BE935 Assessment of Structural Steel Coating Applications

Final Report

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Submitted By

Lu Zhang, Xuan Lv, Kingsley Lau, Subramanian Viswanathan, Muyun Li, and Parasar Gosain,
Florida International University
10555 W Flagler St., Miami, FL 33174

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16. Abstract

Research shows that even with the continuous development of coating technology, coating systems are still susceptible to deterioration and thus unable to provide protection for the long-term designed bridge service life. Recent advancement on data analytics offers an opportunity to leverage the wealth of historical data processed by State Departments of Transportation (DOTs) for improved understanding of coating premature failures. However, the coating-related data (e.g., coating condition data, coating application data) are stored in heterogeneous and unstructured formats (e.g., PDF) with limited data analytics capability. Therefore, better management of the data related to coating systems is needed. To address the need, this project focuses on developing a database system for steel bridge coating systems, which is able to integrate all the relevant but heterogeneous data and allows users to identify and correlate the factors that result in premature coating failures. Users can easily search for, add, edit, delete, or analyze coating-related data through the database. The database system can support more systematic data-driven analysis of coating premature failures, which will lead to new knowledge on factors that impact coating performance and potentially better practices that improve coating lifespans in the field.

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EXECUTIVE SUMMARY

1.1 Background

Corrosion is a major concern for long-term durability and structural integrity of steel components of highway bridges. Approximately 15% of all bridges are structurally deficient due to corrosion (Koch et al., 2002). Out of the approximately 583,000 highway bridges in the United States, 200,000 are steel bridges. Damage to the steel bridge superstructure can be exacerbated when it is unprotected or inadequately protected from the environment. The application of protective coatings has been widely used to protect structural steel from corrosion. Different coating systems for corrosion protection of steel bridges have been developed and implemented over time due to the changes in environmental and health regulations, economics, and advances in technology. However, even with the continuous development of coating technology, coating systems are still susceptible to deterioration and thus unable to provide protection for the long-term designed bridge service life. According to the Florida Department of Transportation (FDOT) Bridge Work Plan reports from fiscal years 2004 to 2015, replacement of steel bridge paint systems typically occupied a significant part of the total repair plan. Furthermore, maintenance of steel bridge coating, including coating removal, containment, and application, is costly. Of the estimated $8.3 billion cost of corrosion in highway bridges in the U.S., half a billion dollars is expended for coating maintenance of highway steel bridges. The annual costs in the state of Florida typically exceed $25 million in addition to the initial painting costs associated with new steel bridges (Pouliotte, 2014, Clarke, 2016).

The large bridge inventory and the decentralized organization of FDOT by districts may encumber retention of institutional knowledge of field coating material degradation and performance. Significant historical data and information are available in the routine bridge inspections and other reports (e.g., maintenance contract, cost summary). These data may include geographic information of bridges, bridge structural conditions, types of steel surface preparation, types of coating systems, service conditions, project-specific modifications to standard requirements, and maintenance and repair methods and costs. However, these data from heterogenous sources may often be disconnected from each other.

Recent advancements in data analytics (e.g., database system, machine learning algorithms) offers an opportunity to leverage the wealth of historical data processed by FDOT for improved understanding of premature coating failures. Currently, many reports (e.g., bridge inspection report) are stored in portable document format (PDF) with limited search and data analytics capability. The reports and documents are different in content, structure, and description methods. In addition, the lengthy reports and documents often make data extraction and analytics extremely challenging and time-consuming as data cleaning and organization is a troublesome procedure. Extracting and analyzing unstructured data for relevant knowledge is not an easy process. Therefore, there is sorely a need to develop a steel bridge coating database which is able to integrate all the relevant but heterogeneous data and allows users to identify and correlate the factors that result in premature coating failures.

