

ENHANCED COST ESTIMATION FOR ABC BRIDGE PROJECT:
DATA COLLECTION, ANALYSIS, AND INTEGRATION

BY

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THESIS

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ABSTRACT

The use of Accelerated Bridge Construction (ABC) methods such as prefabricated elements and lateral slides has been increasingly utilized by state departments of transportation (DOT) to reduce bridge construction time, minimize related traffic disruption, enhance safety, improve quality, and decrease environmental impact. To realize these reported ABC methods benefits, DOT planners need to accurately estimate and compare the cost of alternative bridge construction methods to ensure the selection of the most cost effective method. This presents DOT planners with a major challenge due to the lack of detailed bridge design information that is needed to accurately estimate the construction cost during the early design phase. To support DOT planners in this challenging task, the research objectives of this study focus on (1) conducting a comprehensive literature review on ABC methods, (2) collecting and analyzing a dataset of recently completed ABC projects, and (3) providing insights into the factors affecting cost estimation for ABC bridge projects through statistical and correlation analysis of the collected data.

The main contributions of this research include the creation of an extensive dataset from 22 ABC bridge projects and identifying correlations between construction costs and various project variables. Statistical analysis revealed variability in project costs, while correlation analysis highlighted the impact of each factor. The findings of this study are expected to provide a better understanding of critical factors that affect bridge construction cost and enable the development of the predicted models that can be used to accurately estimate and compare the cost of alternative bridge construction methods during the early design phase.

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CHAPTER 1 - INTRODUCTION

1.1 Overview

Many bridges in the US and around the world are aging and in urgent need of repair and or replacement. For example, the American Road and Transportation Builders Association (ARTBA) 2023 Bridge Report reported that 36% of the 617,000 bridges in the US are in a state requiring repairs, and approximately 78,800 of these are estimated to be in urgent need of replacement. The ARTBA 2023 Bridge Report also reported that 7% of these bridges are rated as "poor" and classified as "structurally deficient", as shown in Figure 1.1 (ARTBA, 2023). These aging and structurally deficient bridges have significant negative impacts on the safety and reliability of the transportation networks in the US and therefore 35 percents are in urgent need of repair and/or replacement as shown in Figure 1.2 (ARTBA, 2023).

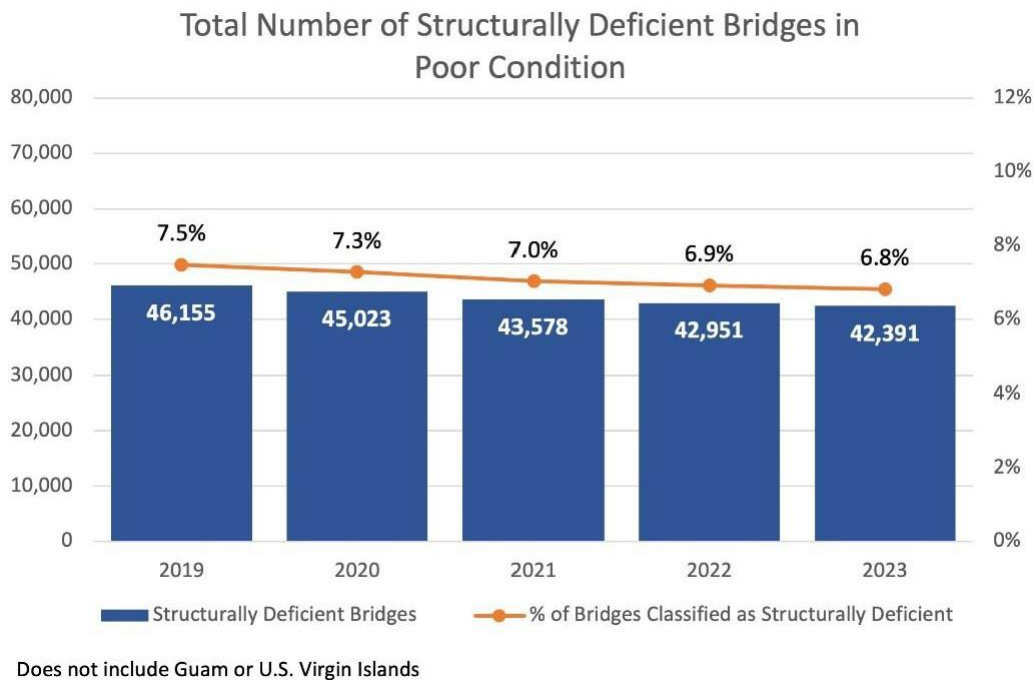


Figure 1.1: Total Number of Structurally Deficient Bridges in United States, ARTBA23

Number of Bridges Needing Work By Type of Repair

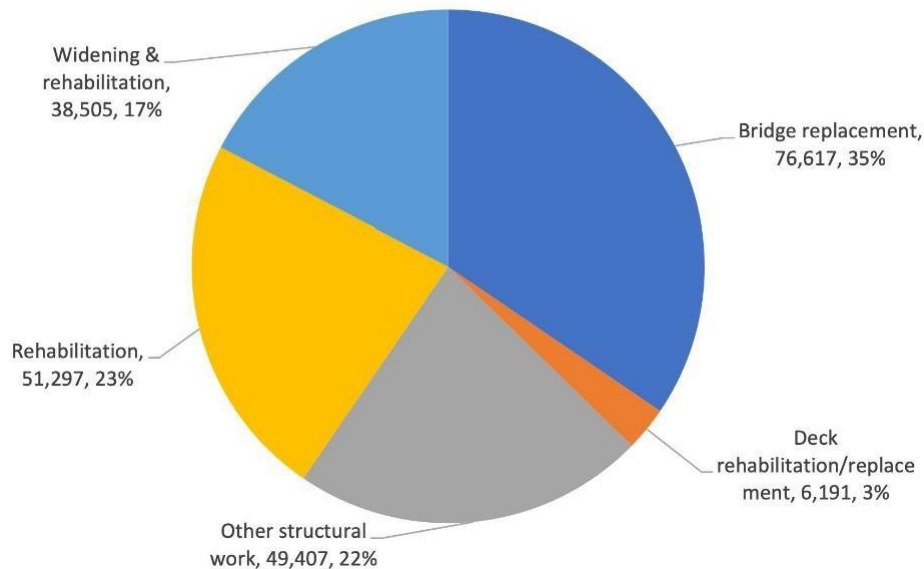


Figure 1.2: Number of Bridges Needing Work by type of Repair, ARTBA23

To address the pressing need for upgrading the aging bridges in US, according to the U.S. Department of Transportation (2022), the federal government ratified that the Federal Infrastructure Investment and Jobs Act (IIJA) in 2021 which provides additional resources for state-by-state infrastructure improvements, marking a response to the long-overdue need for infrastructure enhancements across the nation. Pursuant to this legislation, the Department of Transportation (DOT) has committed to invest more than \$27.5 billion for the restoration of bridges over the upcoming five years, under the auspices of the newly established IIJA Bridge Official Program. Additionally, an extra \$12.5 billion is allocated for projects slated for completion by 2026 through a separate IIJA Discretionary Bridge Program (US DOT,2022).

The committed infrastructure investment under the IIJA enables State DOTs to allocate funding for bridge improvements via federal highway funding programs, including the National Highway Performance Program and the Surface Transportation Block Grant Program (US DOT, 2022).

Furthermore, the fiscal allocation for all these state-focused formal programs is anticipated to increase from \$45 billion in fiscal year 2021 to \$59 billion in fiscal year 2022, underscoring the critical role of these investments in maintaining and enhancing the efficiency, reliability and safety of the transportation infrastructure. (US DOT 2022)

1.2 Problem Statement

The planned investment in bridge rehabilitation and replacements under the IIJA act will significantly increase the number of bridge construction projects in the next decade. These planned projects can be executed using conventional cast-in-place bridge construction methods or Accelerated Bridge Construction (ABC) techniques that have been increasingly utilized in recent years (US DOT 2022). Conventional bridge construction methods often require longer on-site construction time causing traffic congestion and delays (FHWA 2011). To overcome these challenges, several ABC methods such as Prefabrication, Lateral Slide, SPMT have been increasingly utilized to expedite on-site construction time and minimize its negative impacts on the traveling public (MengPoh Tang, 2014).

Despite the benefits of ABC methods, they require higher initial costs and more planning and design coordination as well as construction lead time. This often presents state DOTs with the challenge of balancing conflicting objectives such as minimizing the cost of bridge construction projects while reducing their associated traffic delays and “user delay” costs. To address this challenge, state DOTs need to carefully analyze the impact of conventional and accelerated bridge construction methods on project cost, traffic mobility and safety. To enable this analysis, state DOTs need reliable decision support tools (DST) to accurately estimate the cost of conventional and accelerated bridge construction alternatives during the early planning phase.

Several related cost estimating models have been developed, however their accuracy is limited and they are incapable of estimating the cost of several methods including Lateral slide and SPMT due to the limited dataset used in their development (El-Rayes, 2023). Accordingly, there is a pressing need to collect and analyze a larger dataset of recently constructed conventional and accelerated bridge construction projects to enable the development of reliable and accurate cost estimating DST. This reliable DST is expected to enable state DOTs accurately compare the cost of conventional and accelerated bridge construction alternatives during the early design phase to ensure the selection of the most cost effective construction method for each project based on its specific conditions and requirements (Hadi, 2018).

1.3 Research Objectives

The primary goal of this study is to collect a dataset of bridge construction projects to enable the development of reliable and accurate cost-estimating DST. To accomplish this goal, the main objectives of this study are:

- 1) Conduct a comprehensive literature review of the current practices and latest research conducted on ABC and its cost analysis methods.
- 2) Collect and analyze a dataset of recently completed accelerated bridge construction projects that can be used to expand existing datasets for developing bridge cost estimating DSTs.
- 3) Analyze the collected ABC bridge project datasets to examine the factors affecting bridge costs and their correlations.

1.4 Research Significance

This research is expected to enhance the accuracy and reliability of predicting the construction cost of Accelerated Bridge Construction (ABC) methods by creating and integrating additional bridge project data. This expanded dataset will enable decision-makers in construction management to develop more reliable bridge cost estimating models that can be used during the project early designing phase. This will enable bridge planners and designers to compare the construction cost of alternative construction methods and select the most cost effective construction method before developing a detailed design. Furthermore, this study enhances statistical models, helping decision-makers in various state Departments of Transportation make more informed choices.

1.5 Report Organization

The main findings of this study are organized in five chapters. Chapter 2 provides a literature review that covers definitions and classifications of detailed methods for ABC, comparison of related Decision Support Tools, and analysis of available related cost estimating models. Chapter 3 provides summary of the data collection process, data cleaning and preprocessing steps for the collected data, and methods for updating the model using the collected data and comparison techniques with existing models. Chapter 4 provides statistical and correlation analysis of the collected dataset and presents findings from the analysis. Chapter 5 presents conclusions and recommendations for future work.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

A comprehensive literature review has been conducted to establish a firm foundation for focusing on investigating relevant studies and current practices related to the application of the ABC method in bridge construction. The review particularly emphasized the Decision Support Tool (DST) for determining the applicability of ABC and Cost Estimation tools to aid in this process. This chapter summarizes the literature review into three main sections: (1) Definition and methodologies of ABC, (2) Approaches and classifications of DST, and (3) Key design elements of Cost Estimation model as a support tool for DST.

2.2 Definition and Methods of ABC

ABC is bridge construction that uses innovative planning, design, materials, and construction methods in a safe and cost-effective manner to reduce the onsite construction time that occurs when building new bridges or replacing and rehabilitating existing bridges (FHWA, 2011). The objectives of Accelerated Bridge Construction (ABC) for expediting project delivery include reducing delays for the traveling public, producing high-quality and durable products in a controlled shop environment, enhancing work zone safety by minimizing exposure for motorists and construction workers, and decreasing the overall construction schedule to a fraction of the time typically required on-site. To meet these goals, ABC employs prefabricated bridge elements and systems, utilizing advanced technology to facilitate swift and effective construction processes (MengPoh Tang, 2014).

2.2.1 Prefabricated Bridge Elements and Systems (PBES)

Prefabrication involves constructing bridge components in a controlled environment away from

the actual site. These components can range from small parts to substantial sections of a bridge, which are then transported to the site for assembly (Atorod Azizinamini, 2020). This method allows for component fabrication to occur concurrently with site preparation and other ground operations, thus significantly reducing on-site construction time. Not only does prefabrication shorten the overall project timeline, but it also enhances construction quality due to the controlled manufacturing conditions and reduces environmental impact and safety hazards associated with on-site construction activities.

2.2.2 Lateral Side Bridge

The lateral slide method involves constructing the bridge superstructure adjacent to its final position and then sliding it into place upon completion. This approach is particularly beneficial in areas where space is limited or where maintaining traffic flow is crucial, as building the bridge directly at its final location may not be feasible (Mohiuddin Ali Khan, 2015). The sliding process can be performed during off-peak hours, minimizing disruption to traffic. This technique not only accelerates the construction process but also enhances worker safety by reducing the time spent working near live traffic.

2.2.3 Self-Propelled Modular Transporters (SPMT)

Self-propelled modular transporters are specialized multi-axle platforms designed to transport and precisely position large structures, such as bridge spans. Operated by experienced personnel, SPMTs can navigate even in confined spaces, offering high precision in placing heavy loads. This capability makes them extremely effective for installing prefabricated bridge elements, thereby significantly reducing the construction time on site. By utilizing SPMTs, transportation authorities can dramatically minimize traffic disruptions and decrease the risks associated with constructing

large components at the construction site (Atorod Azizinamini,2020).

2.3 Decision Support Tool Approach and Classification

At the early stages of a construction project, engineers must determine whether Accelerated Bridge Construction (ABC) is feasible and effective for a specific bridge location. The Decision Support Tool (DST) is employed in such scenarios to enable traffic experts and decision-makers to evaluate alternatives with confidence and prevent investment in more costly options. DST supports the decision-making process by creating a hierarchy of related species, where the decision criteria are developed through expert opinions and relevant literature reviews (Benjamin Tang, 2013). The use of DST varies by state, and for the Illinois Department of Transportation.(El-Rayes, 2023) the currently used DSTs can be classified into Quantitative DST and Qualitative DST.

2.3.1 Qualitative Decision Support Tools

Qualitative Decision Support Tools assist the Illinois Department of Transportation (IDOT) in selecting the appropriate construction method for specific planned bridge projects. This decision-making process is structured into three key stages. (1) The Decision Support Tool (DST) initially helps determine if the Accelerated Bridge Construction (ABC) method is suitable for a bridge project by using 21 questions categorized under site constraints, cost, and other factors. These questions are designed to evaluate the feasibility of applying the ABC approach, considering the bridge's location, traffic volume, costs, and environmental requirements. (2) Upon identifying a suitable ABC method, the DST proceeds to pinpoint all viable ABC techniques for the project. It simplifies the decision-making flowchart through a set of nested questions tailored to four predefined scenarios based on the bridge's position and the type of work involved. For example, different sets of nested questions are utilized depending on whether the bridge is situated over a

road or a railway. (3) In the final stage, the DST generates a list of the feasible ABC methods and conventional construction techniques identified in the previous step. This compilation is used for conducting cost estimations and comparisons, thereby enabling IDOT planners to more clearly define the necessary construction approaches to ensure the project's success and facilitate swift decision-making.

2.3.2 Quantitative Decision Support Tools

The Quantitative Decision Support Tool (Quantitative DST) generates rough cost estimates at an approximate level for use by IDOT designers and decision-makers in the early planning and engineering phases of projects, providing detailed cost estimates based on specific designs and dimensions of all bridge elements. This tool collects and analyzes historical cost data of bridge projects to understand and model cost differences based on bridge construction methods, providing crucial foundational data for modeling. Additionally, it builds a cost database based on collected data to be utilized in future cost estimation modeling, providing essential information for cost estimation and comparison. Construction cost modules have been developed for each bridge construction method, enabling rough or specific cost estimates, considering the resources and labor costs required for bridge construction. A road user cost module estimating driver costs incurred due to bridge construction is implemented, considering the time and driving costs of road users. Lastly, a life-cycle cost module is developed considering the bridge's lifespan, including construction, road user, maintenance, and replacement costs, calculating the total ownership cost based on bridge construction methods and aiding decision-making processes.

