC with two parameters represented in the x-axis and y-axis.
According to statistical theory (Gan et al. 2007; Mirkin and Mirkin 2013), the AHC process is as follows:
1. First, clusters iterations are developed by closeness of the data. (Figure 2a,b). Measuring distance was defined by the Euclidean distance in this study. See formula bellow.
\[ d(p, q) = d(q, p) = \sqrt{(q_1 - p_1)^2 + (q_2 - p_2)^2 + \cdots + (q_n - p_n)^2} = \sqrt{\sum_{i=1}^{n}(q_i - p_i)^2} \]

2. Smaller clusters are identified and then the centroids for those clusters are obtained (Figure 2c).
3. Then, the closest distance among clusters is found again to define a bigger cluster (Figure 2d). Then, centroids are obtained (Figure 2e).
4. This process is repeated as many times needed until the clusters are grouped into a major cluster containing all the clusters (Figure 2f).

5.2.2 Considerations regarding the Statistical Analysis.
As mentioned in the section 5.2.1, Agglomerate Hierarchical Clustering (AHC) was selected as statistical Methodology for this study.

5.2.2.1 Software
The statistical analysis will be performed by using a specialized software for statistics analytics and visualization. The software selected is XLSTAT which is an Excel-based plugin. The trial version of the software was used to make the analysis in this study.

5.2.2.2 Statistical analysis considerations.
The software provides several options for the AHC analysis. Considerations regarding software options are as follows:

- Euclidian distance will be used to define proximity of clusters.
- Agglomeration method will be Ward’s method.
- To simplify, projects were identified by their Project ID number rather than project name.
- Missing data will be estimated based on mean or mode.
- The software will test a number of cluster analysis from 1 clusters to 10 clusters.
- Data input for AHC is numerical only.
6 Developing Categorization for ABC projects

6.1 Methodology for categorization
For the development of the categorization, the structured processes shown in Figure 6 was followed. Further insights are explained in the following sections.

![Diagram for Categorization Process]

6.1.1 Gathering Data from Database
In section 3.3, it was explained what information the completed ABC projects database contains. However, more information was obtained by reviewing the individual project web pages in the database. It was by a revision of this information that a compilation of relevant information for this study was created. A selection of parameters was made according to the requirements of the statistical methodology, as well as the objectives of the research. The following sections provide more insight into the considerations for the selection of the relevant parameters.

Appendix A shows the information obtained from the revision of the Excel summary datasheet, and individual web pages from the database. Appendix A was considered the raw data for our study, then this information was modified in preparation for the statistical analysis.

6.1.2 Description of parameters and nomenclature
While gathering the data from the database, some considerations were made regarding the name of the parameters found in the database. In most of the cases, the nomenclature established in the database was considered adequate for this study, however, some parameters’ names were changed to convey a clearer understanding of the information presented. The description for each parameter and some considerations are explained in the following sections.

6.1.2.1 Type of Project
The “Type of Project” parameter has qualitative variables. These variables were obtained from the individual web pages of the completed ABC projects database. In these web pages, a narrative of the project was included, therefore a typology for the projects was inferred. “Type of project” was considered a simple and precise nomenclature for this parameter.

6.1.2.2 Project Delivery Methodology
The “Project Delivery Methodology” parameter has qualitative variables. This variable was already established in the completed ABC project database Excel summary and was named
"procurement", which is included in a bigger category named "planning". "Project Delivery Methodology" was considered a better nomenclature than "procurement" for this study.

6.1.2.3 Location Setting
The "Location Setting" parameter has qualitative variables. This parameter was not included in the Excel summary datasheet; however, it was included in the individual web pages for each project. Almost all of the projects have location setting information on their individual web pages.

6.1.2.4 ADT along structure
The "ADT along structure" parameter has quantitative values. This parameter was not included in the Excel summary datasheet; however, many projects included this parameter information in the individual web pages for projects.

"ADT along structure" refers to the traffic flow that runs through the project structure that is intervened for replacement, construction, or retrofitting. Many projects have the "ADT along structure", and most of them refer to the ADT at the moment of the development of the project. However, some projects have a projected ADT for a future time; in those cases, this ADT was used.

6.1.2.5 Crossing Conditions
The "Crossing Conditions" parameter has qualitative variables. This parameter was obtained from the information presented in the narrative for the projects in the individual web pages for the projects. However, in some cases, the narrative for the project did not provide enough information to obtain the "Crossing Conditions" variable for this project. In those cases, the pictures in the web pages for the individual projects and map information from the project coordinates from the Excel Summary datasheet was used.

6.1.2.6 Project Length
The "Project Length" parameter has quantitative values. All the projects included the measurements for the length of the project in their respective individual web pages. In cases where more than one bridge was developed in the project and more than one longitude was included in the description of the project, the addition of all the lengths for individual portions of the project was considered as the "Project Length". Please refer to the Purging and cleaning data section of this document.

6.1.2.7 Project Width
The "Project Width" parameter has quantitative values. All the projects included the measurements for the width of the project in their respective individual web pages. In cases where more than one bridge or span were developed in the project, and more than one width distance was included in the description of the project, the addition of all the widths for individual portions of the project was considered as the "Project Width". Please refer to the Purging and cleaning data section of this document.

6.1.2.8 Project Max Span
The "Project Max Span" parameter has quantitative values. Most of the projects included the measurements for the spans of the projects. Also, in most of the cases, the longitudes for the many
spans of the projects were included in the description in their respective individual webpage. For this parameter, the maximum span was considered to be the most challenging condition for the project and considered as a parameter that can affect construction time and cost for the whole project as the added complexity of an unusually long span.

6.1.2.9 Winning Bid

The “Winning Bid” parameter has quantitative values. Originally, there were two related parameters for the cost in the individual web pages for the projects. These two related parameters were the “low bid” and the “estimated cost by the engineer”. It was considered that these two parameters were redundant, so only the low bid parameter was left for analysis and was renamed as “Winning Bid” and was considered as the best consideration that reflects the project cost. This parameter was obtained from the individual web pages for the projects.

6.1.2.10 Cost per Square Foot

The “Cost per Square Foot” parameter has quantitative values. It was considered that this parameter relates size parameters with cost parameters, thus becoming relevant for the analysis of this study. This parameter was obtained from the individual web pages for the projects.

6.1.2.11 Construction Time

The “Construction Time” parameter has quantitative values. This parameter was considered very relevant to this study because of the relevance to have an estimated range of construction time for the project. “Construction Time” was obtained from the individual web pages for each project for some cases, but schedule attachments in the individual web pages for each project were also considered in cases where the construction time was not found in the individual web pages. Construction time was not found for all the projects.

In addition, iterations of different construction time units were found as follows:

- Calendar days
- The time between Notice to Proceed and Substantial completion
- Working days

To compare same time units of data, it was decided to use only calendar days as units for this parameter. Therefore, a conversion was made as follows:

- For calendar days, as it is.
- For the time between Notice to Proceed and Substantial Completion; a time calculator was used to get the number of calendar days between those two dates. No holidays were taken into consideration.
- For working days; 2 days were added for every 5 days of work. No holidays were taken into consideration.

6.1.2.12 Time Reduction on Traffic Impact

The “Time Reduction on Traffic Impact” has quantitative values. This parameter is the relationship defined by the Transportation Research Board (TRB) research for the reduction of the disruption to the traffic (TRB 2012). It is given as follows:
- Tier 1: Traffic Impacts within 1 to 24 hours
- Tier 2: Traffic Impacts within 3 days
- Tier 3: Traffic Impacts within 2 weeks
- Tier 4: Traffic Impacts within 3 months
- Tier 5: Overall project schedule is significantly reduced by months to years

For the project database, an added tier was included by the database developer to include a tier for traffic impact within 1 month. The final Impact traffic is as follows:
- Tier 1: Traffic Impacts within 1 to 24 hours
- Tier 2: Traffic Impacts within 3 days
- Tier 3: Traffic Impacts within 2 weeks
- Tier 4: Traffic Impacts within 1 month
- Tier 5: Overall project schedule is significantly reduced by months to years
- Tier 6: Overall project schedule is significantly reduced by months to years

The "Time Reduction on Traffic Impact" will be considered a quantitative parameter despite being pondered as tier variables because the tiers themselves consider a numerical relationship to the reduction of traffic impact. In other words, a low tier means a high reduction in traffic disturbance and a high tier means a low reduction in traffic impact. Originally, it was named "Impact Traffic" in the Excel summary sheet and in the individual web pages of the projects, but it was considered that "Time Reduction on Traffic Impact" was a better nomenclature for this parameter in this study.

### 6.1.3 Defining parameters for analysis

The definition of the relevant parameters for this study was made to relate major characteristics of the projects that are crucial for decision making when selecting ABC as a methodology for bridge construction. The major characteristics that this study sought to relate are descriptive, conditions, size, cost, and time characteristics which would help better assess the benefits of ABC.

The selected parameters also define the constraints for the projects. These constraints can be given in the descriptive, conditions and size parameters which proportionally, or inversely, affect the cost and time parameters. For example, a project with high ADT along structure will certainly increase the cost of the project and the duration of the project.

The diagram in Figure 7 shows these relationships and include the parameters into the major characteristics which will be the defining parameters for the categorization.
Figure 7. Graphical relationships for major characteristics of parameters and parameters.

Qualitative = green, quantitative = blue.
In addition, the nature of the parameter, whether qualitative or quantitative, was also crucial to the
determination of the relevant parameters to consider. This is because the nature of the parameter
determines how to initially process these parameters in preparation for the statistical analysis.
Figure 7 shows the qualitative parameters in green; well, quantitative parameters are shown in
blue.

6.1.4 Preparing data for analysis
Before proceeding to the analysis of the data, the information was processed to convert the raw
data to the proper format for data input and comply to the requirements of the statistical
methodology to be used in this study, as mentioned in section 1. The final data input for the
statistical analysis is shown in Appendix B.

6.1.4.1 Data sample
The whole population of the database is 100 projects; however, 10 projects were selected to
validate the statistical analysis performed with 90 projects left. For this purpose, 10 projects were
randomly selected from the pool of 100 projects. These 10 projects were subtracted from the
Appendix A so the final input data with the 90 remaining projects is given in Appendix B.

6.1.4.2 Purging and cleaning data
Tables in Appendix A and Appendix B are color-coded to show what parameters are either
quantitative or qualitative. Green cells denote qualitative parameters and white cells denote
quantitative parameters. Other re-interpretations were made from the information gathered from
the database to fulfill the numerical-only requirements for the statistical analysis.

<table>
<thead>
<tr>
<th>ID</th>
<th>Bridge Length (ft)</th>
<th>Bridge Width (ft)</th>
<th>Max Span (ft)</th>
<th>Winning Bid</th>
<th>Cost per Sq Ft</th>
<th>Construction Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>253.1</td>
<td>37.4</td>
<td>NA</td>
<td>1080000</td>
<td>57</td>
<td>Not Reported</td>
</tr>
<tr>
<td>59</td>
<td>86.8+60(2)</td>
<td>35+41.1(2)</td>
<td>88.8</td>
<td>3500000</td>
<td>370</td>
<td></td>
</tr>
<tr>
<td>91</td>
<td>297(2)</td>
<td>54.33</td>
<td>66</td>
<td>67970000(11)</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

Table 1. Table with data gathered from the database.

<table>
<thead>
<tr>
<th>ID</th>
<th>Bridge Length (ft)</th>
<th>Bridge Wide (ft)</th>
<th>Max Span (ft)</th>
<th>Winning Bid</th>
<th>Cost per Sq Ft</th>
<th>Construction Time (days)</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>253.1</td>
<td>74.8</td>
<td></td>
<td>1080000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>59</td>
<td>206.8</td>
<td>117.2</td>
<td>86.8</td>
<td>3500000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>91</td>
<td>414</td>
<td>108.66</td>
<td>66</td>
<td>6179990.91</td>
<td>40</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Table with re-interpretation of some variables from the gathered information from the database.