1.2 Project Goal and Objectives

To address this need, this project aims to gather, catalog, and assess historical data available at the FDOT District level with the goal of creating a database capable of identifying and correlating the factors that result in premature coating failures. Furthermore, the project provides recommendations on data that should be required input for an effective, electronic database on all new construction and maintenance projects with coating related activities. The specific objectives of this project are to:

- Identify factors that affect premature coating failures by extracting and analyzing information on the historical use of various bridge coating systems.
- Develop a Web-based digital database on statewide steel bridge coatings data that is capable of correlating the factors that result in premature coating failures.
- Analyze the data and provide assessment of the factors that contribute to premature coating failures, thus offering recommendations on potential areas where FDOT can improve in terms of how coating materials and application requirements are specified.
- Provide recommendations on required data input for an effective electronic database on all future new construction and maintenance projects with steel bridge coating-related activities.

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LIST OF ACRONYMS AND ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Official
DOT	Department of Transportation
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
FIU	Florida International University
ML	Machine Learning
NACE	National Association of Corrosion Engineers
SBC	Steel Bridge Coating
SSPC	The Society for Protective Coatings

CHAPTER 1. INTRODUCTION

1.1 Background

Corrosion is a major concern for long-term durability and structural integrity of steel components of highway bridges. Approximately 15% of all bridges are structurally deficient due to corrosion (Koch et al., 2002). Out of the approximately 583,000 highway bridges in the United States, 200,000 are steel bridges. Damage to the steel bridge superstructure can be exacerbated when it is unprotected or inadequately protected from the environment. In particular, aggressive marine environments that contain a high concentration of coastal airborne salt can expedite corrosion. To address these problems, application of protective coatings has been widely used for corrosion mitigation of structural steel. Different coating systems for corrosion protection of steel bridges have been developed and implemented over time due to the changes in environmental and health regulations, economics, and advances in technology. Coating system developments include not only the material, but also its application and steel surface preparation requirements. However, even with the continuous development of coating technology, coating systems are still susceptible to deterioration and thus unable to provide protection for the long-term designed bridge service life. According to the Florida Department of Transportation (FDOT) Bridge Work Plan reports from fiscal years 2004 to 2015, replacement of steel bridge paint systems typically occupied a significant part of the total repair plan. Figure 1-1 shows a summary of the planned repair actions and the number of bridges slated to have each of the repair actions for fiscal year 2015, where it can be seen that the greatest number of repair actions was for paint system replacement. Periodic maintenance of coatings is required for additional service life against the exposure to the surrounding environment. Any coating system will inevitably require some form of repair due to the elapse of its service life or due to premature damage during service.

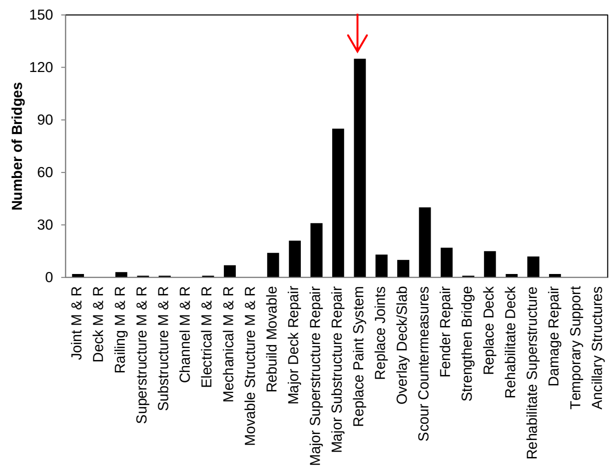

Figure 1-1. Summary of Listed Bridge Repair Actions (Lau et al., 2018).