2.4 ABC Cost Estimation Model

In project planning by evaluating the cost efficiency of various bridge construction methods. This

tool analyzes the costs of three major bridge construction methods, including conventional bridge and Accelerated Bridge Construction (ABC) methodologies.

Machine Learning (ML) and Multiple Linear Regression (MLR) models play crucial roles in the data analysis process, each handling data differently. ML models are utilized when collecting data for conventional bridge construction methods and prefabricated or system construction methods to model complex nonlinear relationships between input and output variables. Various predictive variables such as bridge length, width, project length, design type, location type, among others, were considered, and over 2,000,000 ML models were built.

On the other hand, MLR models are applied to model linear relationships between input and output variables and are used for methods such as Lateral Slide and SPMT (Self-Propelled Modular Transporter) construction. The datasets for these methods are relatively limited, making data analysis using ML methods such as those used for conventional bridge construction and prefabricated or system construction methods difficult. As a result, the Lateral Slide model was developed using 28 MLR models, and the SPMT construction method was developed using 14 MLR models.

In the development process of the cost estimation tool, historical average bid price databases from IDOT and bid item reports from FHWA were the primary data sources. 15,974 unique payment code item data were collected and analyzed, and the average unit costs of each payment code item were adjusted to the current year (2023) costs. This adjustment process was performed by applying inflation ratios using RSMeans construction cost data manuals for each IDOT district. The adjusted cost information was recorded in user-friendly Excel files to facilitate easy access and updates by

IDOT planners.

However, the datasets for Lateral Slide and SPMT construction methods are relatively small, limiting the predictive reliability of the models. Therefore, additional data collection and analysis for these methods are necessary to enhance the accuracy of the cost estimation tool, supporting IDOT planners and decision-makers in conducting more accurate and realistic cost estimates. (El-Rayes, 2023)

CHAPTER 3 - DATA COLLECTION AND ANALYSIS

3.1 Introduction

The objective of this chapter is to collect and analyze a dataset of recently constructed accelerated bridge construction projects that can be used to expand existing datasets for developing bridge cost-estimating DSTs. This objective was accomplished in three main research tasks that focused on (1) identifying an initial list of 42 recently constructed ABC bridges based on a comprehensive review of 11 state Department of Transportation published reports and websites; (2) extracting all available cost estimating data such as construction cost, length and width for each of the identified 42 bridges in the initial list; (3) identifying a short list of 22 ABC bridges that has a complete set of all required cost estimating data; and (4) organizing and storing all the collected bridge dataset for the identified short list of 19 lateral slide and four SPMT bridges in an Excel spreadsheet. The following sections provide a concise description of these four research tasks.

3.2 Initial list of ABC bridges

A comprehensive review of 11 State DOT recently published report and website was conducted to identify an initial list of 42 recently completed ABC projects, as shown in Table 3.1. This initial list of 42 recently constructed ABC bridges projects were obtained from DOT websites of 11 states: Arizona, California, Connecticut, Georgia, Iowa, Michigan, New Hampshire, Pennsylvania, Texas, Utah, Vermont. The following sections provide a sample of the process used to acquire data from four example State DOTs.

Table 3.1 The data list for the 42 ABC bridges collected

Project Name (SN)	Zip Code	Year Built	Construction Methods/Equipment
IA 92 Over small stream	515	2015	Lateral Slide
LP 345 Lateral Slide	782	2013	Lateral Slide
US-131 over 3 mile road	493	2014	Lateral Slide
M-50 over I-96	495	2014	Prefabricated
MD213	216	2019	Lateral Slide
Lafayette Bridge	551	2015	Prefabricated
Route 44 over route 24	27	2021	Lateral Slide
Jacoby Creek Bridge	955	2022	Lateral Slide
Little field Bridge	42	2013	Lateral Slide
Hartford I-91 Bridge	50	2015	Lateral Slide
I-94 2nd avenue	550	2022	SPMT
I-84 Bridge	837	2020	Lateral Slide
Bear Camp River Bridge	38	2121	Lateral Slide
Bearcamp River Relief Bridge	38	2019	Lateral Slide
Bearcamp River Bridge	38	2021	Lateral Slide
WB-224B	150	2017	Lateral Slide
Blackhall Road	302	2019	Lateral Slide
Route 1 over I-95	608	2019	SPMT
I-80 & I-215 Renewed	841	2023	Lateral Slide
State Route 30 A25	150	2016	Lateral Slide
IA 1 over OLD MANS CREEK	522	2020	Lateral Slide
I-215 at 4500 South	841	2007	SPMT
I-80 WB over 300 East	841	2008	SPMT
I-80 WB over 500 East	841	2008	SPMT
I-80 WB over 700 East	841	2008	SPMT
I-80 WB over 900 East	841	2008	SPMT
I-80 WB over 600 East	841	2008	Lateral Slide
I-80 WB On-Ramp over 600 East	841	2011	Lateral Slide
I-80 WB over Highland Drive	841	2008	SPMT
I-80 over SR-32	442	2012	Lateral Slide
I-15 over W Hill Field Road	840	2016	Lateral Slide
I-80 Mount Delle	841	2008	SPMT
I-80 over Echo Dam Road	442	2011	Lateral Slide
I-80 Over 2300 East Ramp	841	2010	Lateral Slide
I-80 EB Structure F-801 at Atkinson Canyon	841	2008	Lateral Slide
I-80; EB/WB over Weber River at Echo Junction	442	2009	Lateral Slide
I-84; Echo Frontage Road	442	2008	Lateral Slide
I-15 over East Nicholas Canyon Road	847	2009	Lateral Slide
1300E over I-80	840	1999	Lateral Slide
1700E over I-80	840	2013	Lateral Slide
I-40: Fourth Street Bridge	860	2020	Lateral Slide

3.2.1 California ABC Bridges

A recently completed ABC bridge in the state of California was Identified based on a review of a recently published report by Caltrans (Caltrans, 2023). The report contains a list of the projects of Eureka-Arcata Route 101 Corridor Project on 2019 including one Lateral slide project, as shown in Figure 3.1.

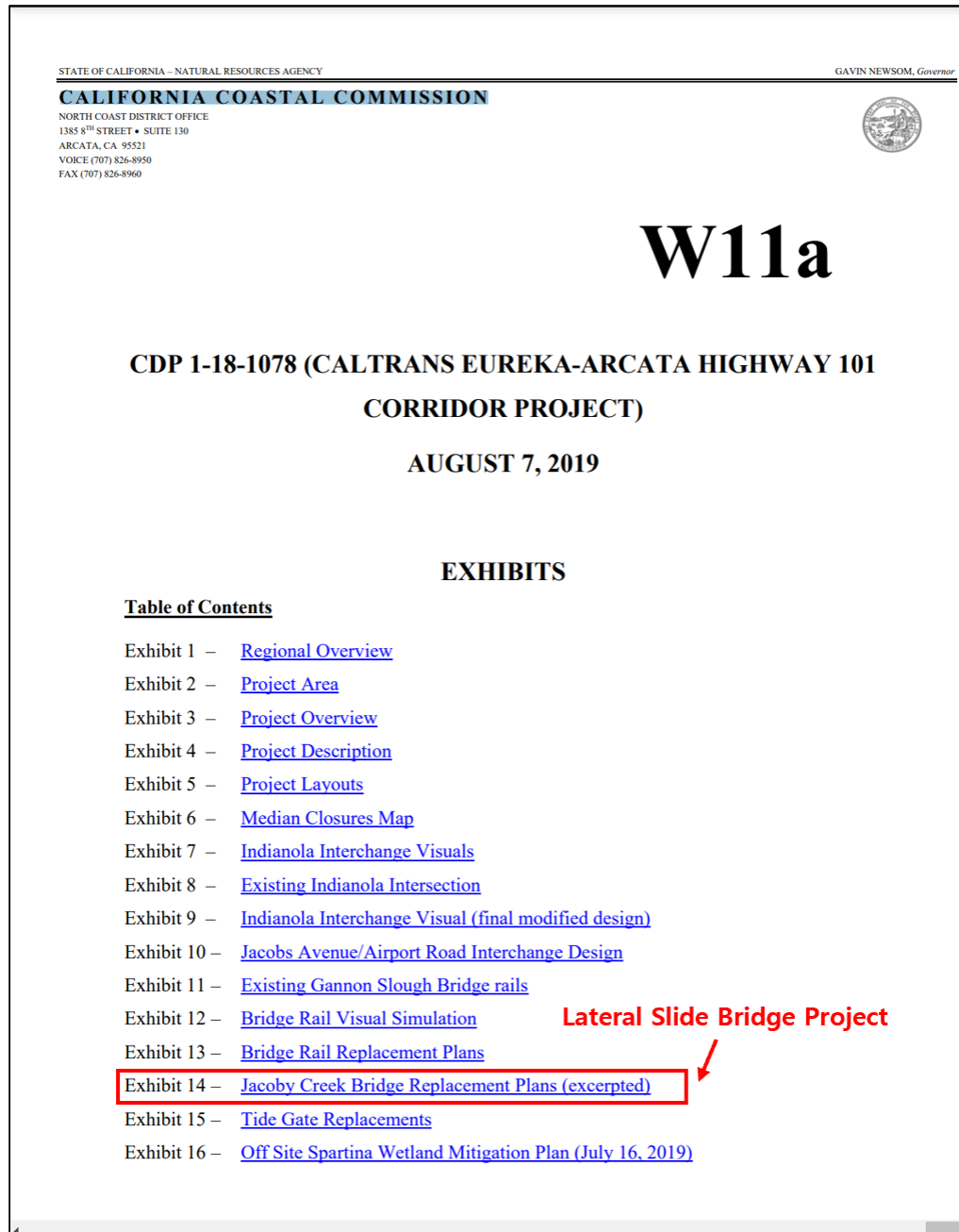


Figure 3.1 Example of Caltrans Eureka-Arcata Highway project list in California (CalTran, 2024).

3.2.2 Iowa ABC Bridges

A recently completed ABC bridge in Iowa State was identified based on a review of Iowa State DOT website, as shown in Figure 3.2. The Iowa DOT ABC project website contains a list of ABC bridges constructed in Iowa from 2012 to 2024 and it provides related bridge reports, construction

timelapse video, and links related to ABC bridge projects that have been carried out in Iowa. Upon reviewing the available reports, the identified Little Silver Creek Bridge project was constructed with a Lateral Slide bridge method. Data collection was subsequently performed on this specific project based on the available information on the Iowa DOT website.



Figure 3.2 Screenshot. Iowa DOT Accelerated Bridge Construction Webpage

3.2.3 Utah ABC Bridges

A list of recently completed ABC bridges in the state of Utah was identified based on a review of a recently published report by Utah DOT (UtahDOT, 2023). The report contains a list of ABC bridge

projects constructed in Utah from 2008 to May 2023 and it provides bridge-assigned numbers, locations, and type of ABC method, as shown in Figure 3.3. This report listed 49 ABC bridge projects that included 10 Lateral Slide bridges and 9 SPMT bridges, as shown in Figure 3.3 and Figure 3.4, respectively.



UTAH DEPARTMENT OF TRANSPORTATION

2023 LESSONS LEARNED INSPECTIONS

3) Bridges Studied

The following table is a list of the bridges studied and the type of ABC work employed.

Table 3-1: Bridges Inspected

Site No.	# of Times Visited	Bridge No.	Bridge Location	Type of ABC Method Used
1	6	C-437	County Road over I-84, Wanship	Full Depth Precast Concrete Deck Panels with CIP Closure Pours
2	4	C-457	I-84 EB over I-15	Precast Deck Panels and Approach Slabs
3	7	C-476	I-84 over Weber Canyon (Site No. 2)	Full Depth Precast Concrete Deck Panels with Welded Tie Connection
4	6	C-477	I-84 over Weber Canyon (Site No. 1)	Full Depth Precast Concrete Deck Panels with Welded Tie Connection
5	7	C-518	I-215 East at 3900 South	Full Depth Precast Concrete Deck Panels with Longitudinal Post-Tensioning
6	7	C-573	I-80: Mt Delle to Lambs Canyon	SPMT Installation with Precast Approach Slabs
7	6	C-578	Parrish Lane over RR	Full Depth Precast Concrete Deck Panels with Longitudinal Post-Tensioning and Precast Pier Cap
8	7	C-596	Parrish Lane at I-215	Full Depth Precast Concrete Deck Panels with Welded Tie Connection
9	3	C-679	US-6 over Railroad (Moark)	Full-depth precast deck panels on steel stringers with UHPC closure pours
10	6	C-931	I-215 East over 3760 South	Prefabricated superstructure moved using heavy lift cranes
11	7	C-953	I-215 at 4500 South	SPMT Installation
12	7	C-956	I-80 WB over 300 East	SPMT Installation
13	7	C-957	I-80 WB over 500 East	SPMT Installation
14	7	C-958	I-80 WB over 700 East	SPMT Installation
15	7	C-959	I-80 WB over 900 East	SPMT Installation
16	7	C-960	I-80 WB over 600 East	SPMT Installation
17	7	C-961	I-80 WB On-Ramp over 600 East	SPMT Installation
18	7	C-963	I-80 WB over Highland Drive	SPMT Installation
19	6	C-966	I-84 at Riverdale Road	Precast Deck Panels with Longitudinal Post-Tensioning
20	6	C-968	I-215 at 3300 South	SPMT Installation
21	5	C-971	Hinckley Drive to SR-108	Full depth precast post-tensioned deck panels on steel beams
22	5	C-986	I-15; South Layton Interchange	Cast-in-place deck on steel beams with Longitudinal slide-in installation
23	5	C-1004	I-80; Summit Park Bridge	Cast-in-place deck on steel beams with lateral slide-in installation

SPMT Bridge projects

SPMT Bridge projects

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Figure 3.3. Sample of recently constructed SPMT bridges in Utah (UtahDOT, 2024).



2023 LESSONS LEARNED INSPECTIONS

UTAH DEPARTMENT OF TRANSPORTATION

Site No.	#of Times Visited	Bridge No.	Bridge Location	Type of ABC Method Used
24	4	C-1011	I-80 over SR-32	Lateral slide installation
25	3	C-1032	I-15 over W Hill Field Road	Lateral slide installation
26	7	F-94	I-84 WB over Weber River	Full Depth Precast Concrete Deck Panels with Welded Tie Connection
27	5	F-114	I-84; Bridge F-114, 0.8 Miles East of Taggart	Full depth precast deck panels on precast AASHTO IV prestressed concrete beams
28	5	F 127	I-15 over 77 (S 3200 W)	Full Depth Post-Tensioned Deck Panels
29	5	F-128	I-15 Shoulder Widening and Deck Treatments: I-15 over US-6	Full depth precast deck panels on precast AASHTO III prestressed concrete beams
30	6	F-129	I-15 over W Utah Avenue	Full Depth Precast Concrete Deck Panels with Longitudinal Post-Tensioning
31	7	F-183	I-80 over Highland Drive (near Kimball)	Full Depth Precast Concrete Deck Panels with Welded Tie Connection
32	6	F-254	I-80: Mount Delle	SPMT Installation with Precast Approach Slabs
33	7	F-741	US-6 over UPRR at MP 200	Precast Substructures and Full Depth Precast Deck Panels with Cast-in-place Closure Pours
34	7	F-759	US-6 Wildlife Crossing at MP 200	Precast Substructures and Full Depth Precast Deck Panels with Welded Tie Connection
35	6	F-755	SR-89 over RR, Pleasant Grove	Full Depth Precast Concrete Deck Panels with Welded Tie Connection, Precast Approach Slabs and Sleeper Slabs.
36	6	F-762	US-6 at MP218.7, Emma Park	Full Depth Precast Concrete Deck Panels with Longitudinal Post-Tensioning, Precast Approach Slabs and Sleeper Slabs.
37	5	F-770	US-6; Tucker MP 203 to 204.2	Full-depth precast deck panels on concrete beams
38	5	F-784	I-15 over 11400 South	Full depth precast post-tensioned deck panels on precast W2400MG prestressed concrete beams
39	6	F-792	I-80 over Echo Dam Road (2 bridges)	Lateral Slide-in Installation with Attached Approach Slabs
40	6	F-793	I-80 over 2300 East Ramp (2 bridges)	Lateral Slide-in Installation with Attached Approach Slabs
41	5	F-801	I-80 EB Structure F-801 at Atkinson Canyon	Lateral slide-in installation
42	5	F-843	I-80; EB/WB over Weber River at Echo	Lateral slide-in installation

Lateral Slide Bridge projects

Lateral Slide Bridge projects

Figure 3.4 Sample of recently constructed Lateral Slide bridges in Utah (UtahDOT, 2024).