In Table 1 and Table 2, some parameters that had miscellaneous values were reformatted to have
numerical-only values. For example, the total bridge width in the project with ID 23, shows two
spans with 37.4 feet wide each. However, this was re-interpreted as the sum of the two spans as the width for the project in the second table.

Another example is the construction time for the same project with ID 23 with a “Not reported” value; this was re-interpreted as no value in the modified table.

The final example is the Winning Bid for the project with ID 91. In the first table, the cost corresponds to the winning bid for 11 projects. However, the information in the database corresponds only for 1 of those projects. In the second table, the same value is represented as the winning bid divided by 11, as an estimated value for the isolated bridge.

6.1.4.3 Cost Analysis

Cost parameters like winning bid and cost per square foot, are given for the cost at the moment of project construction. This means that for a project built in 1995, the cost corresponds to the cost at that time. A cost analysis based on the Net Present Value of the projects was done to compare the values of projects at the present time.


6.1.4.4 Binary conversion of qualitative data

A reinterpretation of the qualitative parameters was needed to comply with the numerical restrictions of the statistical analysis. To describe the possible variables in qualitative parameters, a binary conversion was considered the most appropriate data conversion for the qualitative data.

The binary conversion converts the qualitative data into a binary assessment that denotes the absence or existence of a variable for a parameter for a project. For example, for a deck retrofitting project, the deck retrofitting variable will be denoted as a 1, which denotes the existence of that variable for this case, while the other possible options for that parameter will remain non-existent, having a 0 value as can be observed in Table 3.

<table>
<thead>
<tr>
<th>Type of Project</th>
<th>Deck Retrofitting</th>
<th>New Bridge</th>
<th>Replacement Bridge</th>
<th>Span Replacement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Retrofitting</td>
<td>1</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>New Bridge</td>
<td>0</td>
<td>1</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Replacement Bridge</td>
<td>0</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Span Replacement</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

According to Henry et al., the performance of clustering analysis using binary data for qualitative data is satisfactory. In particular, the performance of hierarchy clustering was remarkable, even with small samples with N ≤ 20 (Henry et al. 2015).
6.1.4.5 Normalizing numerical data

The ranges of values for the qualitative values vary widely depending on the parameters. For example, project width ranges in the tens to hundreds of feet; in contrast, the winning bid for the projects varies from hundreds of thousands to hundreds of millions.

Because of this, a normalization was needed for all the numerical data. A simple normalization was performed to have all the parameters ranging between 0 to 1, which also correlates with the binary conversion from the qualitative parameters.

The quantitative parameters in Appendix B are shown with the normalized data.

6.1.5 Developing Statistical Analysis

6.1.5.1 Data Input

After performed the data preparation procedures explained in section 6.1.4, the data input for the software, XLSTAT, is the digital excel sheet shown in Appendix B. XLSTAT uses dialog boxes in order to request the statistical parameter’s conditions to perform. Then, XLSTAT creates a results sheet with the information explained in sections 6.1.5.2, 6.1.5.3, 6.1.5.4 and 0 for each of the number of clusters defined.

6.1.5.2 Dendrogram

The first result from the analysis of the Agglomerate Hierarchical Clustering (AHC) is the dendrogram. The dendrogram is the graphical representation of the data input in an organizational structure defined by the differences among clusters and similarities among elements inside the same clusters. The resulted dendrogram for the analysis in this study for the completed ABC projects is shown below in Figure 8.

Conjectures can be made by observing this graphic which can help us visualize how the data grouped into clusters behave. For example, two main major groups can be identified. However, further analysis is needed to establish more informed conclusions. Appendix D shows all the dendrograms from the analysis from 1 to 10 cluster analyses.

6.1.5.3 Defining clusters by cutting the dendrogram.

The following step in the development of the statistical analysis is to define the optimal number of clusters. The software does this by testing ranges of numbers of clusters where the dendrogram is cut and then finding the within-class variances for each of the tested numbers of clusters. In other words, the software will perform a multiple AHC statistical analysis for each number of clusters specified, and then the performance of the relevancy of each statistical testing will be evaluated. As mentioned in section 5.2.2.2, the number of cluster analysis to test in this study will be performed from 1 to 10 clusters.
Figure 8. Resulting Dendrogram from Statistical Analysis

Figure 9. Dendrogram for 5-clusters analysis
Figure 9 shows the dendrogram cut for 3-cluster analysis and how this cut line divides the projects into the five clusters shown in different color. This means that each cluster contrasts enough to be considered different to projects in other clusters, and the projects within the same cluster are considered sufficiently similar to be grouped together.

6.1.5.4 Establishing the adequate number of Clusters

After performing the analysis of the clustering analysis range, the software develops a validation procedure by visualizing the within-class variance for the 1 to 10 cluster analyses performed in this study. This is shown in Figure 10 and helped determine the optimal number of clusters taking into consideration the biggest drop in the within-class variance.

![Figure 10. Validation for optimal number of clusters for AHC analysis. From 1 to 10 clusters.](image)

According to the “elbow finding” technique, the optimal number of clusters is defined when the most significant drop in the steepness of the line of the drop in within-class variance occurs. In other words, we can see in Graphic 8, that before the 5-cluster data point, the graph has a stronger steep compared to the change in within-class variance after this point, where the curve has a tendency to be flat from this point forward. This graph is usually referred to as the elbow diagram because of the occurrence of that notorious change in the graph tendency observed. Therefore, from this point forward we will establish the 5-cluster analysis as the number of clusters for our analysis.

In addition, another observation is that the change in within-class variance between the 1-cluster and the 2-clusters analysis is the steepest. Therefore, we will also take in consideration this finding to define the structure of the intended categorization in this study.
6.1.6 Establishing a structure for categorization
The AHC analysis provides insight into the data grouping by considering the dendrograms and the within-class variance diagram. In Figure 11, the 5-cluster dendrogram was used to define a leveled distribution to help us visualize a structure for our categorization.

6.1.6.1 First Structure Proposal
Now we can make some inferences, so we can propose a structure for a categorization. We propose two levels of categorization defined as follows:

1. First Level Categories. Defined by the larger clusters that will group together smaller clusters. This categorization will be defined by the 2-clusters analysis and will group together the smaller groups in the 5-clusters analysis.
2. Second Level Sub-categories. Defined by the clusters in the 5-cluster analysis.

The proposed categorization structure is shown in Figure 12.

![Dendrogram Image]

*Figure 11. Interpretation dendrogram for 2 and 5 clusters to show projects distribution for first structure proposal.*
From this point forward, the clusters will be considered and denoted as categories and sub-categories.

6.1.7 Optimal clusters defined from the Statistical Analysis
After the analysis of the optimal number of clusters and the establishment of the number of clusters for the statistical analysis, the statistical analysis provides the distribution of the projects according to the categories and sub-categories. Table 4 shows the results of the distribution for the 5-cluster analysis that was selected as the appropriate number of clusters for this analysis.
6.1.8 Visualizing analysis results
The differences and similarities among the parameters will be visualized to describe the features of each category and sub-category. The visualization methods are explained in the following sections and depending on the data, different methods were used.

6.1.8.1 Visualizing Qualitative Parameters
For qualitative data, bar graphs showing the frequency of the parameters variables will help observe the single predominant parameter or the multiple predominant parameters.

Figure 13 shows the bar graphs for the crossing condition parameter for the Sub-category 2 in the second level of the categorization as an example of a bar graph. All the bar graphs and the data tables can be reviewed in Appendix E.
6.1.8.2 Visualizing Quantitative parameters

For quantitative data, two types of graphics will be used for visualization.

Parallel Coordinate Plots

The Parallel coordinate plot shows, on a normalized scale, the mean values for all the quantitative parameters for multiple comparisons among the categories and sub-categories. This graph helps to observe in a global perspective all the quantitative parameters, so the similarities and differences among clusters can be observed. The y-axis has a normalized scale for all the parameters that are listed in the x-axis in different color lines that correspond to each sub-category.

Figure 14 show the parallel coordinates for the sub-categories for the categorization in this study.
Figure 14. Parallel coordinate plot of quantitative parameter for sub-categories

Whisker and Box Diagrams
The second graph type will be the Box and Whisker diagrams for each quantitative parameter. This graph will not be scaled and compares the same parameters across all the sub-categories, so a graphical representation of the data can be seen. This diagram is based on the median and quartiles data, so ranges of data can be represented. In addition, this graph type considers outliers, which are extreme data points that cannot be considered within the significance of the data values. These outliers are represented by data points outside the box and whisker for the parameters in that sub-category. For example, in Figure 15, outliers can be observed in sub-categories 1, 2 and 3.

XLSTAT differentiates between two types of outlier according to the following formulas (Addinsoft 2015):

- Outliers noted with an “x” symbol are extreme values defined by the following formula:
  \[ |Q_1 - 3 \times (Q_3 - Q_1); Q_3 + 3 \times (Q_3 - Q_1) | \]

- Whereas outliers denoted with an “o” symbol are extreme values defined by the following formula:
  \[ [Q_1 - 3 \times (Q_3 - Q_1); Q_1 - 1.5 \times (Q_3 - Q_1)] or [Q_3 + 1.5 \times (Q_3 - Q_1); Q_3 + 3 \times (Q_3 - Q_1)] \]

Figure 15 shows the box and whisker diagram for the Project Width Parameter for all the Sub-categories, as an example of this type of graph. The y-axis shows a real scale according to the data parameters shown for the sub-categories represented in the x-axis.
It can be observed in the whisker of the sub-category 1, that it limits the sample data by leaving out the extreme value shown outside the maximum data point. In this case, we can observe both types of outliers.

Box and whisker diagrams will be created for each of the quantitative parameters and for each of the categories and sub-categories. See Appendix to review all the Box and Whisker Diagrams.

**Figure 15. Example Box and Whisker diagram for the 7 subcategories**

6.1.9 Validating Structure

After reviewing all the graphical information for the data, it was deemed that sub-category 3 has enough merits to be considered into an independent category to highlight the differences of the characteristics of these projects. The graphical information considered, included frequency bars
from qualitative parameters, box and whisker diagrams for quantitative analysis, parallel coordinate plots, and dendrograms.

6.1.9.1 Second Structure Proposal
The projects distribution for the second proposal is shown in the Figure 16. The proposed categorization structure is shown in Figure 17 and will be the definitive structure for our categorization.

![Dendrogram](image)

Figure 16. Interpretation dendrogram for 3 and 5 clusters to show projects distribution for second structure proposal for the 90-clusters analysis.

6.2 Results of categorization
The results for the categorization are the following:

- The final categorization of ABC Projects
- The table of the distribution of projects into categories
- The description of features of categories and sub-categories
- The summary table of parameters’ ranges and probabilities

6.2.1 Second categorization proposal of ABC Projects
Figure 17 shows the second categorization proposal hierarchy for the ABC projects. The names of the categories and sub-categories were developed taken in consideration the characteristics of the ranges and variables of the projects observed in the visualization of statistical analysis.
Figure 17. Second categorization proposal of ABC Projects
6.2.2 Distribution of completed ABC projects by sub-categories

Table 5 shows the distribution of the projects according to the sub-categories defined. This table is considered a result of this study, as it defines what projects are into each category and sub-category. In addition, it is intended that this table will help a person looking for more information about the ABC by narrowing down to specific projects that relate to the project this person is developing.