The long-term effectiveness of coating systems is of major importance to reduce maintenance cost. Not only should the coating system provide adequate corrosion control and meet environmental and health regulations, but the coating durability should be commensurate with the bridge design life. Selection of a coating material and compatible repair coating materials as well as proper preparation of the surface are critical for proper protection from environmental exposure. Appropriate surface preparation and identification of environmental exposure parameters such as humidity, surface moisture, air-born salt contamination, and their effects on coating physical properties and corrosion mitigation should be considered. However, the field performance history showed that the steel bridges often require repainting long before the end of their expected service life, and the results from the available FDOT bridge inspection reports imply that conventional paint coatings may require early maintenance. Figure 1-2 shows the age distribution of ~500 repainted steel bridges from the Bridge Work Plan for the period of 2008 to 2015. More than 50% of the repainted bridges had been in service for less than 30 years. The typical recommendation of spot painting for the deteriorated portion of the bridge paint was at condition state 2. As shown in Figure 1-3 for a sampling of bridges, bridges in condition state 2 were reported at the age as low as ~15 years. Full repairs are recommended at higher degradation states (2 to 3) when a substantial portion of the bridge paint deteriorated. This level of degradation has been recorded in sometimes less than 25 years. Level 4 conditions have also been reported in less than 25 years of age. It is apparent that actual service time of bridge coatings can be significantly less than the expected service life for the material. Available research on application susceptibility and coating durability in various aggressive environmental conditions does not provide good prognosis for long-term durability in actual service due to the many material, application, and service variables.

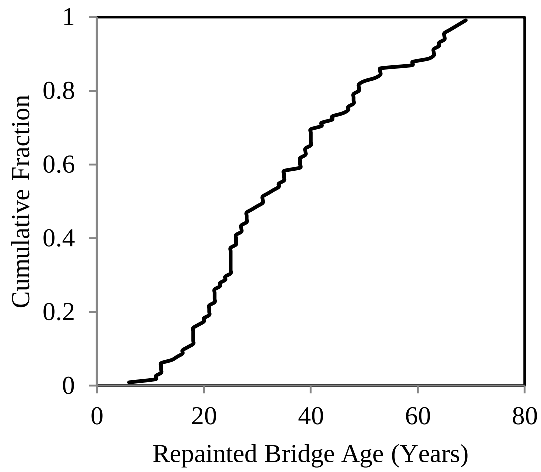

Figure 1-2. Age Distribution of Repainted Bridges (Work Plan 2004-2015) (Lau et al., 2018).

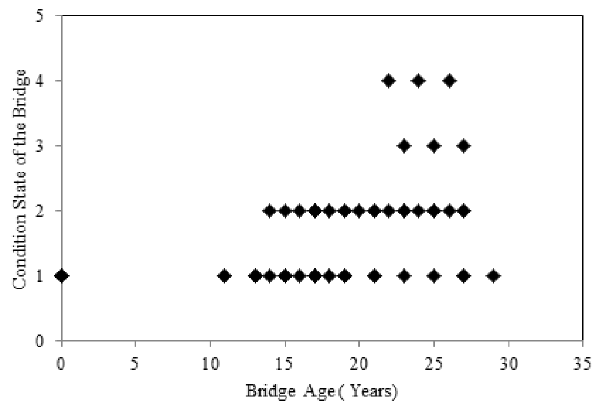

Figure 1-3. Bridge Condition State as a Function of Bridge Age (Lau et al., 2018).

Furthermore, maintenance of steel bridge coating, including coating removal, containment, and application, is costly. Of the estimated $8.3 billion cost of corrosion in highway bridges in the US, half a billion dollars is expended for coating maintenance of highway steel bridges. The number of bridges repainted and the corresponding costs in Florida are shown in Figure 1-4. The annual costs typically exceed $25 million in addition to the initial painting costs associated with new steel bridges (Pouliotte, 2014; Clarke, 2016).