3.2.4 Vermont ABC Bridges

A recently completed Vermont ABC bridge list was identified based on a review of Vermont State DOT website. The Vermont DOT ABC website presents project name and location of each bridge, the ABC method used in construction, and links to related videos This website listed eight ABC bridge projects that included one Lateral Slide bridges, the Hartford I-91, as shown in Figure 3.5.

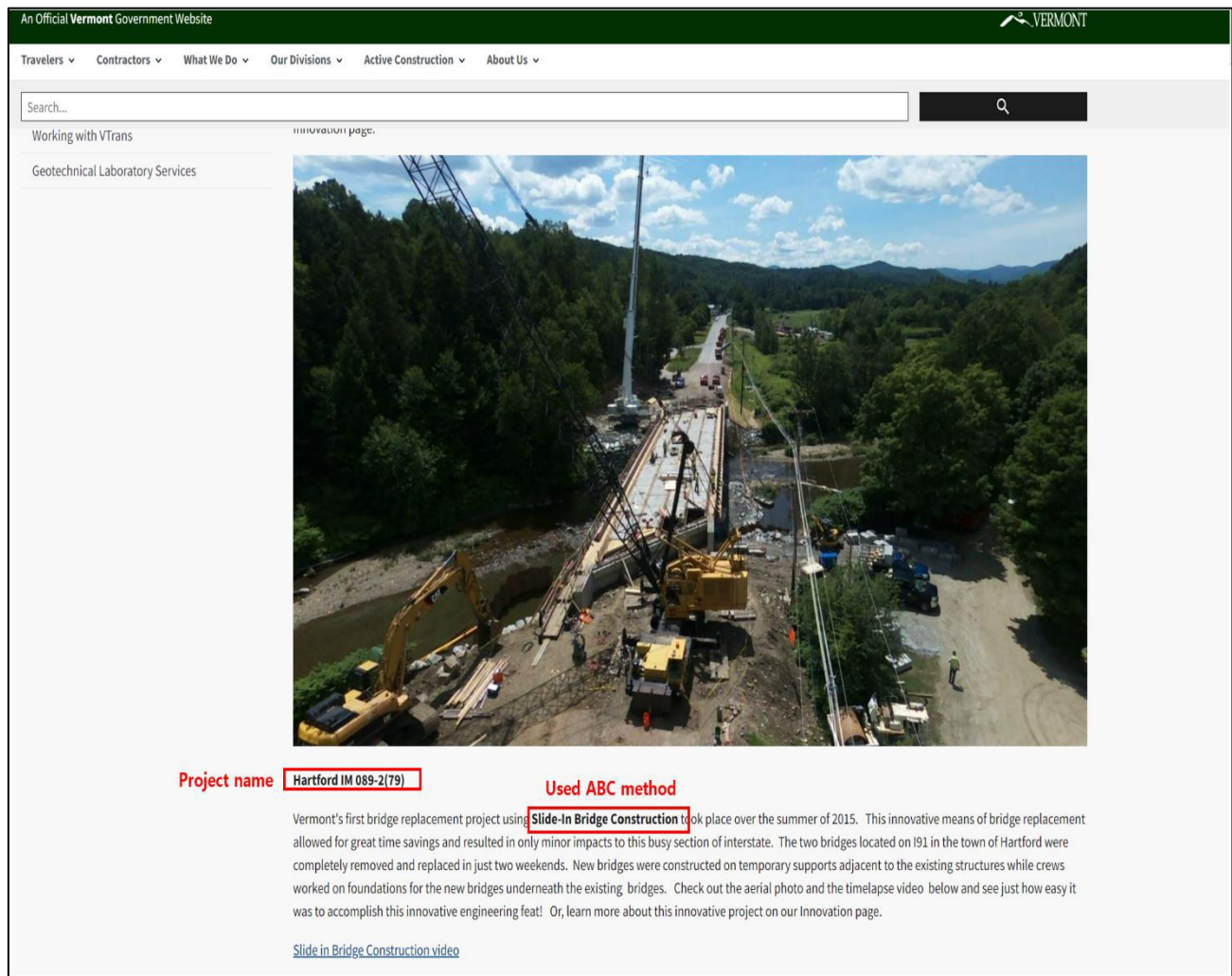


Figure 3.5 Sample of Vermont State DOT Accelerated Bridge Construction Webpage

3.3 Bridge Data Collection

This task focuses on collecting all available data that are needed to estimate bridge cost per square foot for each of the 42 ABC bridges identified in the previous task. For each of these identified 42 bridges, the State DOT maintains different formats for project records, which means the types of data available and the details recorded about bridge projects can vary from one State DOT to another. Accordingly, the cost estimating data for these 42 ABC bridges was extracted from three main sources: (a) project reports published by DOTs, (b) DOT's Bridges Inventory, and (c) contract, planning, and provision documents.

3.3.1 Project Reports and Presentations Published by DOT

The project reports published by each state DOT were reviewed to collect all required bridge cost estimating data including bridge width, length, number of spans, construction method, and location. For example, a published report on a recently completed lateral slide Iowa DOT project was reviewed to collect project name, project length, width, span data, and deck, as shown in Figure 3.6.

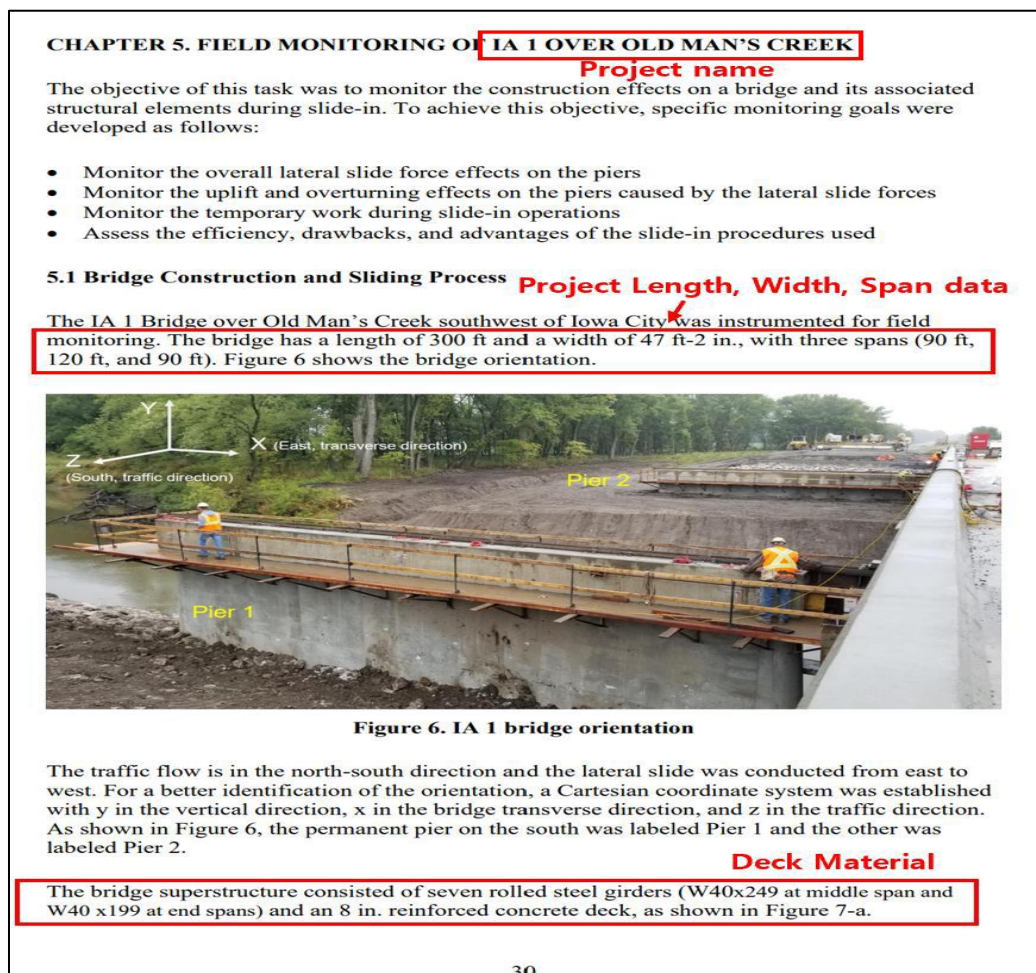


Figure 3.6 Sample of IA 1 Bridge over Old Man's Creek project page in report (Iowa DOT, 2024)

Additional bridge cost estimating data for the 42 identified ABC bridges was collected from monthly academic seminar archives on the FHWA National ABC Project Exchange webpage. For example, Average Daily Traffic (ADT), bridge width, length, and bridge design type were extracted from

FHWA National ABC Exchange webpage, as shown in Figure 3.7 and Figure 3.8, respectively.

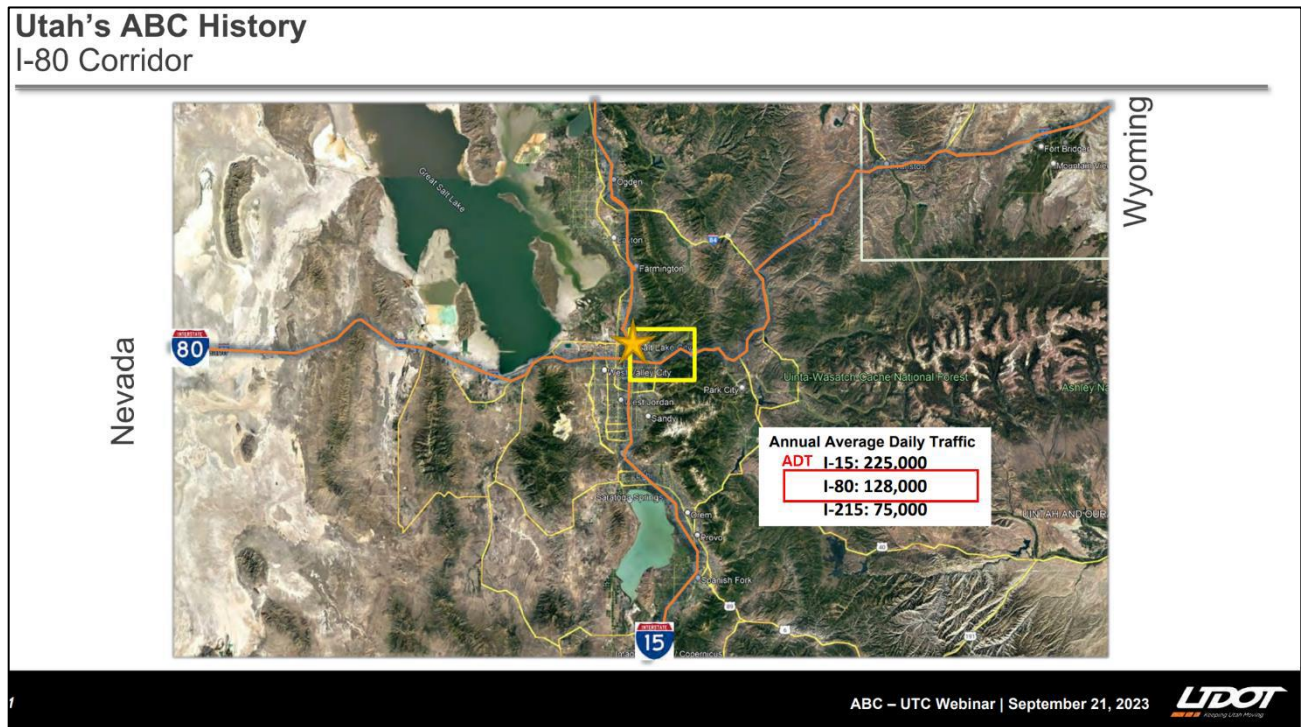


Figure 3.7 Example collection of ADT data for a sample Utah Lateral Slide Bridge (FIU,2024)

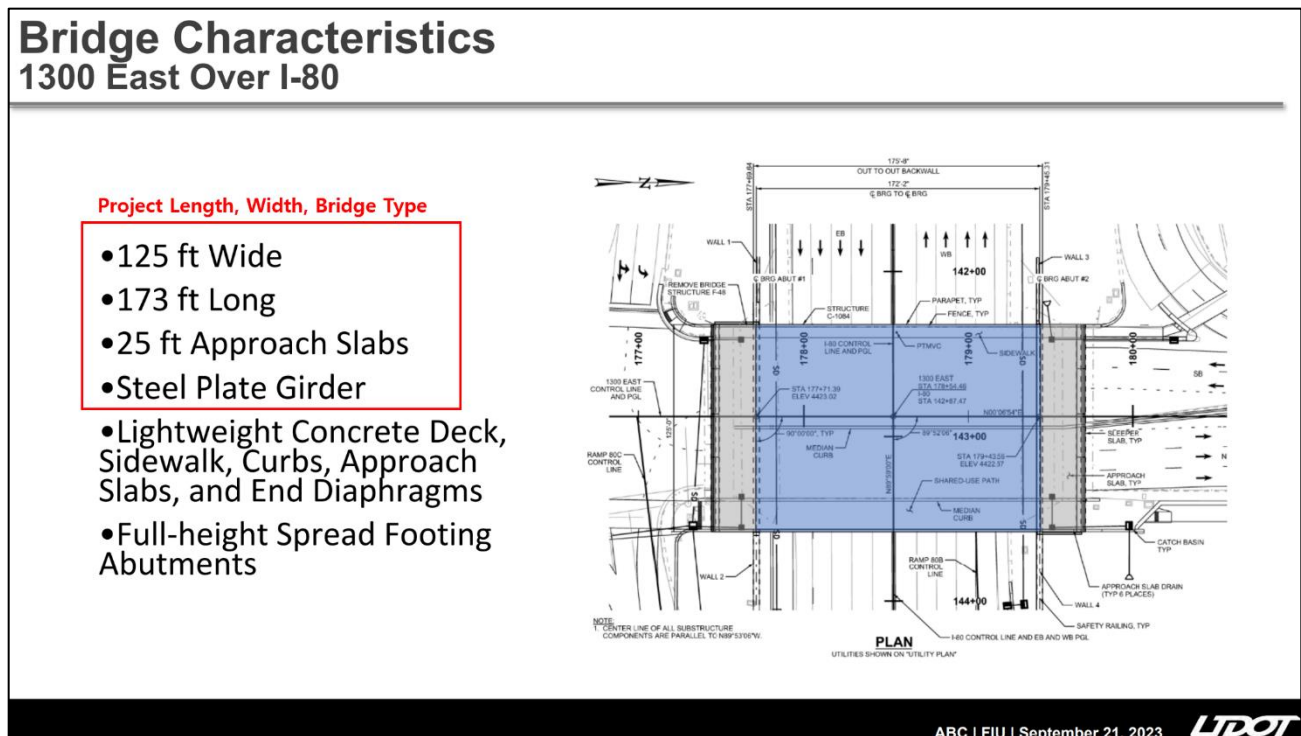


Figure 3.8 Example of Bridge dimension data for a sample Utah Lateral Slide Bridge (FIU,2024)

3.3.2 DOT's Bridges Inventory

Bridge inventories published by Maine DOT and Utah DOT were reviewed to collect additional ABC bridge data. For example, project name, location, span length, year built, ADT, number of spans, span material, and type were extracted from Maine DOT Public Bridge inventory, as shown in Figure 3.9. Similarly, the data of project location, project value, and project start date for the I-80 & I-215 Renewed Bridge were collected from Utah DOT Bridge inventory, as shown in Figure 3.10.