<table>
<thead>
<tr>
<th>Cluster</th>
<th>Category 1</th>
<th>Sub-category 1</th>
<th>Sub-category 2</th>
<th>Sub-category 3</th>
<th>Category 2</th>
<th>Sub-category 3</th>
<th>Sub-category 4</th>
<th>Sub-category 5</th>
<th>Category 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nbr. Of Objects</td>
<td>16 14 5 19 17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td>10</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

6.2.3 Definition of numerical characteristics for sub-categories of the categorization

Table 6 presents a summary table for the parameters data that defines each parameters’ subcategory and will serve for comparison purposes to define the match of a project according to the characteristics of the project. This table is color-coded to denote differences and similarities among variables and parameters in the context of comparison. For the development of this table, some considerations were taken as follows:
• The qualitative parameters in the table were obtained from the analysis of the probability of occurrence of each of the variables for each sub-category. Appendix F shows the probabilistic analysis of the qualitative parameters. These probabilities were then used to complete the data in Table 6.

• The quantitative parameters are in terms of a range which is defined as the values between the inferior and superior limit defined by the whiskers in the whisker and box diagrams to avoid the inclusion of outliers.

• The color-coded diagram serves the purpose to show what variables differ from the norm among the same compared to other categories or sub-categories for the quantitative parameters. Green cells mean a value similar to other categories or sub-categories. Yellow cells denote a value that differs from the norm compared to the similarities of other parameters. Red cells mean extreme values, or in other words values that are very different from other values from another parameter in the accepted range of values. For qualitative parameters, the white cells were used to denote the probabilities of qualitative parameters.
<table>
<thead>
<tr>
<th>Type of Project - Estimated probability of occurrence</th>
<th>Category 1</th>
<th>Category 2</th>
<th>Category 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Retrofitting</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>New Bridge</td>
<td>0.00</td>
<td>0.18</td>
<td>0.18</td>
</tr>
<tr>
<td>Replacement Bridge</td>
<td>0.54</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td>Span Replacement</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project Delivery Methodology - Estimated probability of occurrence</th>
<th>Category 1</th>
<th>Category 2</th>
<th>Category 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMGC</td>
<td>0.00</td>
<td>0.33</td>
<td>0.00</td>
</tr>
<tr>
<td>Design-Bid-Build</td>
<td>0.50</td>
<td>0.15</td>
<td>0.04</td>
</tr>
<tr>
<td>Design-Build</td>
<td>0.00</td>
<td>0.00</td>
<td>0.15</td>
</tr>
<tr>
<td>Other</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location setting - Estimated probability of occurrence</th>
<th>Category 1</th>
<th>Category 2</th>
<th>Category 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>0.58</td>
<td>0.20</td>
<td>0.04</td>
</tr>
<tr>
<td>Urban</td>
<td>0.22</td>
<td>0.11</td>
<td>0.07</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crossing Conditions - Estimated probability of occurrence</th>
<th>Category 1</th>
<th>Category 2</th>
<th>Category 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canyon</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Crossing Road</td>
<td>0.00</td>
<td>0.04</td>
<td>0.00</td>
</tr>
<tr>
<td>Other</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Railroad</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Water flow</td>
<td>0.65</td>
<td>0.11</td>
<td>0.09</td>
</tr>
<tr>
<td>Category</td>
<td>Sub-category 1</td>
<td>Sub-category 2</td>
<td>Sub-category 3</td>
</tr>
<tr>
<td>----------</td>
<td>---------------</td>
<td>---------------</td>
<td>---------------</td>
</tr>
<tr>
<td>ADT along structure - Range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>0</td>
<td>0</td>
<td>14000</td>
</tr>
<tr>
<td>Max.</td>
<td>14200</td>
<td>25000</td>
<td>70000</td>
</tr>
<tr>
<td>ADT Crossing Structure - Range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Max.</td>
<td>0</td>
<td>0</td>
<td>155000</td>
</tr>
<tr>
<td>Project length [ft] - Range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>40</td>
<td>21</td>
<td>2152</td>
</tr>
<tr>
<td>Max.</td>
<td>140</td>
<td>1274</td>
<td>14784</td>
</tr>
<tr>
<td>Project width [ft] - Range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>19</td>
<td>33</td>
<td>50</td>
</tr>
<tr>
<td>Max.</td>
<td>66</td>
<td>74</td>
<td>197</td>
</tr>
<tr>
<td>Project Max Span [ft] - Range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>29</td>
<td>21</td>
<td>121</td>
</tr>
<tr>
<td>Max.</td>
<td>150</td>
<td>375</td>
<td>2389</td>
</tr>
<tr>
<td>Winning Bid ($) - Range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>$189,034</td>
<td>$213,366</td>
<td>$123,652,639</td>
</tr>
<tr>
<td>Max.</td>
<td>$9,130,678</td>
<td>$23,357,120</td>
<td>$687,958,322</td>
</tr>
<tr>
<td>Cost per Sq. Ft - Range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>$30</td>
<td>$78</td>
<td>$118</td>
</tr>
<tr>
<td>Max.</td>
<td>$747</td>
<td>$439</td>
<td>$1,467</td>
</tr>
<tr>
<td>Construction Time - Range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>19</td>
<td>21</td>
<td>974</td>
</tr>
<tr>
<td>Max.</td>
<td>270</td>
<td>136</td>
<td>1340</td>
</tr>
<tr>
<td>Time Reduction on Traffic Impact - Range</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Max.</td>
<td>6</td>
<td>6</td>
<td>6</td>
</tr>
</tbody>
</table>
6.3 Validation of categorization

To validate the methodological procedures performed for the categorization and the results obtained, a process for validation was developed. The validation process for the previous analysis was developed in two phases. See Figure 18.

![Figure 18. Validation process for categorization.](image)

In addition to validate the matching category, the correspondence with the name of the categories and sub-categories was verified.

6.3.1 Phase one: project matching assessment for 10 testing projects

The objective of the matching as a validation tool is to assess the qualitative and quantitative parameters according to the features of each test project to find a belonging sub-category that matches the best for this project. The assessment of the parameters for each project is tested based on the table that was developed in the results in section 6.2.3 where the parameters relevance into sub-categories is evaluated based on probabilities for qualitative parameters and ranges for quantitative parameters. Table 7 shows the table developed as a validation tool for the test project 22.

In phase one, a project matching assessment for projects was developed to find a fitting category for a project according to the parameters established in the statistical analysis. Table 7 presents the test project 22 as example for validation. The matching process is explained as follows:

- The first section is the development of project information profile. Table 7 shows the information from the project 22 as the profile data example.
- The second section is the matching assessment. This section applies only to the quantitative parameters due to the need to establish the matching of the project parameters values to each of the sub-categories ranges from the Table 6. The matching is given on comply or not comply format which is denoted with the symbols. After the matching for all the qualitative parameters is completed, a sum is made for the positive matchings to find the total number of outcomes for the parameters in that case.
  For example, the Winning Bid parameter value for the project example matches only the ranges from sub-categories 2, 4, and 5 in the Table 6; therefore, the total frequency of sub-categories matching is 3.
- The third section is the probability assessment. In this section, the probabilities of occurrence are given to each of the parameters evaluated. For the qualitative parameters, the probability of occurrence is already developed in Table 6; therefore, the probabilities
are transferred from this table to the validation tool depending on the qualitative variable. For the quantitative parameters, the probabilities are distributed according to the results of the matching with the sub-categories that had a positive match in section 2. The formula used is:

$$\text{Prob}_{XI} = \frac{X_{I_{\text{match}}}}{\Sigma(X_I + X_{I+1} + X_{I+2} + \cdots X_n)}$$

For example, the probability values for the Crossing Conditions (qualitative parameter) in the example are the same values shown in the Crossing Road parameter row in Table 6. For the Winning Bid (quantitative parameter), the probability of the value in this project to match sub-category 4 is the division between the probability of this value match sub-category 4 and the number of all the sub-category ranges this value matched.

$$\text{Prob}_{\text{Winning bid value match sub-category 4}} = \frac{1}{3} = 0.33$$

- After computing the probabilities for all the parameters, a sum is made for each column corresponding to the sub-categories.
- Finally, the matching sub-category for the project is the category and sub-category with the higher sum which is highlighted in green.

The higher probability value for the project 22 is 4.06. Category 3 and sub-category 4 are the results of the matching assessment for the project example.

Table 7. Example of validation table for testing projects. Test project 22 shown.
6.3.1.1 Results from project matching assessment

**Project 4**

<table>
<thead>
<tr>
<th>Project ID</th>
<th>Sub-category matching</th>
<th>Total Frequency for quantitative matching</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>A</td>
<td>C1</td>
</tr>
<tr>
<td>Project Name</td>
<td>Pelican Creek</td>
<td>Replacement Bridge</td>
</tr>
<tr>
<td>Qualitative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Delivery Methodology</td>
<td>Design-Bid-Build</td>
<td></td>
</tr>
<tr>
<td>Location Setting</td>
<td>Rural</td>
<td></td>
</tr>
<tr>
<td>Crossing Conditions</td>
<td>Water Flow</td>
<td></td>
</tr>
<tr>
<td>ADT along structure</td>
<td>250.00</td>
<td>✓</td>
</tr>
<tr>
<td>ADT Crossing Structure</td>
<td>0.00</td>
<td>✓</td>
</tr>
<tr>
<td>Project Length (ft)</td>
<td>178.00</td>
<td>✗</td>
</tr>
<tr>
<td>Project Width (ft)</td>
<td>19.00</td>
<td>✓</td>
</tr>
<tr>
<td>Project Max Span (ft)</td>
<td>59.00</td>
<td>✓</td>
</tr>
<tr>
<td>Winning Bid ($)</td>
<td>5137,195,55</td>
<td>✓</td>
</tr>
<tr>
<td>Cost per Sq. Ft</td>
<td>512.00</td>
<td>✓</td>
</tr>
<tr>
<td>Construction Time</td>
<td>25.00</td>
<td>✓</td>
</tr>
<tr>
<td>Traffic Impact</td>
<td>Tier 5</td>
<td>✓</td>
</tr>
</tbody>
</table>

**Assessment** | 4.89 | 2.95 | 0.67 | 1.59 | 2.89 |

The result for the project matching tool shows that the sub-category 1 is the most appropriate for this project, this matches with the sub-category found in the 100-project analysis.

Information in this project matches with the name of the category and sub-category.

**Project 22**

<table>
<thead>
<tr>
<th>Project ID</th>
<th>Sub-category matching</th>
<th>Total Frequency for quantitative matching</th>
</tr>
</thead>
<tbody>
<tr>
<td>22</td>
<td></td>
<td>C1</td>
</tr>
<tr>
<td>Project Name</td>
<td>Black Cat Road</td>
<td>Replacement Bridge</td>
</tr>
<tr>
<td>Qualitative</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Delivery Methodology</td>
<td>Design-Bid-Build</td>
<td></td>
</tr>
<tr>
<td>Location Setting</td>
<td>Urban</td>
<td></td>
</tr>
<tr>
<td>Crossing Conditions</td>
<td>Crossing Road</td>
<td></td>
</tr>
<tr>
<td>ADT along structure</td>
<td>3900.00</td>
<td>✓</td>
</tr>
<tr>
<td>ADT Crossing Structure</td>
<td>7400.00</td>
<td>✗</td>
</tr>
<tr>
<td>Project Length (ft)</td>
<td>196.00</td>
<td>✓</td>
</tr>
<tr>
<td>Project Width (ft)</td>
<td>53.67</td>
<td>✓</td>
</tr>
<tr>
<td>Project Max Span (ft)</td>
<td>97.00</td>
<td>✓</td>
</tr>
<tr>
<td>Winning Bid ($)</td>
<td>5137,713,74</td>
<td>✗</td>
</tr>
<tr>
<td>Cost per Sq. Ft</td>
<td>5297.06</td>
<td>✓</td>
</tr>
<tr>
<td>Construction Time</td>
<td>120.00</td>
<td>✓</td>
</tr>
<tr>
<td>Traffic Impact</td>
<td>Tier 6</td>
<td>✓</td>
</tr>
</tbody>
</table>

**Assessment** | 2.24 | 2.34 | 0.67 | 4.06 | 2.69 |

The result for the project matching tool shows that the sub-category 4 is the most appropriate for this project, this matches with the sub-category found in the 100-project analysis.

Information in this project matches with the name of the category and sub-category.
### Project 26

<table>
<thead>
<tr>
<th>Project ID</th>
<th>26</th>
<th>Sub-category matching</th>
<th>Total Frequency for quantitative matching</th>
<th>Sub-category probability assessment</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Name</td>
<td>U.S. 6 over Hig Creek</td>
<td>SC1</td>
<td>SC2</td>
<td>SC3</td>
<td>SC4</td>
<td>SC5</td>
<td>SC1</td>
<td>SC2</td>
<td>SC3</td>
</tr>
<tr>
<td>Type of Project</td>
<td>Replacement Bridge</td>
<td>0.54</td>
<td>0.04</td>
<td>0.04</td>
<td>0.27</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Delivery Methodology</td>
<td>Design-Bid-Build</td>
<td>0.50</td>
<td>0.15</td>
<td>0.04</td>
<td>0.22</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location Setting</td>
<td>Rural</td>
<td>0.58</td>
<td>0.20</td>
<td>0.04</td>
<td>0.07</td>
<td>0.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossing Conditions</td>
<td>Water flow</td>
<td>0.65</td>
<td>0.11</td>
<td>0.09</td>
<td>0.00</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADT along structure</td>
<td>3800.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.00</td>
<td>0.33</td>
<td>0.33</td>
</tr>
<tr>
<td>ADT Crossing Structure</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Project Length (ft)</td>
<td>204.50</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.00</td>
<td>0.00</td>
<td>0.33</td>
</tr>
<tr>
<td>Project Width (ft)</td>
<td>47.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Project Max Span (ft)</td>
<td>70.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Winning Bid ($)</td>
<td>$2,898,648.97</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Cost per Sq. Ft</td>
<td>$351.72</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td>5.00</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Construction Time</td>
<td>120.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Traffic Impact</td>
<td>Tier 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
<td>0.25</td>
<td>0.25</td>
</tr>
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<td></td>
<td></td>
<td>4.30</td>
<td>2.89</td>
<td>0.67</td>
</tr>
</tbody>
</table>

The result for the project matching tool shows that the sub-category 1 is the most appropriate for this project, this matches with the sub-category found in the 100-project analysis.

Information in this project matches with the name of the category and sub-category.

### Project 37

<table>
<thead>
<tr>
<th>Project ID</th>
<th>37</th>
<th>Sub-category matching</th>
<th>Total Frequency for quantitative matching</th>
<th>Sub-category probability assessment</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Name</td>
<td>Boothbay</td>
<td>SC1</td>
<td>SC2</td>
<td>SC3</td>
<td>SC4</td>
<td>SC5</td>
<td>SC1</td>
<td>SC2</td>
<td>SC3</td>
</tr>
<tr>
<td>Type of Project</td>
<td>Replacement Bridge</td>
<td>0.54</td>
<td>0.04</td>
<td>0.04</td>
<td>0.27</td>
<td>0.10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Delivery Methodology</td>
<td>Design-Bid-Build</td>
<td>0.50</td>
<td>0.15</td>
<td>0.04</td>
<td>0.22</td>
<td>0.08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Location Setting</td>
<td>Rural</td>
<td>0.58</td>
<td>0.20</td>
<td>0.04</td>
<td>0.07</td>
<td>0.11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Crossing Conditions</td>
<td>Water flow</td>
<td>0.65</td>
<td>0.11</td>
<td>0.09</td>
<td>0.00</td>
<td>0.15</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ADT along structure</td>
<td>1550.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3.00</td>
<td>0.33</td>
<td>0.33</td>
</tr>
<tr>
<td>ADT Crossing Structure</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Project Length (ft)</td>
<td>540.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.00</td>
<td>0.00</td>
<td>0.50</td>
</tr>
<tr>
<td>Project Width (ft)</td>
<td>32.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
<td>0.33</td>
<td>0.00</td>
</tr>
<tr>
<td>Project Max Span (ft)</td>
<td>70.00</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.00</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>Winning Bid ($)</td>
<td>$6,066,727.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Cost per Sq. Ft</td>
<td>$270.25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.00</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Construction Time</td>
<td>510.00</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td>2.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Traffic Impact</td>
<td>Tier 6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5.00</td>
<td>0.20</td>
<td>0.20</td>
</tr>
<tr>
<td>Assessment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>4.01</td>
<td>2.92</td>
<td>0.87</td>
</tr>
</tbody>
</table>

The result for the project matching tool shows that the sub-category 1 is the most appropriate for this project, this matches with the sub-category found in the 100-project analysis.

Information in this project matches with the name of the category and sub-category.
Project 42

<table>
<thead>
<tr>
<th>Project ID</th>
<th>42</th>
<th>Sub-category matching</th>
<th>Sub-category probability assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Name</td>
<td>Usbridge-River Road</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Type of Project</td>
<td>Replacement Bridge</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Project Delivery Methodology</td>
<td>Design-Bid-Build</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Location Setting</td>
<td>Urban</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Crossing Conditions</td>
<td>Water flow</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>ADT along structure</td>
<td>8300.00</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>ADT Crossing Structure</td>
<td>0.00</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Project Length (ft)</td>
<td>47.00</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Project Width (ft)</td>
<td>35.25</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Project Max Span (ft)</td>
<td>47.00</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Winning Bid ($M)</td>
<td>$3,808,351.31</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cost per Sq. Ft</td>
<td>53.118.05</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Construction Time</td>
<td>100.00</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Traffic Impact</td>
<td>Tier 3</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Assessment</td>
<td>4.28</td>
<td>2.43</td>
<td>1.69</td>
</tr>
</tbody>
</table>

The result for the project matching tool shows that the sub-category 1 is the most appropriate for this project, this matches with the sub-category found in the 100-project analysis.

Information in this project matches with the name of the category and sub-category.

Project 49

<table>
<thead>
<tr>
<th>Project ID</th>
<th>49</th>
<th>Sub-category matching</th>
<th>Sub-category probability assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Name</td>
<td>TH 65 over Gilbert Creek</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Type of Project</td>
<td>Replacement Bridge</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Project Delivery Methodology</td>
<td>Design-Bid-Build</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Location Setting</td>
<td>Rural</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Crossing Conditions</td>
<td>Water flow</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>ADT along structure</td>
<td>8900.00</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>ADT Crossing Structure</td>
<td>0.00</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Project Length (ft)</td>
<td>114.00</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Project Width (ft)</td>
<td>36.33</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Project Max Span (ft)</td>
<td>41.00</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Winning Bid ($M)</td>
<td>$3,863,417.19</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Cost per Sq. Ft</td>
<td>53.118.05</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Construction Time</td>
<td>100.00</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Traffic Impact</td>
<td>Tier 3</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Assessment</td>
<td>4.10</td>
<td>2.34</td>
<td>0.47</td>
</tr>
</tbody>
</table>

The result for the project matching tool shows that the sub-category 1 is the most appropriate for this project, this matches with the sub-category found in the 100-project analysis.

The ADT along structure for this project is higher than the values in the naming of the category 1. Rest of the information matches the description for the sub-category.
The result for the project matching tool shows that the sub-category 1 is the most appropriate for this project. In this case, the sub-category found in the project matching, does not match with the sub-category found in the 100-project analysis.

Information in this project matches with the name of the category and sub-category.

The result for the project matching tool shows that the sub-category 5 is the most appropriate for this project, this matches with the sub-category found in the 100-project analysis.

Information in this project matches with the name of the category and sub-category.
### Project 87

<table>
<thead>
<tr>
<th>Project ID</th>
<th>87</th>
<th>Sub-category matching</th>
<th>Sub-category probability assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Name</td>
<td>180 over 2300 East</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Type of Project</td>
<td>Replacement Bridge</td>
<td>0.54</td>
<td>0.04</td>
</tr>
<tr>
<td>Project Delivery Methodology</td>
<td>Design-Bid-Build</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Location Setting</td>
<td>Urban</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Crossing Conditions</td>
<td>Crossing Road</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>ADT along structure</td>
<td>26630.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>ADT Crossing Structure</td>
<td>9400.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Project Length (ft)</td>
<td>160.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Project Width (ft)</td>
<td>125.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Project Max Span (ft)</td>
<td>80.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Winning Bid ($)</td>
<td>5732,787.49</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Cost per Sq. ft</td>
<td>135.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Construction Time</td>
<td>4.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Traffic Impact</td>
<td>Tier 2</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Assessment</td>
<td>3.76</td>
<td>1.52</td>
<td>0.00</td>
</tr>
</tbody>
</table>

The result for the project matching tool shows that the sub-category 5 is the most appropriate for this project, this matches with the sub-category found in the 100-project analysis.

Information in this project matches with the name of the category and sub-category.

### Project 95

<table>
<thead>
<tr>
<th>Project ID</th>
<th>95</th>
<th>Sub-category matching</th>
<th>Sub-category probability assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Name</td>
<td>Hood Canal East Approach</td>
<td>C1</td>
<td>C2</td>
</tr>
<tr>
<td>Type of Project</td>
<td>Replacement Bridge</td>
<td>0.54</td>
<td>0.04</td>
</tr>
<tr>
<td>Project Delivery Methodology</td>
<td>Design-Bid-Build</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Location Setting</td>
<td>Rural</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Crossing Conditions</td>
<td>Water flow</td>
<td>0.65</td>
<td>0.11</td>
</tr>
<tr>
<td>ADT along structure</td>
<td>14000.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>ADT Crossing Structure</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Project Length (ft)</td>
<td>605.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Project Width (ft)</td>
<td>40.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Project Max Span (ft)</td>
<td>125.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Winning Bid ($)</td>
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<tr>
<td>Cost per Sq. ft</td>
<td>515.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Construction Time</td>
<td>3.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Traffic Impact</td>
<td>Tier 2</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Assessment</td>
<td>3.42</td>
<td>2.16</td>
<td>1.87</td>
</tr>
</tbody>
</table>

The result for the project matching tool shows that the sub-category 1 is the most appropriate for this project, this matches with the sub-category found in the 100-project analysis.

The ADT along structure for this project is higher than the values in the naming of the category 1. Rest of the information matches the description for the sub-category.
6.3.2 Phase two: Agglomerate Clustering Analysis (100 projects) and comparison with 10 testing projects

Phase two consisted on the development of a completely new AHC statistical analysis for the 100 projects in the database. Then, for the 10 projects tested in phase one, the resulted category and sub-category according to the 100-projects clustering analysis (Phase 2) was then compared to the resulted category and sub-category matched in the project matching assessment (Phase 1).

After performing the statistical analysis for the 100 projects in the same way as before for the 90 projects, the graphical information was created to be able to compare with the information for the 90-project statistical analysis.

Figure 19 shows the within-class variance graphic for validation for the optimal number of clusters for the 100 projects. The 5-clusters analysis was again considered the most optimal for the 5 sub-categories in our categorization which confirms our findings.

![Within-class variance graphic for validation for optimal number of clusters for 100 projects. From 1 to 10 clusters.](image)

The dendrogram shown in Figure 20 is the dendrogram for the 5-clusters analysis for the 100 projects. This diagram shows how the added 10 testing projects affected the clusters developed in the 90 projects analysis. This dendrogram shows how the clusters for the sub-categories were redistributed in accordance with the added influence of the 10 new projects. In this new dendrogram, the numbering of the clusters was remade according to the numbering from the 90-project dendrogram to visualize how the cluster was redistributed. It can also be observed how some sub-categories slightly changed to accommodate the new projects. For example, it is perceived that the
sub-category 1 is the one that changed the most because most of the added projects were included in this cluster. The categories analysis was not considered for the validation.