MAINE PUBLIC BRIDGE STRUCTURES IN THE MUNICIPALITY OF Auburn			
IDENTIFICATION Project name, location Town Auburn Town2 1.5 MI S OF JCT RTE 11 Bridge Name LITTLEFIELDS Location 0110190 Bridge Number 3338 Route Number 1 - Southern Region Feature On HOTEL RD Border Bridge Bridge on Townway or State Aid Road Feature Under LITTLE ANDROSCOGGIN RV Bridge or Minor Span Bridge on Townway or State Aid Road Bridge Road Width (Feet) 34			
CLASSIFICATION Owner MaineDOT Maintainer MaineDOT Maximum Span Length (Feet) 150 Federal Bridge Indicator Y Span length			
AGE AND CONDITION Deck Condition 7 - Good Condition (some minor problems) Culvert Condition N - Not Applicable Superstructure Condition 8 - Very Good Condition (no problems noted) Channel Condition 9 - No noticeable deficiencies Substructure Condition 8 - Very Good Condition (no problems noted) Approach Condition 8 - Equal to present desirable criteria Year Built 2013 ADT Annual Average Daily Traffic 10507			
INSPECTION AND APPRAISAL Date of Inspection 10/27/2022 Federal Sufficiency Rating 90.4 Year Built			
STRUCTURE TYPE AND MATERIAL Span Material Steel Span Type Stringer/Multi-beam or Girder Number of Main Spans 1 Number of Span, Span material and type			
LOAD RATING AND POSTING Posting Status Open Posted Weight (Tons) POSTING TYPE 4-Axle One-Truck Spacing			
Produced by MaineDOT Bridge Maintenance October 1, 2023 32 of 44			

Figure 3.9 Sample of Maine DOT Public Bridges Inventory Search Result (MaineDOT, 2024)

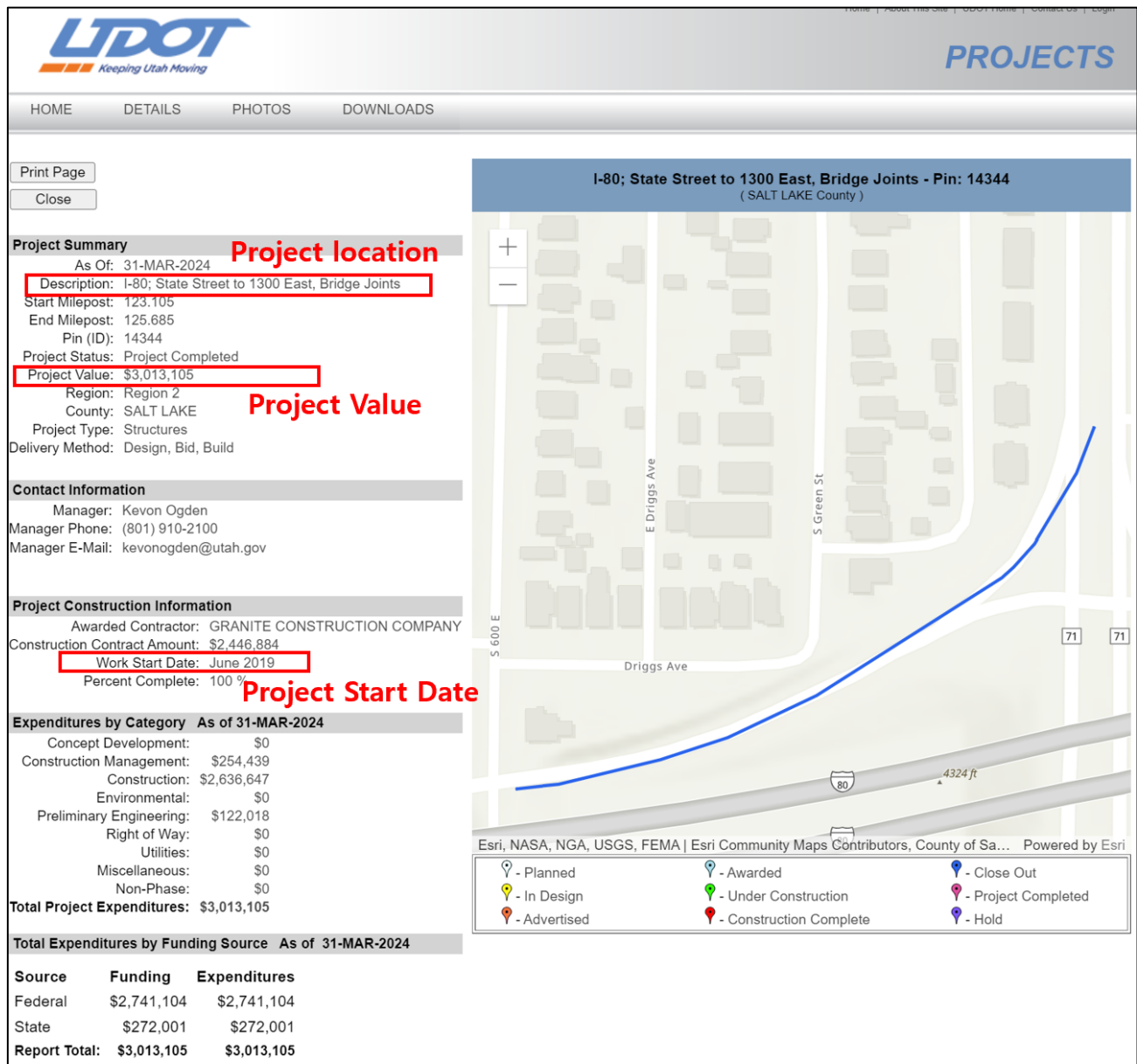


Figure 3.10 Sample of Utah DOT Bridges Inventory Search Result (Utah DOT, 2024)

The Average Daily Traffic (ADT), project length, bridge length, and bridge width were collected from drawings provided by Iowa State DOT website, as shown in Figures 3.11 and 3.12 respectively.

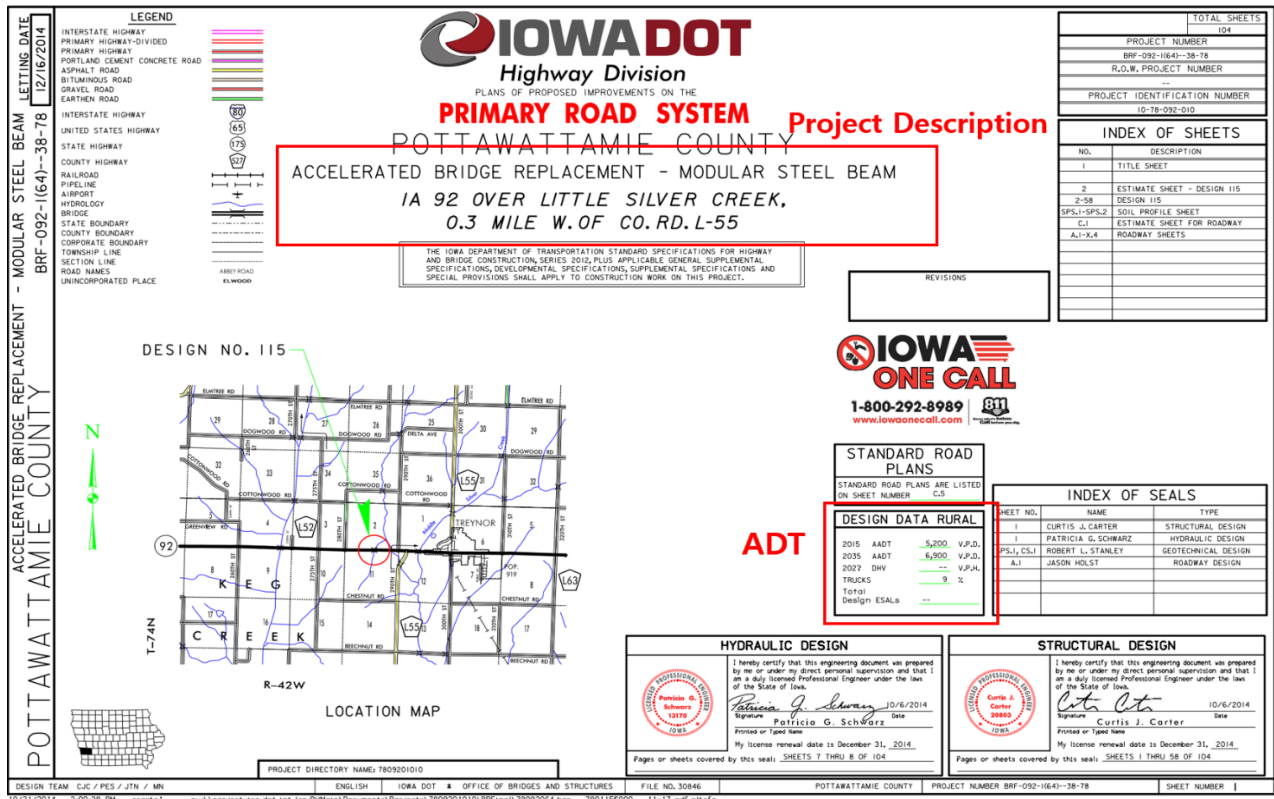


Figure 3.11 Sample of Drawings collected from Iowa DOT (Iowa DOT, 2024)

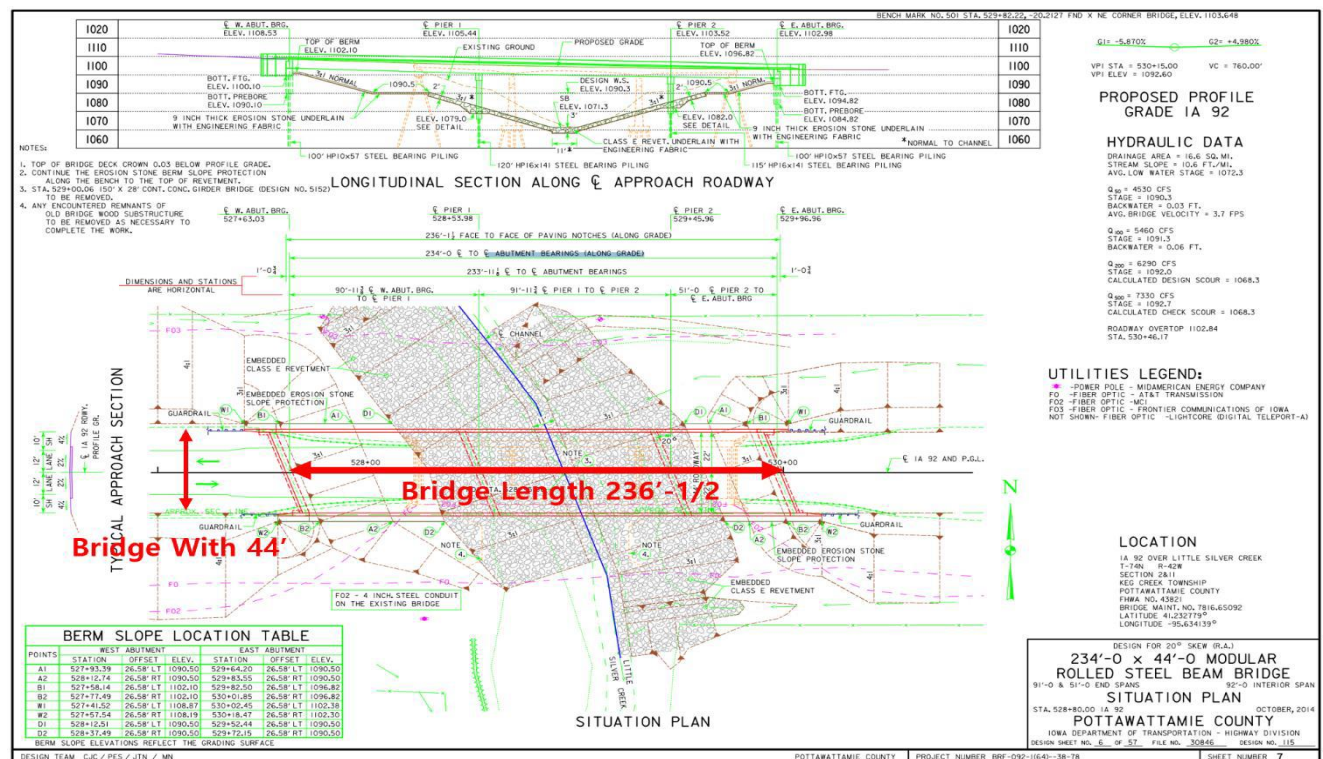


Figure 3.12 Sample of Drawings collected from Iowa DOT (Iowa DOT, 2024)

3.3.3 Planning, Provisions and Contract Documents

Bridge planning, provisions, and contract documents were also reviewed to collect additional project data that are needed to estimate the cost of ABC bridges during the early design phase. For example, the New Hampshire DOT communication plan for the Bearcamp River bridge project was reviewed to collect road closure times, as shown in Figure 3.13.

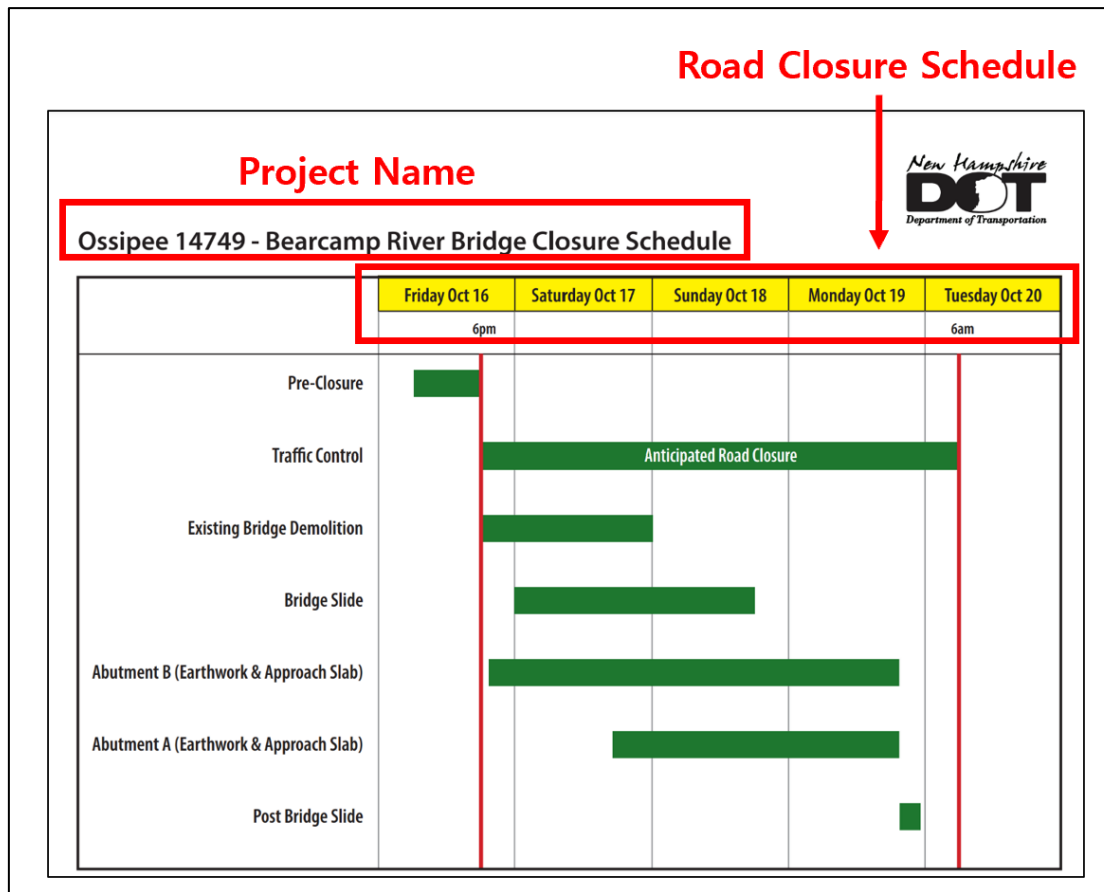


Figure 3.13 Example of MIC data collected from NH DOT (NH DOT, 2024).