![Dendrogram](image)

Figure 20. Dendrogram for 5-cluster analysis for the 100 projects.

6.3.3 Analysis of the results from validation

Table 8 was the result of the statistical analysis for the 100 projects. The color-coded cells highlight the added 10 projects that were used for the validation process. Green cells denote projects that matched the validation and the categorization from the section 6.3. Red cells denote projects that did not matched the validation in this section. Therefore, a conclusion can be made that this categorization has a 90% success rate to match the projects into the categorization developed.
<table>
<thead>
<tr>
<th>Class</th>
<th>Category 1</th>
<th>Category 2</th>
<th>Category 3</th>
<th>Category 4</th>
<th>Category 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nbr. Of Objects</td>
<td>1</td>
<td>3</td>
<td>4</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>1</td>
<td>45</td>
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<td>14</td>
<td>15</td>
<td>16</td>
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<tr>
<td>2</td>
<td>42</td>
<td>15</td>
<td>13</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>3</td>
<td>22</td>
<td>60</td>
<td>13</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
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</tr>
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<td>7</td>
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<td>43</td>
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<td>28</td>
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<td>49</td>
<td>94</td>
<td>94</td>
<td>98</td>
<td>98</td>
<td>98</td>
</tr>
</tbody>
</table>

6.3.4 Summary of validation
Table 9 shows a summary of the results of the validation process for the 10 testing projects compared. The result of matching the testing projects with a category and sub-category was then compared to the category and sub-category found in the 100-projects statistical analysis. In addition, the information of the project was compared to the naming of the category and sub-category found in the project matching.
### Table 9. Summary table of validation of 10 testing projects.

<table>
<thead>
<tr>
<th>Project ID</th>
<th>Matching category and Sub-category with 100-project analysis</th>
<th>Matching Category and Sub-category description</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td>22</td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td>26</td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td>37</td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td>42</td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td>49</td>
<td>Both</td>
<td>Sub-category only</td>
</tr>
<tr>
<td>72</td>
<td>None</td>
<td>Both</td>
</tr>
<tr>
<td>78</td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td>87</td>
<td>Both</td>
<td>Both</td>
</tr>
<tr>
<td>95</td>
<td>Both</td>
<td>Sub-category only</td>
</tr>
</tbody>
</table>

#### 6.4 Recommended practices

While reviewing the completed ABC project database and during the categorization process, recommendations were found from the information of the individual projects to improve the project outcomes of ABC projects and to improve the collection of lessons learned. These recommendations are summarized as follows:

1. Include qualifications and additional procurement times from specialty contractors, like pre-casters and special equipment, into the bid documentation to achieve on-time schedule and desired quality for the project.
2. Design contracts to include prospective scenarios of problems or alternatives, to establish strategies for mitigation and improvement.
3. Pre-assemble the structure under controlled environments, preferably in the pre-cast plant, to anticipate issues in the field.
4. Mandatory pre-bid meetings to promptly explain to bidders the expectations for the project.
5. Provide access to the public through the live construction cameras to help coordinate traffic.
6. Have a person in charge of measuring the impact and tolerance of the project to the public during the construction. This role may be called the Public Relationship Officer.
7. Include the Public Relationship Officer into the contract requirements for the bidders. This person is paid by the contractor.
8. Find strategies to mitigate stress and fatigue in projects where contractor works 24/7, for periods of time longer than 3 days. For example, this practice refers to projects built in time lapses of 30 days working 24/7, but not the case of a weekend replacement bridge where the concentrated effort is less than 3 days and personnel can de-stress after that.
9. Early advertising of the project to give additional time to contractors to prepare their bids and develop feedback for the project.
11. Promote concurrent or late-phase recording of project information for lessons learned to share.
12. Follow an established lesson learned framework to record project.
7 Results

This section compiles the results of this study. Some of the results are directly taken from the results given in the Categorization developed; however, some results were updated to take in consideration the validation process performed after the proposition of results in the categorization.

Five main results are given in this section as follows:

1. The final categorization
2. The description of the features of categories and sub-categories
3. The project Distribution by categories and sub-categories
4. The table of probabilities and ranges of parameters
5. The project matching tool

7.1 Final Categorization

The final categorization is the one developed in the section 6.2.1 after being confirmed in the validation process in section 6.3. See Figure 21.

![Categorization of ABC Projects](image)

Figure 21. Final categorization of ABC Projects

7.2 Description of the features of Categories and Sub-Categories

After having reviewed the graphical information developed, a description of the features for the projects for individual categories and sub-categories is explained as follows. Please review Appendix E for all the data and graphics that were taken into consideration for the description of
sub-categories and categories. The descriptions were developed taken into consideration the statistics of the 90-projects statistical analysis. The description of the features for the categories was developed, taking into consideration the features and characteristics of the sub-categories inside, making a generalization of them.

<table>
<thead>
<tr>
<th>Name of Category:</th>
<th>Category 1: Low ADT projects with no traffic crossing.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-categories included in category:</td>
<td>Sub-Catgory 1: Replacement bridges over water bodies.</td>
</tr>
<tr>
<td></td>
<td>Sub-Catgory 2: Deck retrofitting and replacement bridges with no traffic crossing.</td>
</tr>
<tr>
<td>Number of projects in category:</td>
<td>60</td>
</tr>
<tr>
<td>Description:</td>
<td>Category 1 projects are mostly replacement bridges, including some deck retrofitting and new bridges. Design-bid-build is the predominant project delivery methodology. Location is mostly rural and crossing condition is almost exclusively water flow. These projects are the less transited and do not have any traffic crossing. These projects have short lengths, and are the narrowest of all the projects, and have short spans. The winning bid for these projects are low, as well as its cost per square foot. These projects need short periods of time to finish, however, their reduction in traffic impact is high which means that the disturbance to the traffic was lowly reduced.</td>
</tr>
<tr>
<td>The projects in this category differentiate from the projects in other categories by:</td>
<td>Deck retrofitting projects can only be observed in this category.</td>
</tr>
<tr>
<td></td>
<td>These projects have the lowest ADT among all the projects.</td>
</tr>
<tr>
<td></td>
<td>Projects in this category do not have traffic crossing.</td>
</tr>
<tr>
<td></td>
<td>These projects are the narrowest of all the projects.</td>
</tr>
<tr>
<td></td>
<td>Construction time for these projects is the shortest.</td>
</tr>
</tbody>
</table>

Project examples
<table>
<thead>
<tr>
<th>Name of Category</th>
<th>Category 2: Megaprojects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-categories included in category</td>
<td>Sub-Category 3: Megaprojects</td>
</tr>
<tr>
<td>Number of projects in category</td>
<td>5</td>
</tr>
</tbody>
</table>

**Description:** Category 2 projects are replacement bridges and new bridges. Design-Bid-Build and design-build are the project delivery methodology for these projects. Location for the projects can be either urban or rural. Water flow is the only crossing condition for these projects. Traffic in these projects is the highest but no traffic is crossing. Length and max span of the projects is the longest, however not the widest. The winning bid and cost per square foot is the most expensive for all the projects. Construction time for these projects is the longest for all the projects and all the projects in this category have a tier of 6, which means that these projects meekly reduce their construction time.

The projects in this category differentiate from the projects in other categories by:

- The projects in this category are unique, having some of the largest quantitative parameters among all the projects.
- Crossing condition for these projects is only water flow.
- Length, max span, winning bid and construction time are parameters where these projects have extremely higher values to projects in other categories.
- The tier value for the time reduction on traffic impact is only 6.

**Project examples**
<table>
<thead>
<tr>
<th>Name of Category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category 3: High ADT projects with traffic crossing.</td>
<td>Category 3 projects (n=35) are mostly replacement bridges but some new bridges and span replacement projects can be included. Design-bid-build is the predominant project delivery methodology but some cases of design-build and CMGC can occur. The predominant location is urban, but some rural projects can occur. Crossing road is the predominant crossing condition with the possibility of few projects with water flow crossing conditions. ADT along structure is higher than category 1 but lower than category 3. These projects are the only ones that have traffic crossing. Project length and max span are low and similar to category 1. Width for these projects can be the widest of all the projects, however, the range is varied. Winning bid and cost per square foot is low and similar to category 1. Construction time is lower than category 2 projects but can be higher than category 1. Time reduction on traffic impact is very varied but it concentrates on tier 2 and 5.</td>
</tr>
<tr>
<td>Sub-Categories included in category</td>
<td></td>
</tr>
<tr>
<td>Sub-Category 4: Replacement bridges with high/medium ADT crossing.</td>
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</tr>
<tr>
<td>Number of projects in category:</td>
<td>35</td>
</tr>
</tbody>
</table>

The projects in this category differentiate from the projects in other categories by:

- Only in this category, the span replacement projects occur.
- The projects in this category are the only ones that have a traffic crossing.

Project examples
<table>
<thead>
<tr>
<th>Name of Category</th>
<th>Sub-Category 1: Replacement bridges over water bodies.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of projects in category:</td>
<td>• 46</td>
</tr>
<tr>
<td>Description:</td>
<td>• Sub-category 1 projects are only replacement bridges with design-bid-build as project delivery methodology. Location for these projects is mostly rural but urban projects can occur. Crossing conditions are only water flow. Traffic on these projects is the lowest of all and no traffic is crossing because of the crossing condition. Project length, width and max span are among the lowest of all the projects. Winning bid and cost per square foot is low but that is typical for all the sub-categories except sub-category 3. Construction time is low. Reduction time on traffic impact is varied and having predominance in the highest tier values.</td>
</tr>
<tr>
<td>The projects in this category differentiate from the projects in other categories by:</td>
<td>• Projects have three defining characteristics as being replacement projects with design-bid-build on water flow crossing in 100% of the projects in this sub-category.</td>
</tr>
<tr>
<td>Project examples</td>
<td><img src="image1.png" alt="Project example 1" />, <img src="image2.png" alt="Project example 2" /></td>
</tr>
<tr>
<td>Name of Category:</td>
<td>• Sub-Category 2: Deck retrofitting and replacement bridges with no-traffic crossing.</td>
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</tr>
<tr>
<td>Number of projects in category:</td>
<td>• 14</td>
</tr>
<tr>
<td>Description:</td>
<td>• Sub-category 2 projects are mostly deck retrofitting projects, however, new bridges and replacement bridges projects can occur. Project delivery methodology is mostly Design-bid-build. Location for these projects can be rural or urban. Water flow is the predominant crossing condition, but all the other crossing conditions can occur. Traffic is low and no traffic crossing for these projects. Traffic in these projects is lower than Sub-category 1, also lower is the traffic crossing. Length is lower than sub-category 1; however, width top range is slightly higher than sub-category 1. Max project span is almost the same as sub-category 1. Projects in this sub-category cost less compared to the projects in sub-category 1, however, the cost per square foot for these projects is higher than sub-category 1. Construction time is lower than sub-category 1, but the reduction in traffic impact has a higher top limit. Length, width and max span for these projects are low. Construction time and cost per square foot are low. Construction time is the shortest having a varied reduction time on traffic impact.</td>
</tr>
</tbody>
</table>
| The projects in this category differentiate from the projects in other categories by: | • Deck retrofitting projects only occur in this sub-category.  
• Canyon, railroad and other are the only types of crossing conditions that can occur in this sub-category. |
<p>| Project examples          | <img src="image1.png" alt="Project example 1" /> <img src="image2.png" alt="Project example 2" /> |</p>
<table>
<thead>
<tr>
<th>Name of Category</th>
<th>Sub-Category 3: Megaprojects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of projects in category</td>
<td>5</td>
</tr>
<tr>
<td>Description</td>
<td>Sub-category 3 projects are replacement bridges and new bridges. Project delivery methodology is design-bid-build and design-build. Location can be either urban or rural. The crossing condition is water flow only. Traffic for these projects is the highest among all the projects and no traffic is crossing. Length and max span for these projects is the longest by a big margin compared to the projects in other sub-categories. These projects are wider than projects in category 1 but narrower than projects in category 3. These projects are also a lot more expensive than projects in other sub-categories. Cost per square foot is also the highest among all the sub-categories. These projects also take the longest to build among the projects in all the other sub-categories. Reduction in traffic Impact time is low for these projects, having a high tier for traffic impact.</td>
</tr>
<tr>
<td>The projects in this category differentiate from the projects in other categories by</td>
<td>Projects in this sub-category report extreme high values for length, max span, winning bid, and construction time compared to the projects in other sub-categories. Reduction time on traffic impact is exclusively a tier 6. This is coherent with the construction time parameter highlighting that these projects take years to build.</td>
</tr>
<tr>
<td>Project examples</td>
<td><img src="image1.jpg" alt="Project example 1" /> <img src="image2.jpg" alt="Project example 2" /></td>
</tr>
<tr>
<td>Name of Category:</td>
<td>Sub-Category 4: Replacement bridges with high/medium ADT crossing.</td>
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<tr>
<td>Number of projects in category:</td>
<td>19</td>
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<tr>
<td>Description:</td>
<td>Sub-category 4 projects are only replacement bridge. Project delivery methodology is mostly design-bid-build. Location for these projects is mostly urban, however, few rural projects can occur. Crossing conditions for these projects is only crossing road. Traffic on these projects is higher than most other sub-categories except sub-category 3. These projects have the most traffic crossing among all the projects. These projects have short length and max span, however, these projects are the widest among all the projects. The winning bid and cost per square foot is low for these projects which are typical to projects in categories 1 and 3. Construction time is higher than projects in category 1 but lower than category 2. Reduction in traffic impact is varied, ranging from 1 to 6.</td>
</tr>
<tr>
<td>The projects in this category differentiate from the projects in other categories by:</td>
<td>All the projects in this sub-category are replacement bridges. The only crossing condition that occurs for this sub-category is crossing road. These projects have the highest traffic crossing among all the projects. These projects are the widest among all the projects.</td>
</tr>
<tr>
<td>Project examples</td>
<td>![Project example images]</td>
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<tr>
<td>Name of Category</td>
<td>Description</td>
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</table>

- Sub-category 5 projects can be new bridges or replacements bridges, including few span replacements. The predominant project delivery methodology is design-build; however, design-bid-build can occur in few cases. Location for these projects can be urban or rural. Crossing road and water flow are the probable crossing conditions for these projects. Traffic on these projects is higher than projects in category 1 but lower than projects in sub-categories 3 and 4. Traffic crossing is lower than traffic in projects in sub-category 4. Project length and max span is low, which is similar to the projects in categories 1 and 3. Project width is similar to projects in categories 1 and 3. The winning bid and cost per square foot is low compared to category 2, but typical to projects in categories 1 and 3. Construction time is low but slightly higher than projects in sub-categories 1, 2 and 4. Reduction time on traffic impact is medium to low, having the highest number of cases between the tiers 2 and 4.

- Span replacements projects occur only in this sub-category.

| Project examples |
### 7.3 The project distribution by categories and sub-categories

Table 10. Final project distribution by sub-categories for the 100 completed ABC projects.

<table>
<thead>
<tr>
<th>Class</th>
<th>Sub-category 1</th>
<th>Sub-category 2</th>
<th>Sub-category 3</th>
<th>Sub-category 4</th>
<th>Sub-category 5</th>
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</thead>
<tbody>
<tr>
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<td>100</td>
<td>7</td>
<td></td>
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</tr>
</tbody>
</table>
### 7.4 The table of probabilities and ranges of parameters

Taken from Table 6, this table was not modified.

<table>
<thead>
<tr>
<th>Category 1</th>
<th>Category 2</th>
<th>Category 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sub-category 1</td>
<td>Sub-category 2</td>
<td>Sub-category 3</td>
</tr>
</tbody>
</table>

#### QUALITATIVE PARAMETERS

<table>
<thead>
<tr>
<th>Type of Project - Estimated probability of occurrence</th>
<th>Sub-category 1</th>
<th>Sub-category 2</th>
<th>Sub-category 3</th>
<th>Sub-category 4</th>
<th>Sub-category 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deck Retrofitting</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>New Bridge</td>
<td>0.00</td>
<td>0.18</td>
<td>0.18</td>
<td>0.00</td>
<td>0.64</td>
</tr>
<tr>
<td>Replacement Bridge</td>
<td>0.54</td>
<td>0.04</td>
<td>0.04</td>
<td>0.27</td>
<td>0.10</td>
</tr>
<tr>
<td>Span Replacement</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>1.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project Delivery Methodology - Estimated probability of occurrence</th>
<th>Sub-category 1</th>
<th>Sub-category 2</th>
<th>Sub-category 3</th>
<th>Sub-category 4</th>
<th>Sub-category 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMGC</td>
<td>0.00</td>
<td>0.33</td>
<td>0.00</td>
<td>0.67</td>
<td>0.00</td>
</tr>
<tr>
<td>Design-Bid-Build</td>
<td>0.50</td>
<td>0.15</td>
<td>0.04</td>
<td>0.22</td>
<td>0.98</td>
</tr>
<tr>
<td>Design-Build</td>
<td>0.00</td>
<td>0.00</td>
<td>0.15</td>
<td>0.00</td>
<td>0.85</td>
</tr>
<tr>
<td>Other</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Location setting - Estimated probability of occurrence</th>
<th>Sub-category 1</th>
<th>Sub-category 2</th>
<th>Sub-category 3</th>
<th>Sub-category 4</th>
<th>Sub-category 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural</td>
<td>0.58</td>
<td>0.20</td>
<td>0.94</td>
<td>0.07</td>
<td>0.11</td>
</tr>
<tr>
<td>Urban</td>
<td>0.22</td>
<td>0.11</td>
<td>0.07</td>
<td>0.23</td>
<td>0.27</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crossing Conditions - Estimated probability of occurrence</th>
<th>Sub-category 1</th>
<th>Sub-category 2</th>
<th>Sub-category 3</th>
<th>Sub-category 4</th>
<th>Sub-category 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canyon</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Crossing Road</td>
<td>0.00</td>
<td>0.04</td>
<td>0.00</td>
<td>0.64</td>
<td>0.32</td>
</tr>
<tr>
<td>Other</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Railroad</td>
<td>0.00</td>
<td>1.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Water flow</td>
<td>0.65</td>
<td>0.11</td>
<td>0.09</td>
<td>0.00</td>
<td>0.15</td>
</tr>
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</table>
### Table 11 (Continued). Table of Probabilities and ranges of parameters

<table>
<thead>
<tr>
<th></th>
<th>Category 1</th>
<th>Category 2</th>
<th>Category 3</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sub-category 1</td>
<td>Sub-category 2</td>
<td>Sub-category 3</td>
</tr>
<tr>
<td><strong>QUANTITATIVE PARAMETERS</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ADT along structure - Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>0</td>
<td>0</td>
<td>14000</td>
</tr>
<tr>
<td>Max.</td>
<td>14200</td>
<td>25000</td>
<td>70000</td>
</tr>
<tr>
<td><strong>ADT Crossing Structure - Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Max.</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Project length (ft) - Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>40</td>
<td>21</td>
<td>2152</td>
</tr>
<tr>
<td>Max.</td>
<td>140</td>
<td>1274</td>
<td>14784</td>
</tr>
<tr>
<td><strong>Project width (ft) - Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>18</td>
<td>33</td>
<td>56</td>
</tr>
<tr>
<td>Max.</td>
<td>66</td>
<td>74</td>
<td>77</td>
</tr>
<tr>
<td><strong>Project Max Span (ft) - Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>29</td>
<td>21</td>
<td>121</td>
</tr>
<tr>
<td>Max.</td>
<td>150</td>
<td>375</td>
<td>1389</td>
</tr>
<tr>
<td><strong>Winning Bid ($) - Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>$195,034</td>
<td>$213,186</td>
<td>$123,857,539</td>
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<tr>
<td>Max.</td>
<td>$9,130,678</td>
<td>$23,357,120</td>
<td>$687,958,322</td>
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<tr>
<td><strong>Cost per Sq. Ft - Range</strong></td>
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<td></td>
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</tr>
<tr>
<td>Min.</td>
<td>$30</td>
<td>$78</td>
<td>$118</td>
</tr>
<tr>
<td>Max.</td>
<td>$747</td>
<td>$439</td>
<td>$1,467</td>
</tr>
<tr>
<td><strong>Construction Time - Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>19</td>
<td>21</td>
<td>974</td>
</tr>
<tr>
<td>Max.</td>
<td>270</td>
<td>136</td>
<td>1340</td>
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<tr>
<td><strong>Time Reduction on Traffic Impact - Range</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Min.</td>
<td>1</td>
<td>1</td>
<td>6</td>
</tr>
<tr>
<td>Max.</td>
<td>6</td>
<td>6</td>
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</tbody>
</table>
7.5 The project matching tool
A how-to guide that shows instruction for using the project matching tool is included as the Appendix G of this document.

<table>
<thead>
<tr>
<th>Project ID</th>
<th>Sub-category matching</th>
<th>Total Frequency for quantitative matching</th>
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<tbody>
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</tr>
<tr>
<td></td>
<td>C1 SC1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C2 SC2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C3 SC3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C4 SC4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>C5 SC5</td>
<td></td>
</tr>
<tr>
<td>Project Name</td>
<td>1-80 over 2300 East</td>
<td></td>
</tr>
<tr>
<td>Type of Project</td>
<td>Replacement Bridge</td>
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</tr>
<tr>
<td>Project Delivery Methodology</td>
<td>Design-Build</td>
<td></td>
</tr>
<tr>
<td>Location Setting</td>
<td>Urban</td>
<td></td>
</tr>
<tr>
<td>Crossing Conditions</td>
<td>Crossing Road</td>
<td></td>
</tr>
<tr>
<td>ADT along structure</td>
<td>26630.00</td>
<td>X X ✔ ✔ ✔ ✔ 3.00 0.00 0.00 0.33 0.33 0.33</td>
</tr>
<tr>
<td>ADT Crossing Structure</td>
<td>9402.00</td>
<td>X X X ✔ ✔ ✔ 2.00 0.00 0.00 0.00 0.50 0.50</td>
</tr>
<tr>
<td>Project Length (ft)</td>
<td>160.00</td>
<td>✔ ✔ ✔ ✔ ✔ ✔ 3.00 0.00 0.33 0.33 0.33 0.33</td>
</tr>
<tr>
<td>Project Width (ft)</td>
<td>125.66</td>
<td>X X X ✔ ✔ ✔ 2.00 0.00 0.00 0.00 0.50 0.50</td>
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<tr>
<td>Project Max Span (ft)</td>
<td>90.00</td>
<td>✔ ✔ ✔ ✔ ✔ ✔ 4.00 0.25 0.25 0.25 0.25 0.25</td>
</tr>
<tr>
<td>Winning Bid ($)</td>
<td>557,122,767.49</td>
<td>✔ ✔ ✔ ✔ ✔ ✔ 4.00 0.25 0.25 0.25 0.25 0.25</td>
</tr>
<tr>
<td>Cost per Sq. Ft</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction Time</td>
<td>135.00</td>
<td>✔ ✔ ✔ ✔ ✔ ✔ 4.00 0.25 0.25 0.25 0.25 0.25</td>
</tr>
<tr>
<td>Traffic Impact</td>
<td>Tier 2</td>
<td>✔ ✔ ✔ ✔ ✔ ✔ 4.00 0.25 0.25 0.25 0.25 0.25</td>
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</table>

<table>
<thead>
<tr>
<th>Qualitative Assessment</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>C5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Qualitative</td>
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<td></td>
<td></td>
</tr>
</tbody>
</table>

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8 Limitations of Research

This study is limited to the databases established in the completed ABC projects database from the FHWA. This database, at the time of this study has 100 projects. However, more ABC projects have been developed in the United States, although these projects had not been included in the completed ABC database from the FHWA because of various reasons. The reasons that these projects are not included are because of:

- The inclusion of a project in the database includes a vetting and validation process that takes time to complete.
- The lack of interest or knowledge from project developers and authorities to include their projects into the completed ABC projects database.
- The insufficient resources from the completed ABC projects database developers to cope with the demand for inclusion of projects into the database.