Similarly, Texas DOT Detail Letting Schedule was reviewed to collect the bridge's structure number, length, and actual cost information for the LP345 bridge, as shown in Figure 3.14

CCSJ: 0072-08-122			
District:	San Antonio	Project name and number	Let Date: AUG 2011
Highway:	LP 345		Let Status: Actual
Project ID:	HP 1102(265)		CSJ: 0072-08-122
Description:	GRADE SEPARATION @ MEDICAL & OPERATIONAL IMPVMENTS ON MEDICAL		Handling Code:
Limits From:	AT MEDICAL DRIVE	Fund Cat:	7
Limits To:	.	Estimate:	\$16,188,597
Length:	0.2 Miles	Actual:	\$10,850,899
District:	San Antonio	Let Date:	AUG 2011
Highway:	LP 345	Let Status:	Actual
Project ID:	RW 72-8-134	CSJ:	0072-08-134
Description:	UTILITY ADJUSTMENTS		Handling Code:
Limits From:	AT MEDICAL DRIVE	Fund Cat:	ROW
Limits To:	.	Estimate:	\$739,338
Length:	0.2 Miles	Actual:	\$1,291,148
Award Status Bid Tabulations Back...		Totals for 0072-08-122	
		Length:	0.4 Miles
		Estimate:	\$16,927,935
		Actual:	\$12,142,047

Bridge Length and Cost

Figure 3.14 Example of Bridge dimension and Cost data collected from Texas DOT (Texas DOT, 2024).

3.4 Short list of bridges with complete dataset

The objective of the this research task is to identify a short list of 22 ABC bridges that has a complete set of all required cost-estimating data. Based on comprehensive literature review, the required data to estimate bridge cost during the early design phase consist of include bridge width, bridge length, number of lanes, maximum span length, Average Daily Traffic (ADT), construction method/equipment, design type, location type, project type, deck material, girder material, service type, mobility impact category,

high-performance materials, structural solutions, and geotechnical solutions, construction cost (Hollar et al., 2013; Jia et al., 2018). Accordingly, a total of 22 out of the 42 bridges identified in the previous task were found to have a complete dataset. A list of these 22 ABC bridges with a complete cost-estimating dataset is shown in Table 3.2.

Table 3.2 A list of 22 ABC Bridge projects with a complete cost-estimating dataset

Project Name (SN)	Zip Code	Year Built	Construction Methods/Equipment	Design Type	Location Type	Max Span Length (ft.)	Bridge Width	Bridge Length	Total Cost	Adjusted Total Cost 2024	Adjusted Cost/ sf 2024
IA 92 Over small stream	515	2015	Lateral Slide	Beam	Rural	91.8	44	234	\$ 3,200,000.00	\$ 5,412,942.76	\$525.73
LP 345 Lateral Slide	782	2013	Lateral Slide	Beam	Urban	92.4	65	359.5	\$ 12,142,047.00	\$ 22,554,500.57	\$965.21
US-131 over 3 mile road	493	2014	Lateral Slide	Beam	Rural	83.6	57	85.9	\$ 4,000,000.00	\$ 6,831,529.82	\$1,395.24
MD213	216	2019	Lateral Slide	Beam	Rural	68	50	74	\$ 5,287,000.00	\$ 8,420,892.86	\$2,275.92
Route 44 over route 24	27	2021	Lateral Slide	Girder	Urban	83	104	166	\$ 19,900,000.00	\$ 24,225,525.29	\$1,403.24
Jacoby Creek Bridge	955	2022	Lateral Slide	Beam	Rural	23.9	43	73	\$ 1,893,671.68	\$ 1,788,718.56	\$569.84
Little field Bridge	42	2013	Lateral Slide	Girder	Rural	150	34	158	\$ 2,900,000.00	\$ 4,972,976.00	\$925.72
Hartford I-91 Bridge	50	2015	Lateral Slide	Girder	Rural	127.9	45	136	\$ 2,547,786.00	\$ 4,501,782.88	\$735.59
I-94 2nd avenue	550	2022	SPMT	Girder	Urban	245	96.5	254	\$ 26,000,000.00	\$ 25,856,370.62	\$1,054.89
I-84 Bridge	837	2020	Lateral Slide	Girder	Rural	111.8	61.3	113	\$ 13,300,000.00	\$ 19,433,856.76	\$2,805.56
Bearcamp River Relief Bridge	38	2019	Lateral Slide	Girder	Rural	85	37	178	\$ 4,300,000.00	\$ 6,327,656.70	\$960.77
Bearcamp River Bridge	38	2021	Lateral Slide	Girder	Rural	172.9	38	418	\$ 3,200,000.00	\$ 4,246,287.68	\$267.33
WB-224B	150	2017	Lateral Slide	Girder	Rural	74.75	70.5	149.6	\$ 5,487,866.00	\$ 8,085,578.86	\$766.64
Blackhall Road	302	2019	Lateral Slide	Girder	Urban	92.8	41.3	195	\$ 2,037,000.00	\$ 3,076,686.48	\$382.03
Route 1 over I-95	608	2019	SPMT	Girder	Rural	120	77.5	270	\$ 14,800,000.00	\$ 17,562,423.83	\$839.30
State Route 30 A25	150	2016	Lateral Slide	Girder	Urban	54	62.6	58	\$ 2,333,212.00	\$ 3,542,124.05	\$975.58
IA 1 over OLD MANS CREE	522	2020	Lateral Slide	Girder	Rural	118	44	299	\$ 2,341,500.00	\$ 3,443,598.39	\$261.75
I-215 at 4500 South	841	2007	SPMT	Girder	Urban	172	82	172	\$ 3,506,597.00	\$ 7,259,837.18	\$514.74
I-80 Mount Delle	841	2008	SPMT	Girder	Rural	84	57	84	\$ 5,872,317.00	\$ 11,416,352.97	\$2,384.37
I-80 over Echo Dam Road	442	2011	Lateral Slide	Girder	Rural	80	40	80	\$ 1,550,000.00	\$ 2,796,985.09	\$874.06
I-80 Over 2300 East Ramp	841	2010	Lateral Slide	Girder	Urban	80	73	82	\$ 5,876,450.00	\$ 11,231,387.37	\$1,876.28
I-40: Fourth Street Bridge	860	2020	Lateral Slide	Girder	Urban	133.8	94.8	138	\$ 13,900,000.00	\$ 21,034,334.14	\$1,607.83

The collected data for the 22 bridges in the identified shortlist included cost estimates for the bridges that were constructed during 11 years from 2010 to 2021. Accordingly, these costs need to be updated with time and location factor. All collected cost data were adjusted by time and location to account for any changes in material, labor, and equipment costs over time and between different states. This adjustment involves modifying project cost data to reflect variations in the bridge's construction year and location, using the 2024 RS Means construction cost data manual. Adjusting for time means modifying the cost of any bridge project from the year it was constructed to its current year cost. This

adjustment is made using the Historical Cost Index section of the 2024 RS Means construction cost data manual, as shown in Table 3.3. The cost indices can be used to adjust historical construction costs for all years ranging from 2010 to 2024 using time adjustment equation shown in Eq 3.1, as shown in Table 3.3

Table 3.3 Sample of historical cost indices in RS Means 2024 (Dohney, 2024)

Cost	
Year	Historical Cost Index Jan1,1993 = 100
2010	183.5
2011	191.2
2012	194.6
2013	201.2
2014	204.9
2015	206.2
2016	207.3
2017	213.6
2018	222.9
2019	232.2
2020	234.6
2021	257.5
2022	297.1
2023	293.7
2024	288.1

$$Cost\ in\ Year\ 2024 = \frac{Index\ for\ Year\ 2024}{Index\ for\ Year\ X} \times Cost\ in\ Year\ X. \quad (3.1)$$

Project Cost Adjustment by location involves modifying the collected bridge costs based on regional construction cost differences. This adjustment is done by using location factors to compare the costs with the national average. The national average cost can then be used to estimate bridge costs in specific locations. The methodology for adjusting location costs uses the Location Factors

section of the 2024 RS Means construction cost data manual, as shown in Table 3.4

Table 3.4 Sample of location factors of Utah in RS Means 2024 (Dohney, 2024)

State	Zip Code	City	Total Cost Factor
UTAH	840	Salt Lake City	90.9
UTAH	841	Salt Lake City	90.9
UTAH	842	Ogden	88.4
UTAH	843	Logan	89.3
UTAH	844	Ogden	88.4
UTAH	845	Price	86.5
UTAH	846	Provo	89.2
UTAH	847	Provo	89.2

The results of the cost per square foot (cost/sf) for bridge construction costs, adjusted for location and region are shown in Table 3.5.

Table 3.5 Screenshot. ABC Bridge list with Cost Adjustment

Project Name (SN)	Year Built	Construction Methods/Equipment	Total Cost	Adjusted Total Cost 2024	Adjusted Cost/ sf 2024
IA 92 Over small stream	2015	Lateral Slide	\$ 3,200,000.00	\$ 5,412,942.76	\$525.73
LP 345 Lateral Slide	2013	Lateral Slide	\$ 12,142,047.00	\$ 22,554,500.57	\$965.21
US-131 over 3 mile road	2014	Lateral Slide	\$ 4,000,000.00	\$ 6,831,529.82	\$1,395.24
MD213	2019	Lateral Slide	\$ 5,287,000.00	\$ 8,420,892.86	\$2,275.92
Route 44 over route 24	2021	Lateral Slide	\$ 19,900,000.00	\$ 24,225,525.29	\$1,403.24
Jacoby Creek Bridge	2022	Lateral Slide	\$ 1,893,671.68	\$ 1,788,718.56	\$569.84
Little field Bridge	2013	Lateral Slide	\$ 2,900,000.00	\$ 4,972,976.00	\$925.72
Hartford I-91 Bridge	2015	Lateral Slide	\$ 2,547,786.00	\$ 4,501,782.88	\$735.59
I-94 2nd avenue	2022	SPMT	\$ 26,000,000.00	\$ 25,856,370.62	\$1,054.89
I-84 Bridge	2020	Lateral Slide	\$ 13,300,000.00	\$ 19,433,856.76	\$2,805.56
Bearcamp River Relief Bridge	2019	Lateral Slide	\$ 4,300,000.00	\$ 6,327,656.70	\$960.77
Bearcamp River Bridge	2021	Lateral Slide	\$ 3,200,000.00	\$ 4,246,287.68	\$267.33
WB-224B	2017	Lateral Slide	\$ 5,487,866.00	\$ 8,085,578.86	\$766.64
Blackhall Road	2019	Lateral Slide	\$ 2,037,000.00	\$ 3,076,686.48	\$382.03
Route 1 over I-95	2019	SPMT	\$ 14,800,000.00	\$ 17,562,423.83	\$839.30
State Route 30 A25	2016	Lateral Slide	\$ 2,333,212.00	\$ 3,542,124.05	\$975.58
IA 1 over OLD MANS CREE	2020	Lateral Slide	\$ 2,341,500.00	\$ 3,500,423.44	\$266.07
I-215 at 4500 South	2007	SPMT	\$ 3,506,597.00	\$ 7,259,837.18	\$514.74
I-80 Mount Delle	2008	SPMT	\$ 5,872,317.00	\$ 11,416,352.97	\$2,384.37
I-80 over Echo Dam Road	2011	Lateral Slide	\$ 1,550,000.00	\$ 2,796,985.09	\$874.06
I-80 Over 2300 East Ramp	2010	Lateral Slide	\$ 5,876,450.00	\$ 11,231,387.37	\$1,876.28
I-40: Fourth Street Bridge	2020	Lateral Slide	\$ 13,900,000.00	\$ 21,034,334.14	\$1,607.83

3.5 Data Organization and Storage

The objective of this research task is to organize and store all the collected ABC bridge datasets for the identified shortlist of 22 ABC bridges, which consist of 18 lateral slides and four SPMT bridges, in an Excel spreadsheet. This organized dataset can be used to develop cost-estimating tools for accelerated bridge construction (ABC) projects. The dataset consists of 18 fields that provide key data

for each ABC bridge project. These include Project Name (SN), Zip Code, Construction Methods/Equipment, Design Type, Location Type, Project Type, Deck Material, Beam Material, Type of Service, MIC, Number of Spans, Max Span Length, Bridge Width, Bridge Length, Total Cost, Adjusted Total Cost 2024, Adjusted Cost/sf 2024, and Current Year Adjusted Cost.

Projects are categorized by construction methods/equipment, such as "Lateral Slide" and "SPMT," location type differentiating between "Rural" and "Urban," and project type classified into "Replace" and "New". These three factors are primary data for classifying projects at a high level and represent key differences that determine the overall strategy and costs of bridge construction. Other fields fall under these high-level classifications, providing more detailed project information such as the number of spans, maximum span length, and bridge width. An example of the project categorization is shown in Table 3.6.

Table 3.6 Screenshot. ABC Bridge List Categorization

Project Name (SN)	Construction Methods/Equipment	Design Type	Location Type	Project Type
IA 92 Over small stream	Lateral Slide	Beam	Rural	Replace
LP 345 Lateral Slide	Lateral Slide	Beam	Urban	Replace
US-131 over 3 mile road	Lateral Slide	Beam	Rural	Replace
MD213	Lateral Slide	Beam	Rural	Replace
Route 44 over route 24	Lateral Slide	Girder	Urban	New
Jacoby Creek Bridge	Lateral Slide	Beam	Rural	Replace
Little field Bridge	Lateral Slide	Girder	Rural	Replace
Hartford I-91 Bridge	Lateral Slide	Girder	Rural	New
I-94 2nd avenue	SPMT	Girder	Urban	New
I-84 Bridge	Lateral Slide	Girder	Rural	Replace
Bearcamp River Relief Bridg	Lateral Slide	Girder	Rural	Replace
Bearcamp River Bridge	Lateral Slide	Girder	Rural	Replace
WB-224B	Lateral Slide	Girder	Rural	Replace
Blackhall Road	Lateral Slide	Girder	Urban	New
Route 1 over I-95	SPMT	Girder	Rural	Replace
State Route 30 A25	Lateral Slide	Girder	Urban	Replace
IA 1 over OLD MANS CREEK	Lateral Slide	Girder	Rural	New
I-215 at 4500 South	SPMT	Girder	Urban	New
I-80 Mount Delle	SPMT	Girder	Rural	Replace
I-80 over Echo Dam Road	Lateral Slide	Girder	Rural	Replace
I-80 Over 2300 East Ramp	Lateral Slide	Girder	Urban	New
I-40: Fourth Street Bridge	Lateral Slide	Girder	Urban	Replace

The dataset is designed to be easily updated with additional project data or fields, making it adaptable for future research and the development of cost-estimating tools for ABC bridge projects. The final list of collected ABC bridge projects for the lateral slides and SPMT bridges is shown in Table 3.7. By organizing and categorizing the dataset in this manner, the research provides a robust foundation for analyzing and estimating costs in ABC bridge projects, facilitating future advancements in construction methodologies and efficiency.