A limitation exists on the parameters according to the information available. As mentioned, our sole data source was the completed ABC projects database. The parameters were defined from the information already established in the database, also more information was gathered from the individual webpages of the projects. Other information that may be relevant to his study but does not have a base parameter from the completed ABC projects database will not be considered. For example, information about the experience of the contractor companies may be relevant to define a readiness from stakeholders for projects of this kind.

According to the FHWA functional classification for roads (FHWA 2013), roads in United States are classified in four main categories: principal arterial, minor arterial, collector and local. This classification was not taken in consideration into the analysis in this study because there is no mention of this classification in the FHWA database of ABC Projects. It was a limitation of this study that this classification was not considered because the inclusion of it will imply a deeper analysis of each of the 100 projects to establish the appropriate functional road category. However, information from other parameters like the Conditions Parameters can be considered to establish the type of functional road classification of a specific project.

The Agglomerate Hierarchy Clustering (AHC) statistical analysis, as an exploratory methodology, has some limitations on the distribution of projects into sub-categories. The main limitation is that each iteration of the statistical analysis will bring differing results according to the data input. In this study, two AHC analysis were performed for the 90-projects and 100-projects statistical analyses. We observed that the additional data from the added 10 projects changed the distribution of the dendrogram and some projects. In this case, the changes were slightly differing and still relevant for comparison purposes. However, the current status of the categorization in this study may drastically change in the future when a radical number of projects are considered. For example, if a 500-projects analysis is performed in the future, there is uncertainty if the 3 categories and 5 sub-categories found in this study will remain, so more or less categories and sub-categories may be found by a 500-projects statistical analysis. However, this leaves space for further research when information from more projects can be obtained.

A limitation of this study is that we are limited to the data input available at this moment, and the results are defined as the current status of ABC projects development.


9 Discussion

This study effectively presents a categorization that considers an integral approach to the
evaluation of ABC projects. By considering basic information of size and conditions, this study
also evaluates these factors as a cause for the selection of ABC as methodology over traditional
construction. The selection of ABC also influences the outcomes of the projects that are considered
in this study, such as construction and cost information. Therefore, the categorization presented in
this study connects these relationships and presents them in a graphical and easy to understand
style by means of the categorization structure, the table for project distribution according to sub-
categories, and the project matching tool.

9.1 Findings about variables and values of parameters

The variables and ranges found for the 5 sub-categories are a product of the characteristics of the
projects in the database. Because of this, the ranges for quantitative parameters among sub-
categories have gaps and overlaps between data parameters information among different categories
and sub-categories.

Variables of qualitative parameters depend on the values already defined from the completed ABC
project database. For example, the project delivery methodology parameter includes only CMGC,
design-bid-build, design-build and other as parameter’s variables. However, it is well known that
other project delivery methodologies do exist, like Public Partner Partnerships (PPP). In addition,
there are record of ABC projects that have used PPP as project delivery methodology has been
developed. However, because this study is limited to the projects in the FHWA completed ABC
project database, we are not considered those projects, and because none of the projects in the
database make use of this methodology, PPP does not appear as a variable for that parameter.

9.2 Decision-making parameters and consequential parameters

The parameters selected for the development of the categorization in this study were selected
because reasonably describe characteristics that project developers may consider justifying the use
of ABC as project development methodology in early decision-making stages of project
development. However, the completed ABC project database collected more parameters that were
consider a consequence of using ABC as methodology and therefore, not highly relevant for
decision-making, we consider these parameters consequential. Structural systems and geotechnical
solutions parameters are these consequential parameters. These consequential parameters also
support the definition of the means and methods for project development of ABC projects used in
past projects. Although these parameters were not included in the categorization development, it
is expected that stakeholders consider them when reviewing the narrowing projects for the
categories in this study to find lessons learns and predict means and methods for their projects.

9.3 About the data analysis

This study used an exploratory data analysis to infer its results. The robustness of the data analysis
is based on the number of projects. This was confirmed during the validation process when the
second statistical analysis was performed for the 100 projects and then compared to the statistical
analysis for the 90 projects. In this case, sub-categories changed, although slightly, to
accommodate the added information for the new 10 projects that can drastically affect a portion of

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the analysis. In our case, the sub-category 1 was the one that changed the most, because this sub-category received most of the added projects.

Figure 22 and Figure 23 are shown below to compare the 90-projects dendrogram and the 100-project dendrogram.

![Dendrogram](image)

*Figure 22. Interpretation dendrogram for 3 and 5 clusters to show projects distribution for second structure proposal for the 90-clusters analysis.*
9.4 About the project matching tool

The probabilistic approach used in the project matching tool sustain the occurrence of certain parameters’ values and values that have a high probability of occurrence under certain conditions or ranges. For example, Table 12 shows the matching for the project with ID 37 which have a matching sub-category 1 as a result of the matching tool operations. However, it can be observed that this project matches all the ranges for the sub-category 5 for quantitative parameters. In contrast, the matching for the sub-category 1, missed 2 parameters’ ranges. This can be interpreted that the weight of the parameters for the project matching tool is sustained in both, the probabilities of its parameter’s values in quantitative parameters, and variables for qualitative parameters.
9.5 Purpose as decision-making tool

This study may provide support at any stage in the project development of ABC projects in the following ways.

- This study may help to estimate parameters according to the evaluation of known information and suggest parameters ranges or parameters alternatives, depending on the qualitative or quantitative nature of the information during the planning and design phase of a project.

- This study may expand the lessons learned information available for a project, based on the finding of the matching category and sub-category for the project in development and review the projects for the matching parameters. By doing this, the stakeholders may have a more specific case study poll to evaluate, or alternatively, evaluate other categories or sub-categories of projects to accommodate the project needs and avoid conflicts that may help finish a project on-time by learning from the lessons learned for other projects from the past.

The categorization in this study may lead project developers to specific case studies defined by the categorization; however, the dependency of the completed ABC database by the ABC-UTC becomes obvious as this is the repository where a project developer would have to overview in order to get the grasp of all the information presented for specific project or projects.

For all the exposed, the relevance of this study lies in the interests that stakeholders may have to make a deeper exploration of case studies and their need to simplify the exploration to focus in more specific and relevant cases that best suits their needs.

9.6 Trends

This study also provides some trends that can be based on what type of projects are performed in ABC. For example, the projects with the characteristics in the sub-category 1 account for 40% of the total of projects for the 90 projects analysis and 46% of the total of projects for the 100 projects analysis. In contrast, the projects with the categories from the sub-category 3 only account for...
5.55% for the 90 projects analysis and after reviewing the 100 projects, this dropped to 5.00%. These statistics may help transportation authorities to focus their research efforts to improve their processes into a specific category or sub-category to maximize efforts, or in contrast, focus on a low-percentage category to increase the applicability of the projects with those characteristics.
10 Areas of Future Research

Future research can be done in the future to develop the same statistical analysis study with a database with more number of projects that will render the status at the time of this future study.

Future research can be done to include the functional road classification of the FHWA into a future categorization. A recommendation can be given to the developers of the FHWA completed ABC project database to include this functional classification as an additional parameter to consider into the completed ABC projects database.

A relational analysis can also be performed between the categorization in this study and the consequential parameters included in the completed ABC projects database. By furthering research in this area, it may be possible to find if certain geotechnical and structural solutions is a key factor in the performance in projects for certain category and sub-category.

Further analysis of the databases and results of this study may help to determine cause and effect of project distribution in the categorization developed in this study. For example, a factor analysis may help to find the effect of the parameters defined as input data for the statistical methodology and help develop a better understanding of the causes of the project distribution found in the categorization in this study.

The analysis of the trends performed in this study was basic. Further research can be made by developing a correlation analysis to define better trends from the past and from the future.

The best practices found in this study were not assessed to define its relevance. Further research can be done by vetting them by means of Delphi analysis and finding its relevance by using a statistical analysis such as Analytical Hierarchy Process and Pairwise Comparisons with relevant stakeholder.

This research contributes to the body of knowledge by proposing a base framework for future research that may need a typology of ABC projects. Future research could be the development of a Flash-track framework of best practices for each of the categories and sub-categories presented in this study to continue supporting states’ Department of Transportations’ (DOTs) efforts for the quick development of transportation projects. Recommended practices and improvements to advance the lessons learned databases of ABC projects can also considered for future research.
11 Bibliography


Table of relevant parameters obtained from the database.

This table was obtained after reviewed the information available from the completed ABC database taking in consideration the parameters needed for this study to complement the information presented in the original ABC database excel sheet. See sections 6.1.1, 6.1.2 and 6.1.3.

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<th>Crossing Condition</th>
<th>ADT Crossing Structure</th>
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<th>Project Width (ft)</th>
<th>Max Span (ft)</th>
<th>Weighting (bf)</th>
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### Appendix B

Final input table for statistical analysis.

This table shows the information from the Appendix A after the procedures of data preparation in order to have acceptable data inputs for the statistical analysis. See section 6.1.4.