Table 3.7 Shortlist of ABC Bridge Dataset

Project Name (SN)	Construction Methods/Equipment	Location Type	Project Type	Deck Material	Beam Material	Type of Service	MIC	ADT	No of Lanes	No of Spans	Max Span Length (ft.)	Bridge Width	Bridge Length	Total Cost	Adjusted Cost/ sf 2024
IA 92 Over small stream	Lateral Slide	Rural	Replace	Concrete	Concrete	Highway	3	4480	2	3	91.8	44	234	\$ 3,200,000.00	\$525.73
LP 345 Lateral Slide	Lateral Slide	Urban	Replace	Concrete	Steel	Highway	2	31545	4	4	92.4	65	359.5	\$ 12,142,047.00	\$965.21
US-131 over 3 mile road	Lateral Slide	Rural	Replace	Concrete	Concrete	Highway	2	20300	2	1	83.6	57	85.9	\$ 4,000,000.00	\$1,395.24
MD213	Lateral Slide	Rural	Replace	Concrete	Concrete	Highway	2	17000	2	1	68	50	74	\$ 5,287,000.00	\$2,275.92
Route 44 over route 24	Lateral Slide	Urban	New	Concrete	Concrete	Highway	0	28006	6	2	83	104	166	\$ 19,900,000.00	\$1,403.24
Jacoby Creek Bridge	Lateral Slide	Rural	Replace	Concrete	Concrete	Highway	0	18125	2	3	23.9	43	73	\$ 1,893,671.68	\$569.84
Little field Bridge	Lateral Slide	Rural	Replace	Steel	Steel	Highway	4	9561	2	1	150	34	158	\$ 2,900,000.00	\$925.72
Hartford I-91 Bridge	Lateral Slide	Rural	New	Concrete	Steel	Highway	0	31000	2	1	127.9	45	136	\$ 2,547,786.00	\$735.59
I-94 2nd avenue	SPMT	Urban	New	Steel	Concrete	Highway	0	985	2	1	245	96.5	254	\$ 26,000,000.00	\$1,054.89
I-84 Bridge	Lateral Slide	Rural	Replace	Concrete	Concrete	Highway	2	13750	2	1	111.8	61.3	113	\$ 13,300,000.00	\$2,805.56
Bearcamp River Relief Brid	Lateral Slide	Rural	Replace	Concrete	Steel	Highway	1	10251	2	2	85	37	178	\$ 4,300,000.00	\$960.77
Bearcamp River Bridge	Lateral Slide	Rural	Replace	Concrete	Steel	Highway	1	10251	2	3	172.9	38	418	\$ 3,200,000.00	\$267.33
WB-224B	Lateral Slide	Rural	Replace	Concrete	Steel	Highway	1	22663	4	2	74.75	70.5	149.6	\$ 5,487,866.00	\$766.64
Blackhall Road	Lateral Slide	Urban	New	Concrete	Steel	Highway	4	7920	4	3	92.8	41.3	195	\$ 2,037,000.00	\$382.03
Route 1 over I-95	SPMT	Rural	Replace	Concrete	Steel	Highway	1	33000	5	2	120	77.5	270	\$ 14,800,000.00	\$839.30
State Route 30 A25	Lateral Slide	Urban	Replace	Concrete	Steel	Highway	1	21798	4	1	54	62.6	58	\$ 2,333,212.00	\$975.58
IA 1 over OLD MANS CREE	Lateral Slide	Rural	New	Concrete	Steel	Highway	0	5900	2	3	118	44	299	\$ 2,341,500.00	\$261.75
I-215 at 4500 South	SPMT	Urban	New	Concrete	Concrete	Highway	1	66,000	4	1	172	82	172	\$ 3,506,597.00	\$514.74
I-80 Mount Delle	SPMT	Rural	Replace	Concrete	Steel	Highway	1	51742	4	1	84	57	84	\$ 5,872,317.00	\$2,384.37
I-80 over Echo Dam Road	Lateral Slide	Rural	Replace	Concrete	Concrete	Highway	1	16000	2	1	80	40	80	\$ 1,550,000.00	\$874.06
I-80 Over 2300 East Ramp	Lateral Slide	Urban	New	Concrete	Concrete	Highway	1	72301	3	1	80	73	82	\$ 5,876,450.00	\$1,876.28
I-40: Fourth Street Bridge	Lateral Slide	Urban	Replace	Concrete	Concrete	Highway	2	25389	4	1	133.8	94.8	138	\$ 13,900,000.00	\$1,607.83

CHAPTER 4 - ANALYSIS OF COLLECTED DATA

4.1 Overview

This chapter presents a detailed analysis of the collected 22 ABC dataset and is organized in three main sections that provide (1) statistical analysis of the collected dataset, (2) correlation analysis between each variable and the bridge adjusted cost per square foot 2024, and (3) discussion of the main findings of the data analysis.

4.2 Statistical Analysis of Collected Dataset

A statistical analysis was conducted to evaluate the numerical variables in the collected dataset and analyze their distribution. This statistical analysis focuses on numerical variables of the dataset including Adjusted cost per square foot 2024, ADT, number of lanes, number of spans, maximum span length, bridge width, and bridge length. Table 4.1 provides a summary of the count, mean, standard deviation, minimum, 25th percentile, median, 75th percentile, and maximum for each of the numerical variables of the dataset. For example, the mean cost per square foot is \$1,107.62 while its standard deviation, minimum and maximum values are 700.1, 261.75, and 2805.56, respectively, as shown in Table 4.1.

Table 4.1 The results of descriptive statistics for Adjusted Cost/sf 2024, Max Span Length, Bridge Width and Length

Variable	Count	Mean	Standard Deviation	Minimum	25th Percentile	Median	75th Percentile	Maximum
Adjusted Cost/sf 2024	22	1107.62	700.1	261.75	611.27	943.25	1401.24	2805.56
ADT	22	23543.95	18801.33	985	10251	19212.5	30251.5	72301
Number of Lanes	22	3	1.23	2	2	2	4	6
Number of Spans	22	1.77	0.97	1	1	1	2.75	4
Maximum Span Length (ft.)	22	106.58	47.53	23.9	80.75	92.1	125.93	245
Bridge Width (ft.)	22	59.89	20.89	34	43.25	57	72.38	104
Bridge Length (ft.)	22	171.68	98.4	58	84.48	153.8	224.25	418

4.2.1 Distribution Analysis of Collected Dataset

In the distribution analysis, histograms and box plots are used to examine the distribution of key numerical variables. The histograms and box plots for the 22 collected data points regarding the adjusted cost per square

foot in 2024, ADT, No of Lanes, No of Spans, maximum span length, bridge width, and bridge length.

Most of the adjusted costs per square foot in 2024 for the projects are concentrated around the mean, although some projects exhibit significantly higher costs as shown in Figure 4.1. This indicates a right-skewed distribution, with outliers evident in the box plot which is shown in Figure 4.2. One of the outlier is the I-84 Bridge project, that has an adjusted cost of \$2,805.56 per square foot, which is considerably higher than other projects.

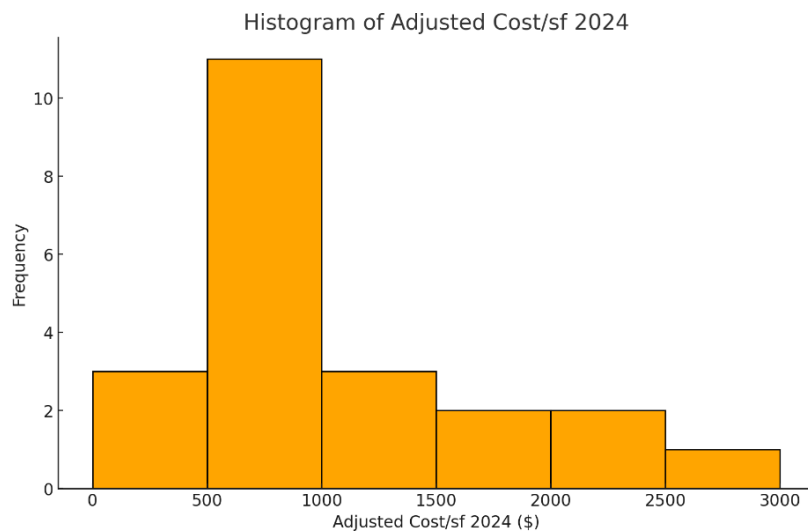


Figure 4.1 Histogram of Adjusted Cost/ sf 2024

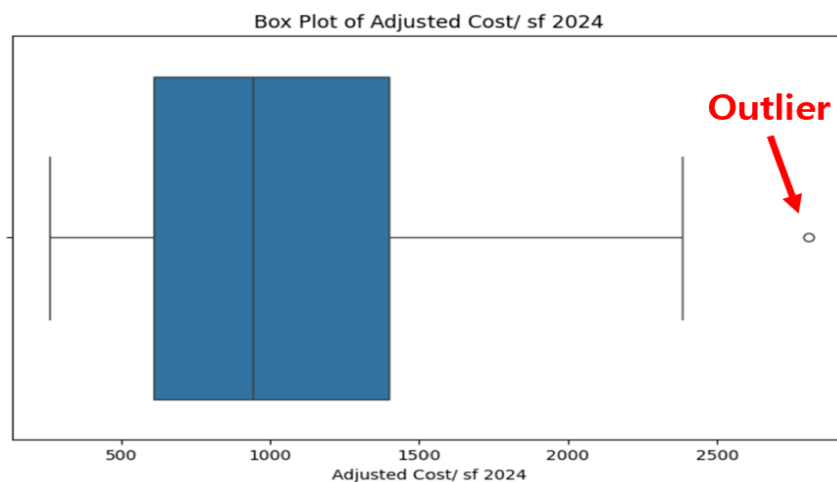


Figure 4.2 Box Plot of Adjusted Cost/ sf 2024

The histogram for ADT shows that most ADT values are concentrated between 0 and 30,000 as shown in Figure 4.3. However, there are a few projects with ADT values around 70,000, indicating that some projects have very high ADT values. The box plot in Figure 4.4 for ADT shows that the median is around 20,000. Two bridge projects with ADT values of approximately 70,000 are identified as outliers, representing projects with exceptionally high ADT values.

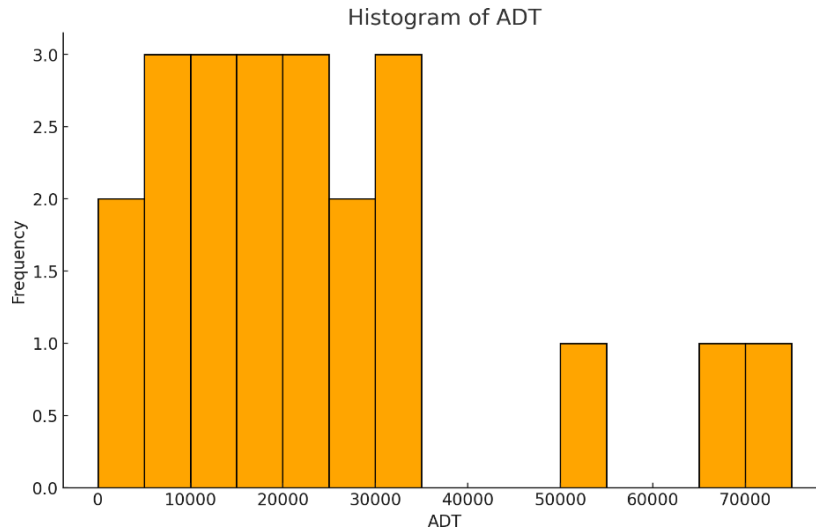


Figure 4.3 Histogram of ADT

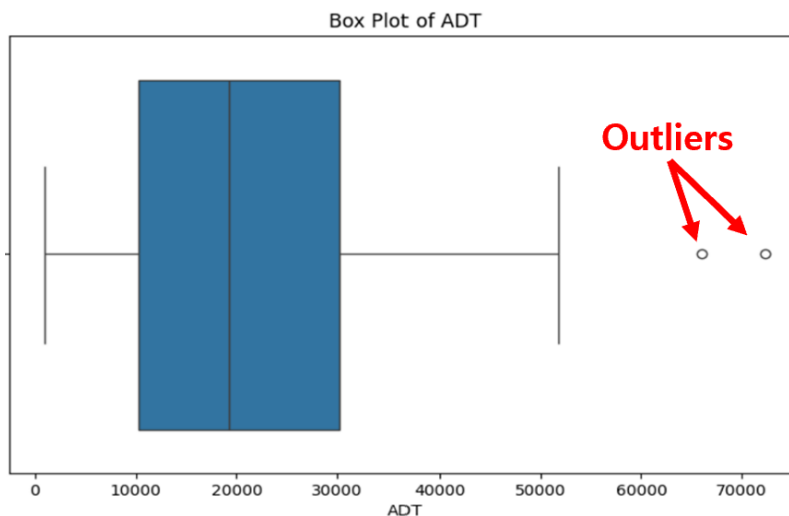


Figure 4.4 Box Plot of ADT

The histogram for the number of lanes shows that the majority of projects have 2 lanes, with 12 projects falling into this category as shown in Figure 4.5. There are also notable frequencies at 4 lanes, while fewer

projects have 3, 5, and 6 lanes. This distribution suggests that most bridges in the dataset are designed with either 2 or 4 lanes. The box plot in Figure 4.6 shows that the median number of lanes is 2, as shown by the line in the middle of the box. The interquartile range (IQR) extends from 2 to 4 lanes, indicating that the middle 50% of the data falls within this range. The whiskers extend to 6 lanes, and there are no outliers beyond this range. This plot highlights the central tendency and spread of the data, showing that the number of lanes is concentrated around 2 and 4 lanes.

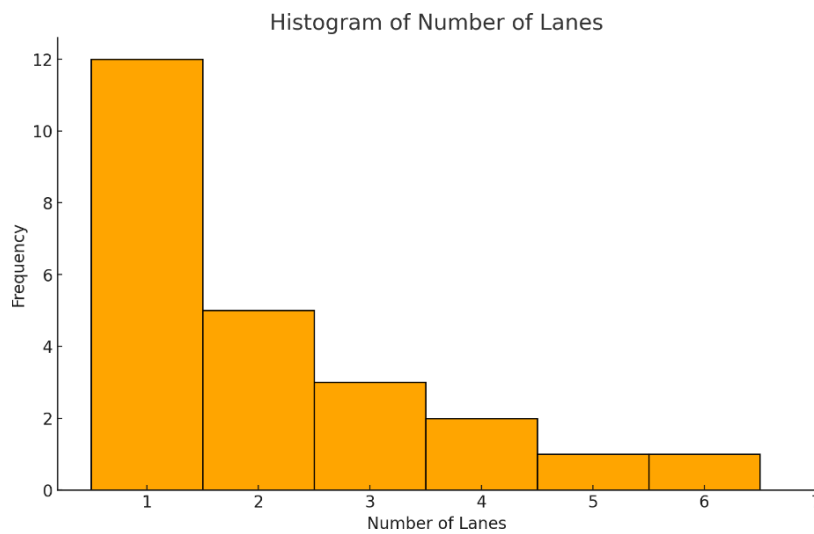


Figure 4.5 Histogram of Number of Lanes

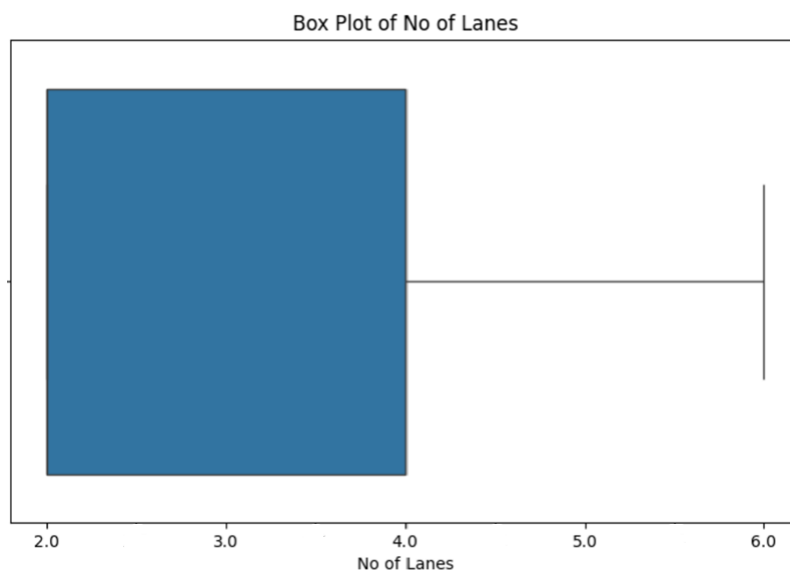


Figure 4.6 Box Plot of Number of Lanes

The histogram for the number of spans shows that the majority of projects have 1 span, with 12 projects falling into this category. There are also frequencies for projects with 2, 3, and 4 spans. This distribution suggests that most bridges in the dataset are designed with a single span, followed by projects with 3 spans as shown in Figure 4.7. The box plot in Figure 4.8 shows that the median number of spans is 1, as shown by the line in the middle of the box. The interquartile range (IQR) extends from 1 to 3 spans, indicating that the middle 50% of the data falls within this range. The whiskers extend to 4 spans, and there are no outliers beyond this range. This plot highlights the central tendency and spread of the data, showing that the number of spans is concentrated around 1 and 3 spans.

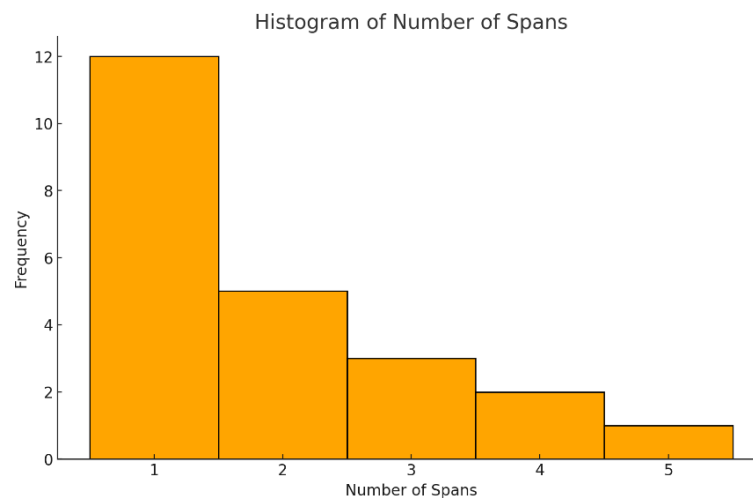


Figure 4.7 Histogram of Number of Spans

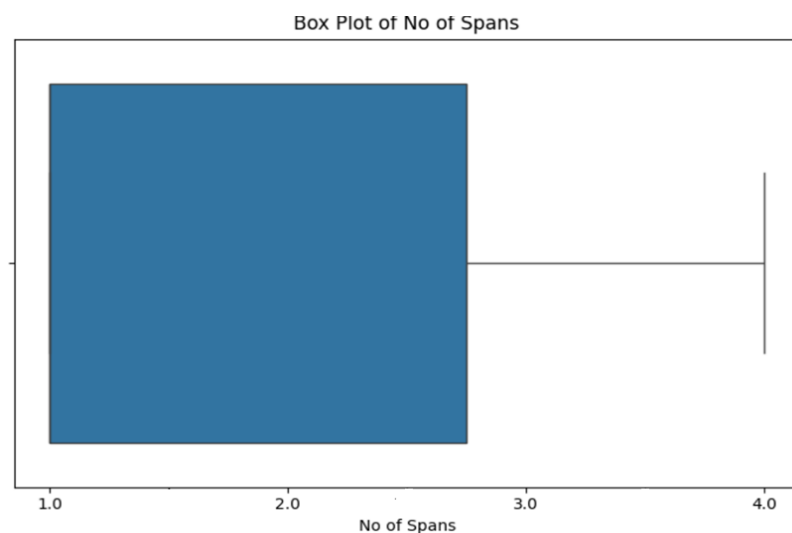


Figure 4.8 Box Plot of Number of Spans

The histogram and box plot for maximum span length show that this variable follows a relatively normal distribution, though some projects have abnormally long spans as shown in Figure 4.9 and 4.10 respectively. The I-94 2nd Avenue project has a maximum span length of 245 feet, which is identified as an outlier beyond the typical range of span lengths.

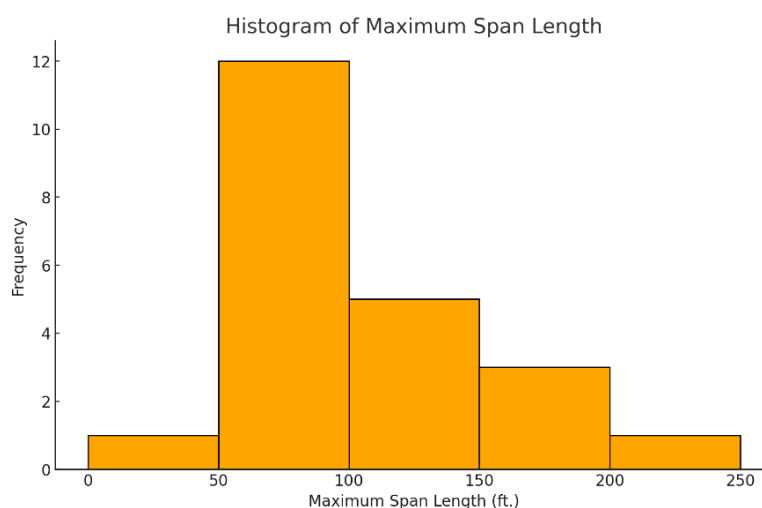


Figure 4.9 Histogram of Max Span Length (ft.)

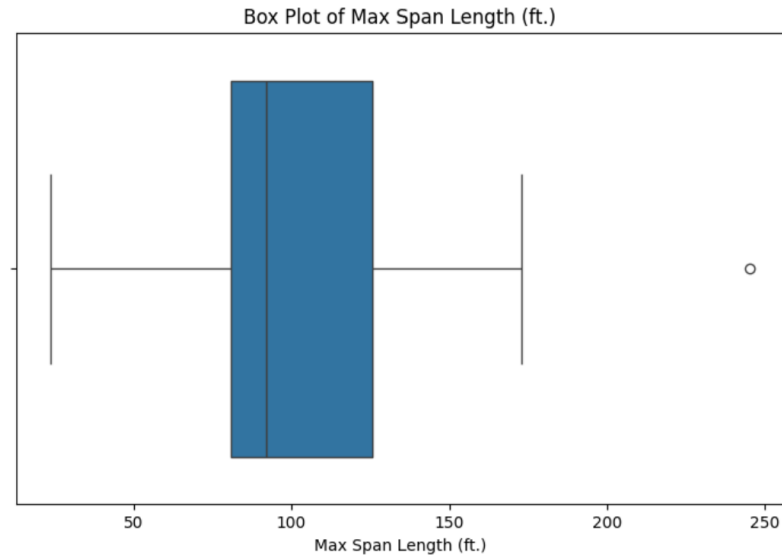


Figure 4.10 Box Plot of Max Span Length (ft.)

Most of the data points of bridge width and length clustered around the mean as shown in Figure 4.11 and 4.12 respectively, while the box plot for the bridge width and length highlights a few outliers as shown in Figure 4.13 and 4.14. This suggests that some projects have significantly wider bridges compared to others.

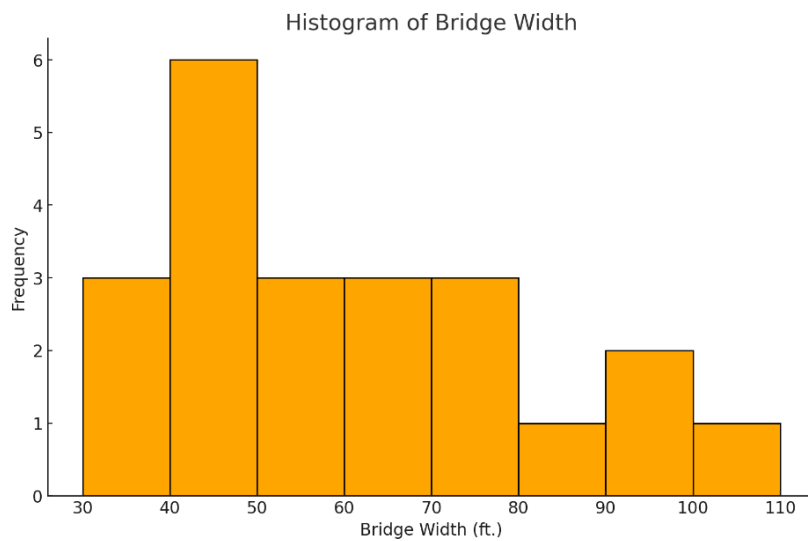


Figure 4.11 Histogram of Bridge width

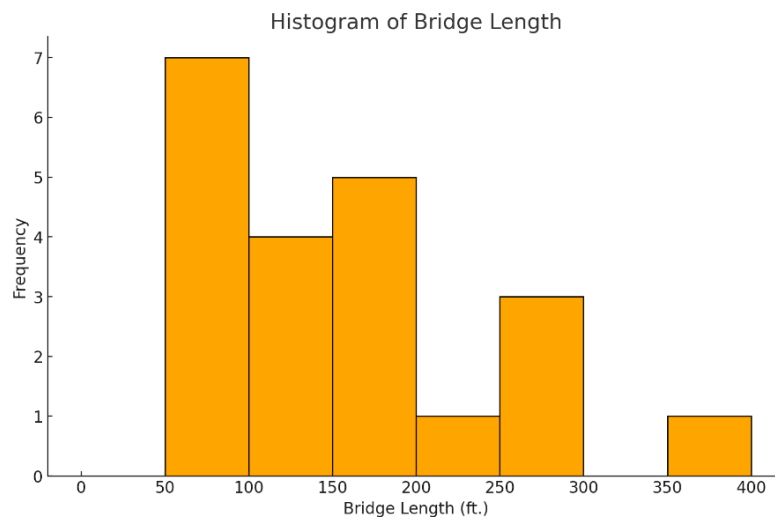


Figure 4.12 Histogram of Bridge Length

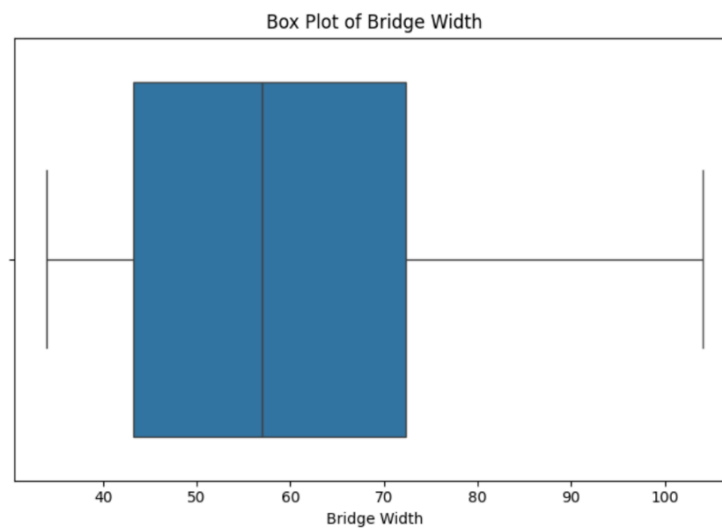


Figure 4.13 Box Plot of Bridge Width

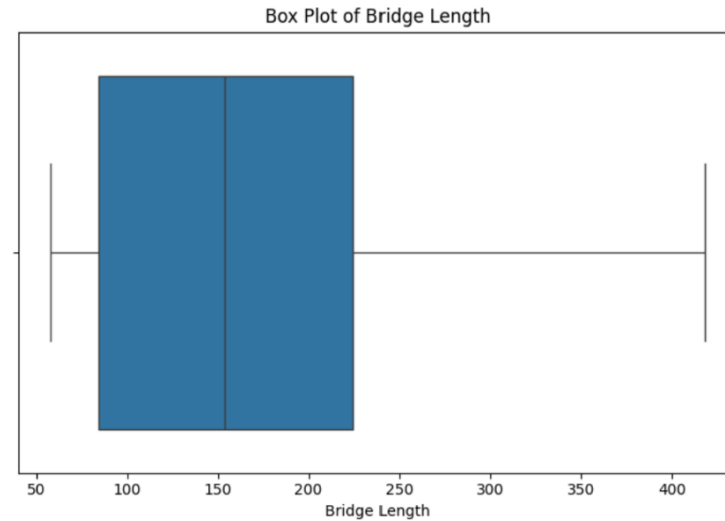


Figure 4.14 Box Plot of Bridge Length

4.2.2 Normality Test of Collected Dataset

The objective of the normality test is to evaluate whether the collected 22 ABC bridge data points follow a normal distribution. If the data do not follow a normal distribution, the reliability and validity of subsequent correlation analysis results may be compromised. The Q-Q plot (Quantile-Quantile) was used as the normality test tool because it is simple, intuitive, and allows for a visual assessment of whether the data follow a normal distribution (Nasrollahi, 2015). Q-Q plots were made for the adjusted cost per square foot in 2024, maximum span length, bridge width, and bridge length. Each Q-Q plot compares the observed quantiles of the data against the theoretical quantiles of a normal distribution.

For the adjusted cost per square foot in 2024, the Q-Q plot is shown in Figure 4.15. The plot shows that most data points lie along the reference line, indicating that the adjusted costs are approximately normally distributed. However, a few data points deviate from the line, suggesting the presence of outliers.

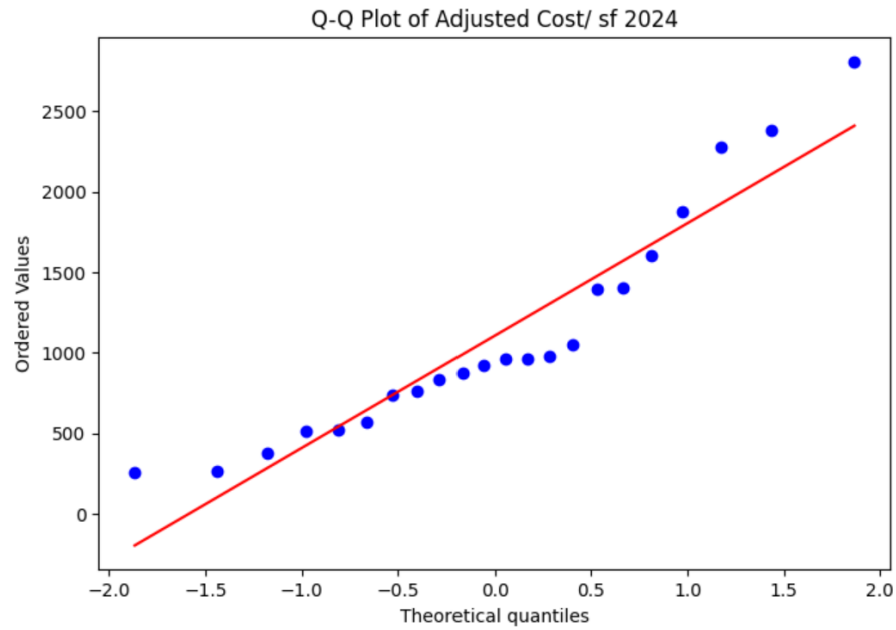


Figure 4.15 Q-Q Plot of Adjusted Cost/sf 2024

The Q-Q plot for ADT shows that many data points are located around the diagonal line, suggesting that the ADT data follows a normal distribution. However, several high ADT values significantly deviate from the line, indicating the presence of outliers as shown in Figure 4.16.

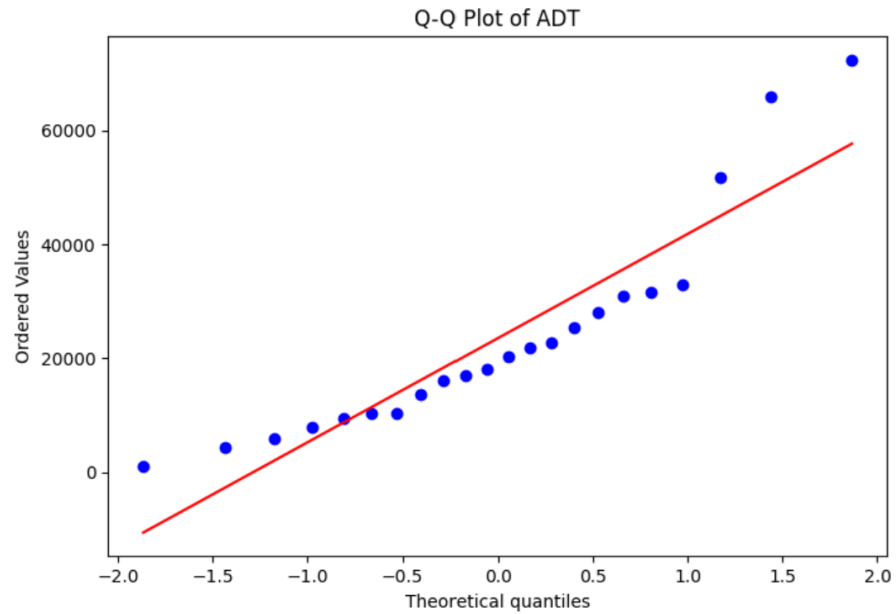


Figure 4.16 Q-Q Plot of ADT

The Q-Q plot for the number of lanes indicates that most data points deviate from the diagonal line, showing

that the number of lanes does not follow a normal distribution. Instead, the data points are clustered at specific values, such as 2, 4, and 6 lanes, which is expected for categorical data like the number of lanes as shown in Figure 4.17.