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## Descriptive Parameters

| Project ID | Deck Type | Maintained Bridge | Replacement Bridge | Span Replacement | Bridge | CMSC Design- Built Bridge | Design- Built | Other | Rural | Urban | NORM ADT | Canyon | Crossing Road | Other conditions | Railroad | Water | ABAT | NORMM Project Length (mi) | NORMM Project Length (ft) | NORMM Project Cost ($) | NORMM Project Cost/SqFt | NORMM Project Mean Span (%) | NORMM Project Mean Span/SqFt | NORMM Contract Time (years) | NORMM Time Reduction on Traffic Impact |
|-----------|-----------|-------------------|--------------------|------------------|--------|--------------------------|--------------|-------|-------|-------|--------|---------|--------|----------------|---------------------|---------|-------|-------|------------------|----------------------|-----------------------------|------------------------|-------------------------------|--------------------------|-------------------------------|------------------------|
| 96        | 1         | 0                 | 0                  | 0                | 0      | 0                        | 0            | 0     | 0     | 0     | 0      | 0       | 0      | 0              | 1                   | 0       | 0     | 0     | 1.00             | 0.0252               | 0.1570                      | 0.0086                  | 0.0299                        | 0.0553                    | 0.067                      |
| 99        | 0         | 0                 | 1                  | 0                | 0      | 0                        | 0            | 0     | 0     | 0     | 0      | 0       | 0      | 0              | 0                   | 0       | 0     | 0     | 0.06             | 0.0180               | 0.1570                      | 0.0086                  | 0.0299                        | 0.0565                    | 0.167                      |
| 99        | 0         | 0                 | 1                  | 0                | 0      | 0                        | 0            | 0     | 0     | 0     | 0      | 0       | 0      | 0              | 1                   | 1       | 0     | 0     | 0.06             | 0.0180               | 0.1570                      | 0.0086                  | 0.0299                        | 0.0565                    | 0.167                      |
| 99        | 0         | 0                 | 1                  | 0                | 0      | 0                        | 0            | 0     | 0     | 0     | 0      | 0       | 0      | 0              | 1                   | 0       | 0     | 0     | 0.06             | 0.0180               | 0.1570                      | 0.0086                  | 0.0299                        | 0.0565                    | 0.167                      |
| 99        | 0         | 0                 | 1                  | 0                | 0      | 0                        | 0            | 0     | 0     | 0     | 0      | 0       | 0      | 0              | 1                   | 0       | 0     | 0     | 0.06             | 0.0180               | 0.1570                      | 0.0086                  | 0.0299                        | 0.0565                    | 0.167                      |
| 99        | 0         | 0                 | 1                  | 0                | 0      | 0                        | 0            | 0     | 0     | 0     | 0      | 0       | 0      | 0              | 1                   | 0       | 0     | 0     | 0.06             | 0.0180               | 0.1570                      | 0.0086                  | 0.0299                        | 0.0565                    | 0.167                      |
| 99        | 0         | 0                 | 1                  | 0                | 0      | 0                        | 0            | 0     | 0     | 0     | 0      | 0       | 0      | 0              | 1                   | 0       | 0     | 0     | 0.06             | 0.0180               | 0.1570                      | 0.0086                  | 0.0299                        | 0.0565                    | 0.167                      |
| 99        | 0         | 0                 | 1                  | 0                | 0      | 0                        | 0            | 0     | 0     | 0     | 0      | 0       | 0      | 0              | 1                   | 0       | 0     | 0     | 0.06             | 0.0180               | 0.1570                      | 0.0086                  | 0.0299                        | 0.0565                    | 0.167                      |
| 99        | 0         | 0                 | 1                  | 0                | 0      | 0                        | 0            | 0     | 0     | 0     | 0      | 0       | 0      | 0              | 1                   | 0       | 0     | 0     | 0.06             | 0.0180               | 0.1570                      | 0.0086                  | 0.0299                        | 0.0565                    | 0.167                      |
| 99        | 0         | 0                 | 1                  | 0                | 0      | 0                        | 0            | 0     | 0     | 0     | 0      | 0       | 0      | 0              | 1                   | 0       | 0     | 0     | 0.06             | 0.0180               | 0.1570                      | 0.0086                  | 0.0299                        | 0.0565                    | 0.167                      |
| 99        | 0         | 0                 | 1                  | 0                | 0      | 0                        | 0            | 0     | 0     | 0     | 0      | 0       | 0      | 0              | 1                   | 0       | 0     | 0     | 0.06             | 0.0180               | 0.1570                      | 0.0086                  | 0.0299                        | 0.0565                    | 0.167                      |
Appendix C

Table of Net Present Value for Projects.
The net present value analysis was made to compare project costs at the same point in time, in this case 2017, to add relevance to the comparative values of analysis. See section 6.1.4.3.

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Appendix D

Dendrograms
The following dendrogram diagrams are the product of the AHC analysis performed with the statistical analysis. The statistical analysis was performed for the 1-cluster to 10-clusters analyses in order to have comparative diagrams to analyze to define the optimal number of clusters and the categorization structure. See sections 6.1.5, 6.1.6 and 6.1.7.

As follows is shown the dendrograms for the cluster analysis from 1-cluster to 10-clusters.

1-Cluster Dendrogram
No dendrogram is generated for this case.

2-Cluster Dendrogram
3-Cluster Dendrogram

![Dendrogram Image]

4-Clusters Dendrogram

![Dendrogram Image]
5-Clusters Dendrogram

6-Clusters Dendrogram

7-Clusters Dendrogram
8-Clusters Dendrogram

9-Clusters Dendrogram
10-Clusters Dendrogram
Appendix E

Descriptive Statistics.
As follows, the information for the statistical information is presented. This statistical information was developed after the statistical analyses were performed and after defined the optimal number of clusters. The information in this Appendix, helped to evaluate the characteristics of the qualitative and quantitative parameters to compare the sub-categories defined. See section 6.1.8.

Qualitative Parameters

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Category 1
Bar Graphs

Type of Project

Frequency (Type of Project | Sub-category 1)

Frequency (Type of Project | Sub-category 2)
Project Delivery Methodology

Frequency (Project Delivery Methodology | Sub-category 1)

Frequency (Project Delivery Methodology | Sub-category 2)
Urban Setting

Frequency (Location setting | Sub-category 1)

Frequency (Location setting | Sub-category 2)
Crossing Condition

Frequency (Crossing Conditions | Sub-category 1)

Frequency (Crossing Conditions | Sub-category 2)
Category 2
Bar Graphs

Type of Project

Frequency (Type of Project | Sub-category 3)

Frequency (Type of Project | Sub-category 4)

Categories

Frequency

Categories

Frequency
Project Delivery Methodology

Frequency (Project Delivery Methodology | Sub-category 3)

Frequency (Project Delivery Methodology | Sub-category 4)
Urban Setting

Frequency (Location setting | Sub-category 3)

Frequency (Location setting | Sub-category 4)
Frequency (Location setting | Sub-category 5)

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Quantitative Parameters
ADT along structure – Table and Whiskers and Box Diagram – All Sub-categories

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Box plots

[Box plot image with labels for mean, outliers, and sub-categories]
ADT crossing Structure – Table and Whiskers and Box Diagram – All Sub-categories

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Box plots

+ Mean ○ Outliers(1) × Outliers(2)
### Project Length – Table and Whiskers and Box Diagram – All Sub-categories

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#### Box plots

![Box plots](image-url)

- **Mean**
- **Outliers (2)**
Project Width – Table and Whiskers and Box Diagram – All Sub-categories

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Box plots

![Box plots Image]
Project Max Span – Table and Whiskers and Box Diagram – All Sub-categories

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Box plots

Mean + Outliers(1) • Outliers(2)
### Winning Bid – Table and Whiskers and Box Diagram – All Sub-categories

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<th>Statistic</th>
<th>Sub-category 1</th>
<th>Sub-category 2</th>
<th>Sub-category 3</th>
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<td>$123,652,640</td>
<td>$1,037,730</td>
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<td>$42,496,348</td>
<td>$687,958,323</td>
<td>$34,248,924</td>
<td>$193,347,764</td>
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<td>$564,305,088</td>
<td>$33,111,194</td>
<td>$192,823,188</td>
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<td>$1,900,497</td>
<td>$225,349,550</td>
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<td>$263,504,000</td>
<td>$6,596,944</td>
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<td>$16,058,329</td>
<td>$287,274,937</td>
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| Variance (n)       | 3,631          | 3,775          | 3,800          | 2,388          | 5,460          |
| Standard deviation (n) | $19,770,457   | $13,015,368    | $193,366,692   | $9,713,159     | $51,667,305    |

**Box plots**

- **Mean**
- **Outliers (1)**
- **Outliers (2)**
### Cost per Square Foot – Table and Whiskers and Box Diagram – All Sub-categories

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<th>Sub-category 2</th>
<th>Sub-category 3</th>
<th>Sub-category 4</th>
<th>Sub-category 5</th>
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<td>$241.71</td>
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#### Box plots

- **Mean**: +
- **Outliers(1)**: ○
- **Outliers(2)**: ×
Construction Time – Table and Whiskers and Box Diagram – All Sub-categories

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<th>Sub-category 2</th>
<th>Sub-category 3</th>
<th>Sub-category 4</th>
<th>Sub-category 5</th>
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Box plots
### Time Reduction on Traffic Impact (Tiers) – Table and Whiskers and Box Diagram – All Sub-categories

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<th>Sub-category 3</th>
<th>Sub-category 4</th>
<th>Sub-category 5</th>
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</table>

**Box plots**

- **Mean**
- **Outliers (2)**
## Appendix F

Probabilistic analysis of qualitative parameters

This Appendix shows how the probabilities that a qualitative variable to happen according to the occurrence of cases for each sub-category. For example, for the Type of Project/Sub-category 1, Deck Retrofitting shows only 9 cases among all the 90 projects and in this sub-category shows that zero (0) cases can occur, therefore probabilities are 0. In contrast, Bridge Replacement shows a 0.54 probability because for all the 67 cases of replacement bridge in all the 90 projects, in this sub-category, 36 cases occurred. See section 6.3 for validation and Table 6 for sub-categories characteristics.

<table>
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<tr>
<th>Variable</th>
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<th>Total number of cases</th>
<th>Frequency per category</th>
<th>Probability</th>
</tr>
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Appendix G

Project Matching Instructions
To help stakeholders make more informed decisions about their projects by reviewing completed projects from the past, the project matching tool help narrow the number of projects to consider according to the related projects by considering the categorization in this study.

This Appendix was developed to explain the procedure to develop a project matching with an external project by following 4 main steps for the project matching process. These steps will be explained in this Appendix.

01 Collect
Collect all the information available about the project to develop a project profile.

02 Match
Match the project profile with the Project Matching Tool.

03 Review
Review information of matched category and sub-category.
Review information project cases for category and sub-category.

04 Learn or Predict
Learn about the specific project cases.
Predict missing parameters for matched project.

Step 1: Collect
The first step is to gather together all the information available about the project according to the parameters established in this study.

The table below shows an example for the Project with ID 95.
This example was selected because it shows how an incomplete project profile still renders a valid data input for the project matching tool.

Step 2: Match
The second step is to perform the project matching of the project with the project matching tool. The steps to do this assessment was explained in the section 6.3.1.
The steps to complete the Project matching is the following:

1. Section 1 is the Project Profile.
2. Section 2 is the quantitative assessment. In this section, all the quantitative parameters have to be check if the parameters’ values are within the ranges for each of the sub-categories. The ranges for the subcategories are given in the Table 11. A positive check mark is given when the value of the quantitative parameter is within the sub-categories range; on the contrary, a negative remark is given.
3. Section 3 is the probability assessment. For the qualitative parameters, the probabilities are given in the Table 11 for each of the possible variables for each parameter. Simply copy and paste the row for the probability of the variable for all the sub-categories into the corresponding row in the project matching tool. The quantitative parameters will be automatically filled with from the input in section 2.
4. After completing all the sections, the sum of the probabilities will be automatically added. The matched category will be the category and sub-category with the highest assessment value.

The assessment for this project example rendered a matching category 1 and sub-category 1.

**Step 3: Review**

Having the matched category and sub-category, a review of additional information about the category and sub-category can be done by checking the following sections of this document:

- A description of the categories and sub-categories features are included in the section 7.2. Stakeholders can review this information to know details about all the categories and sub-categories.
- Finally, to review the lists of the specific projects of each category and sub-category, stakeholders can refer to Table 10. After that, you can review the information about the projects in the completed ABC Project Database or the Appendix H.

In this example, the missing parameters can be predicted according to the information in the Table 10 according to the ranges. The ranges are the following:

- Cost per Sq. Ft = 30 to 747 $/ft.
- Construction Time = 19 to 270 days.

From the Table 10, we can find 46 projects for the sub-category 1 that matched the project example.

**Step 4: Learn or Predict**

The needs of the stakeholders dictate the final benefits of matching a project with this methodology.

- A stakeholder can narrow his scope for lessons learned finding by narrowing the scope of projects to review according to this categorization of the completed ABC projects database.
- Stakeholders can apply the project matching methodology in this study to an incomplete project profile to be able to predict missing parameters or ranges that can help in the decision-making process in project development.

More information can be find about the projects in sub-category 1 from the Appendix H.
## Appendix H

### Summary Table of Project Parameters for Project Matching

The table below is purposed to be used in the step 3 of the project matching described in Appendix G. This table includes all the parameters in this study plus additional complementary information about the projects like the state, owner, year built, funding and link to the individual website database. This table is sorted in ascending order according to the categorization column.

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<th>Project ID</th>
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<th>Type of Structural Bridge</th>
<th>Identification</th>
<th>Safety Features</th>
<th>Category</th>
<th>Sub-category</th>
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<th>Project Width (ft)</th>
<th>Project Area (sq ft)</th>
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<th>Cost par Membrane [ft³]</th>
<th>Construction Time</th>
<th>Time Induction on Traffic Impact</th>
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