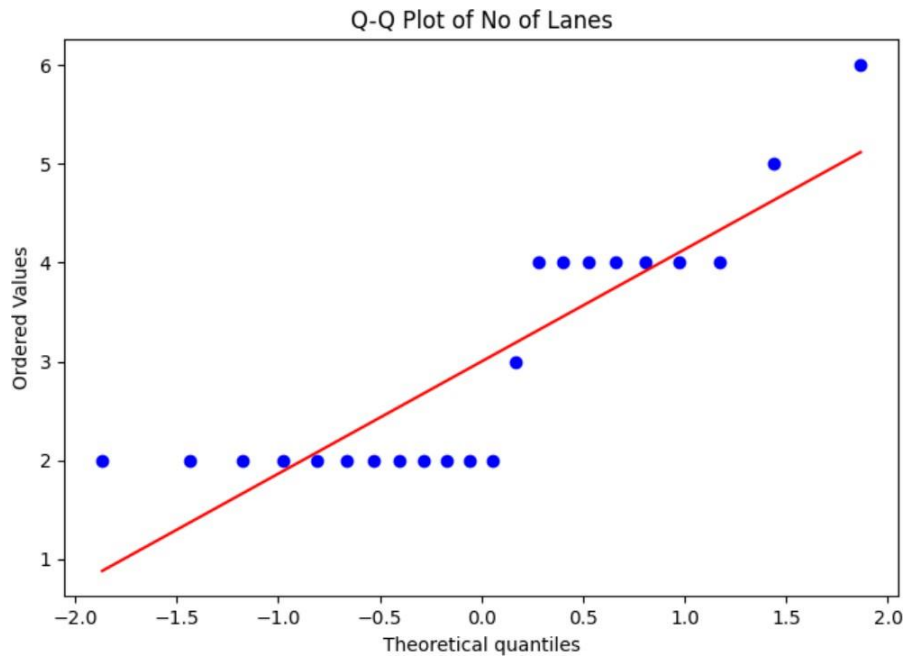


Figure 4.17 Q-Q Plot of Number of Lanes

The Q-Q plot for the number of spans indicates that most data points deviate from the diagonal line, showing that the number of spans does not follow a normal distribution. Instead, the data points are clustered at specific values, such as 1, 2, 3, and 4 spans, which is expected for categorical data like the number of spans as shown in Figure 4.18.

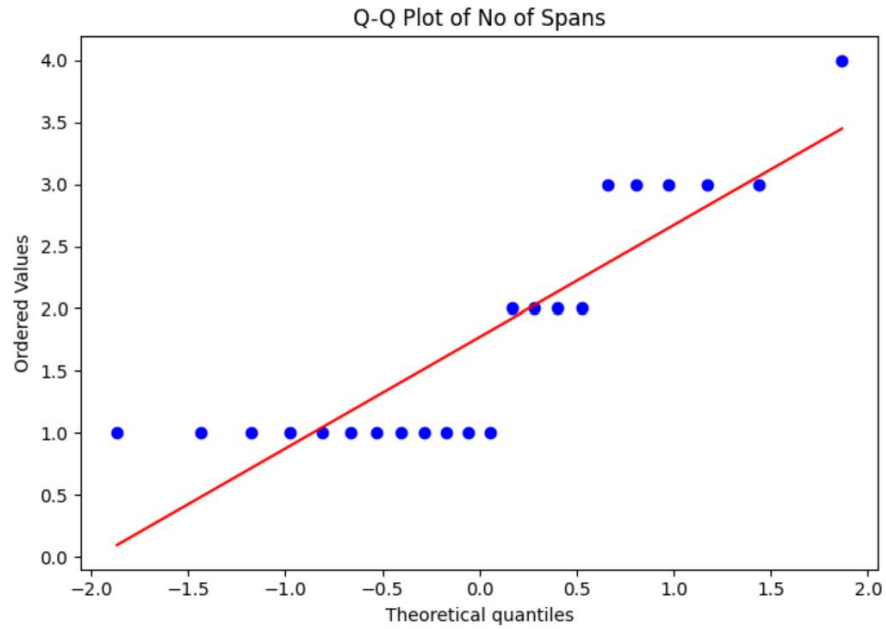


Figure 4.18 Q-Q Plot of Number of Spans

The Q-Q plot for maximum span length indicates that the data is fairly normally distributed, with most points following the reference line closely. There are some deviations at the tails, which suggest potential outliers or slight skewness in the data as shown in Figure 4.19.

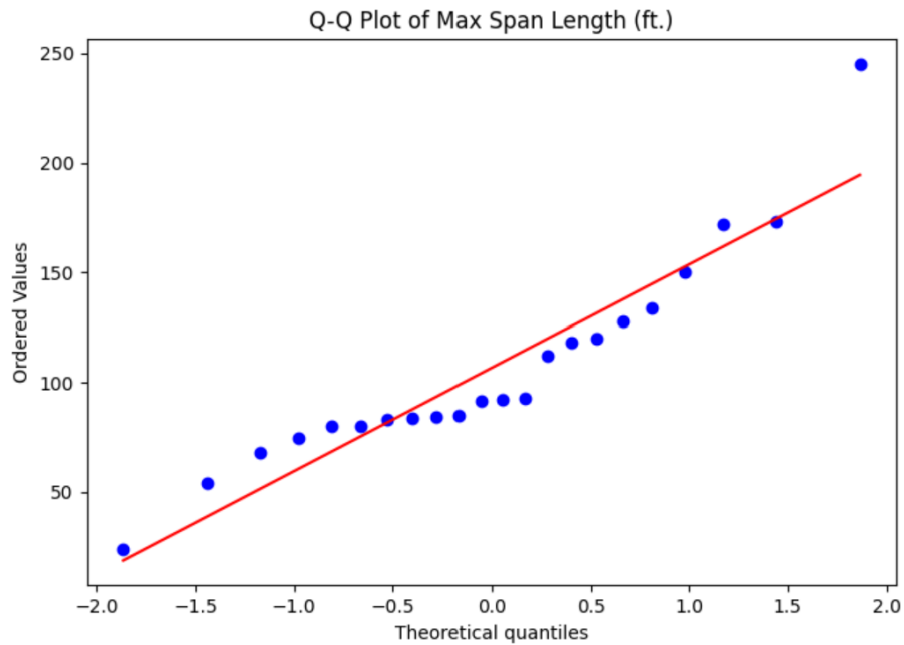


Figure 4.19 Q-Q Plot of Max Span Length

The Q-Q plot for bridge width shows that the data points generally follow the reference line, indicating normality. However, a few points deviate significantly, indicating the presence of outliers as shown in Figure 4.20.

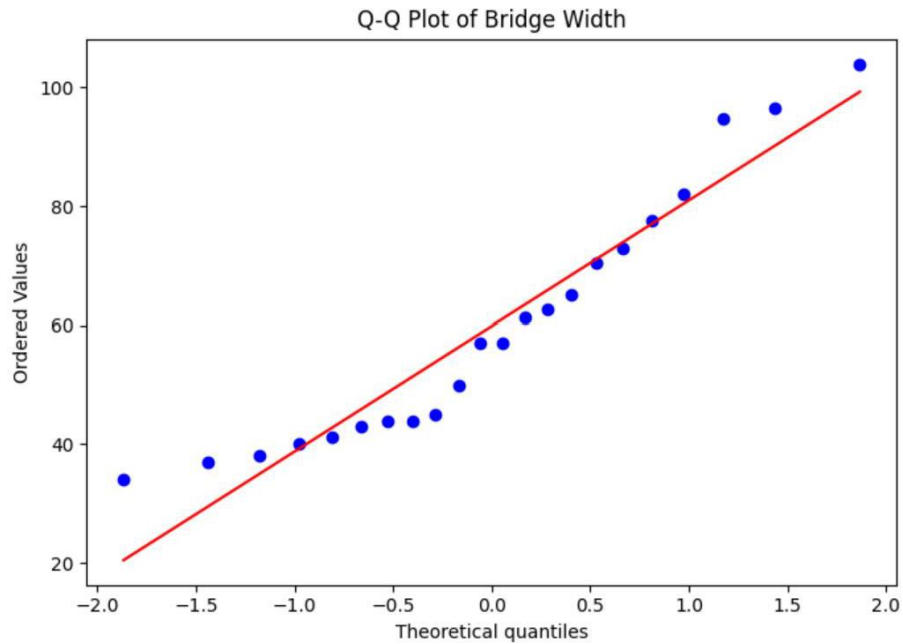


Figure 4.20 Q-Q Plot of Bridge Width

The Q-Q plot for bridge length suggests that the data is approximately normally distributed, but there are notable deviations at the tails. These deviations indicate potential outliers and skewness in the data as shown in Figure 4.21.

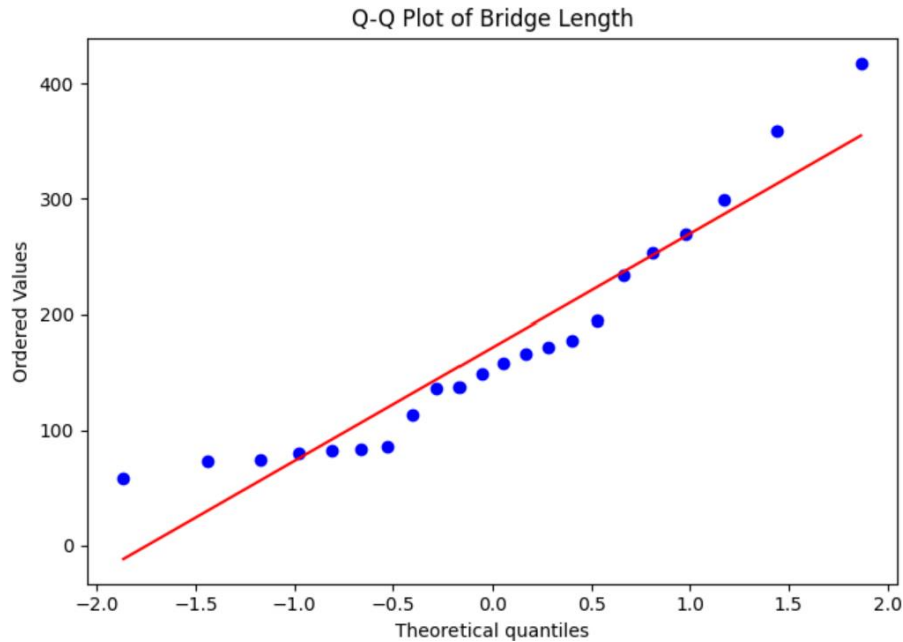


Figure 4.21 Q-Q Plot of Bridge Length

The Q-Q plot analysis indicates that the collected data generally follow a normal distribution across most variables. However, some variables exhibit outliers, which should be removed when using this data in the cost estimation tool.

4.3 Correlation Analysis of Collected Dataset

This task focuses on analyzing the correlation between Adjusted Cost per Square Foot 2024 and other dependent variables in the dataset. Correlation analysis helps to understand the strength and direction of the relationship between two variables. A correlation coefficient (ranging from -1 to 1) indicates the nature of this relationship: values close to 1 suggest a strong positive relationship, values close to -1 suggest a strong negative relationship, and values around 0 suggest no linear relationship (Thatte, 2017).

The primary tool used for correlation analysis was the Pearson correlation coefficient, which measures the linear relationship between two variables and provides a value between -1 and 1. Adjusted Cost per Square Foot 2024 was selected as the dependent variable and all other relevant numerical variables as dependent

variables, which excluding variables such as Zip Code and Year Built to focus on more impactful factors. Using statistical software, the Pearson correlation coefficient was calculated for each pair of variables using the equation shown in Eq 4.1.

$$r = \frac{\sum (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum (x_i - \bar{x})^2 \sum (y_i - \bar{y})^2}} \quad (4.1)$$

Where x_i and y_i are the values of the two variables, and $\bar{x}$ and $\bar{y}$ are their respective means (Thatte, 2017). To determine the statistical significance of the correlation coefficients, hypothesis testing was conducted, considering a p-value less than 0.05 as statistically significant. This indicated a strong likelihood that the observed correlation was not due to random chance. This methodology ensured that the correlation analysis was thorough, accurate, and meaningful.

The results of the correlation analysis between adjusted cost per square foot 2024 and other variables are summarized in Table 4.2. The correlation coefficient between MIC and adjusted cost per square foot 2024 is 0.659 which shows positive correlation between the two variables, as shown in Table 4.2. Similarly, the result shows positive correlation between the adjusted cost per square foot in 2024 and MIC, ADT, and bridge width, respectively, as shown in Table 4.2. The results also show negative correlation between the adjusted cost per square foot in 2024 and number of spans, maximum span length, and bridge length. On the other hand, the result shows no correlation between the adjusted cost per square foot in 2024 and number of lanes. These correlation analysis results suggest that the adjusted cost per square foot of the bridges in the dataset are positively affected by MIC, ADT, and bridge width; and negatively affected by number of spans, maximum span length, and bridge length.

Table 4.2 Correlation analysis summary between adjusted cost per square foot 2024 and other variables

Variable	Correlation with Adjusted Cost/ sf 2024
MIC	0.659
ADT	0.136
Number of Lanes	-0.003
Number of Spans	-0.545
Maximum Span Length (ft.)	-0.115
Bridge Width	0.39
Bridge Length	-0.472

4.4 Discussion of the Main Findings of the Data Analysis

The statistical analysis revealed significant variability in variables such as adjusted cost per square foot (2024), max span length, bridge width, and bridge length. For example, the mean adjusted cost per square foot in 2024 was \$1,107.62, with a standard deviation of \$700.10, indicating considerable diversity in project costs.

The distribution analysis using histograms and box plots showed that most projects had costs concentrated around the mean, but some projects exhibited higher costs, indicating a right-skewed distribution. For instance, the I-84 Bridge project had an adjusted cost of \$2,805.56 per square foot, identified as an outlier. Similar variability and outliers were observed in the distributions of ADT, number of lanes, number of spans, max span length, bridge width, and bridge length. The normality test using Q-Q plots indicated that most variables approximately followed a normal distribution, although some variables had notable outliers.

The correlation analysis identified correlations between Adjusted Cost per Square Foot (2024) and other variables. For example, the adjusted cost per square foot had a positive correlation of 0.659 with MIC and a weak positive correlation of 0.136 with ADT. On the other hand, the adjusted cost per

square foot had no or minor correlation with other variables such as a number of lanes that had a correlation coefficient of 0.003.

The analysis of the collected bridge dataset provided detailed insights into the distribution, correlations, and characteristics of key variables. Significant variability and notable outliers were observed in project costs and dimensions. These findings highlight important factors to consider in further analysis and the application of the ABC bridge cost estimation tool.

CHAPTER 5 - CONCLUSIONS

5.1 Summary

This research focused on enhancing cost estimation methods for Accelerated Bridge Construction (ABC) projects through data collection, analysis, and integration. The research aimed to address the limitations of existing cost estimation tools by expanding the dataset and supplementing the developed decision support tools (DST). The primary objectives included conducting a literature review, collecting data on recently constructed ABC projects especially for the lateral slide and SPMT bridge project, analyzing and integrating this data. The findings demonstrated significant variability in project costs and dimensions and established strong correlations between key variables.

5.2 Research Contribution

The contributions of this research are manifold. Firstly, it expanded the dataset for ABC projects, strengthening the foundation of cost estimation models and enhancing the accuracy and reliability of cost predictions for lateral slide bridge projects. Secondly, it identified significant correlations between key variables, such as adjusted cost per square foot and mobility impact category (MIC), providing valuable insights for decision-makers. These contributions are expected to help state Departments of Transportation supplement more accurate and reliable DSTs, improving project planning and cost management.

5.3 Future Research Work

Future research should focus on further expanding the dataset to include more ABC projects, particularly those employing methods such as Self-Propelled Modular Transporters (SPMT) and prefabricated bridge elements. Additionally, exploring advanced machine learning techniques could

improve the accuracy of cost estimation models. Investigating the impact of environmental and site-specific factors on construction costs would also be beneficial. Finally, developing user-friendly software tools that incorporate these advanced models and datasets will facilitate their practical application in real-world bridge construction projects, enabling more informed decision-making and efficient resource allocation.

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