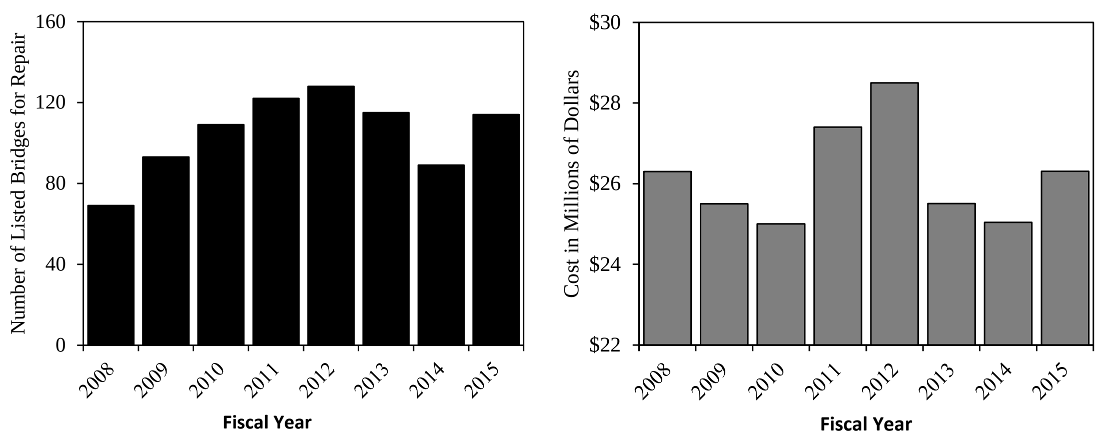

Figure 1-4. FDOT Cost for Steel Bridge Repainting (Lau et al., 2018).

The large bridge inventory and the de-centralized organization of FDOT by districts may encumber retention of institutional knowledge of field coating material degradation and performance. Significant historical data and information are available in the routine bridge inspections and other reports (e.g., maintenance contract, cost summary). These data may include geographic information of bridges, bridge structural conditions, types of steel surface preparation, types of coating systems, service conditions, project-specific modifications to standard requirements, and maintenance and repair methods and costs. However, these data from heterogenous sources may often be disconnected from each other. For example, coating performance data is not connected to the coating maintenance history or costs, thus resulting in difficulties for identifying and assessing the factors contributing to premature coating failures.

Recent advancement on data analytics (e.g., database system, machine learning algorithms) offers an opportunity to leverage the wealthy historical data processed by FDOT for improved understanding of premature coating failures. Currently, many reports (e.g., bridge inspection report) are stored in portable document format (PDF) with limited search and data analytics capability. The reports and documents are different in content, structure, and description methods. In addition, the lengthy reports and documents often make data extraction and analytics extremely challenging and time-consuming as data cleaning and organization is a troublesome procedure. Extracting and analyzing unstructured data for relevant knowledge is not an easy process. Therefore, there is sorely a need to develop a steel bridge coating database, which is able to integrate all the relevant but heterogeneous data and allows users to identify and correlate the factors that result in premature coating failures.

The Florida Department of Transportation (FDOT), which is charged to manage the state's bridges, develop long range plans, and recommend bridge investment and policy decisions, seeks to advance the understanding of factors that contribute to premature coating failures. The development of the steel bridge coating database will allow users to review bridge conditions, identify coating materials for various environments, and examine costs and frequencies of bridge coating maintenance and repair activities. It will also lead to long-term benefits on state bridge data management since data input recommendations will be provided to all new construction and maintenance projects with steel bridge coating related activities. This project has the potential to allow beneficial changes to the coating materials and application requirements of Florida bridges. The expected benefits of decisions based on the results (such as specification changes) is longer service of coatings, thus significant reduction in annual maintenance costs related to coating failures. Coatings on steel bridges will last longer (in line with expected service life) and less money will be spent on repainting work.

1.2 Project Goal and Objective

Research is needed to gather, catalog and assess historical data available at the FDOT District level with the goal of creating a database capable of identifying and correlating the factors that result in premature coating failures. To limit the scope of the project, the project focuses on collecting and analyzing the historical data of a selected sample of bridges in District 6. Besides gathering and assessing historical data, the research provides recommendations on data that should be required input for an effective, electronic database on all new construction and maintenance projects with coating related activities. The specific objectives of this project are to:

- Identify factors that affect premature coating failures by extracting and analyzing information on the historical use of various bridge coating systems.
- Develop a web-based digital database on statewide steel bridge coatings data that is capable of correlating the factors that result in premature coating failures.
- Analyze the data and provide assessment of the factors that contribute to premature coating failures, thus offering recommendations on potential areas where FDOT can improve in terms of how coating materials and application requirements are specified.
- Provide recommendations on required data input for an effective, electronic database on all future new construction and maintenance projects with steel bridge coating related activities.

1.3 Research Approach

A serious of interrelated tasks were conducted to accomplish the above-mentioned research objectives. Various methods were used for each research task. Figure 1-5 presents an overview of the research tasks with the research approaches.

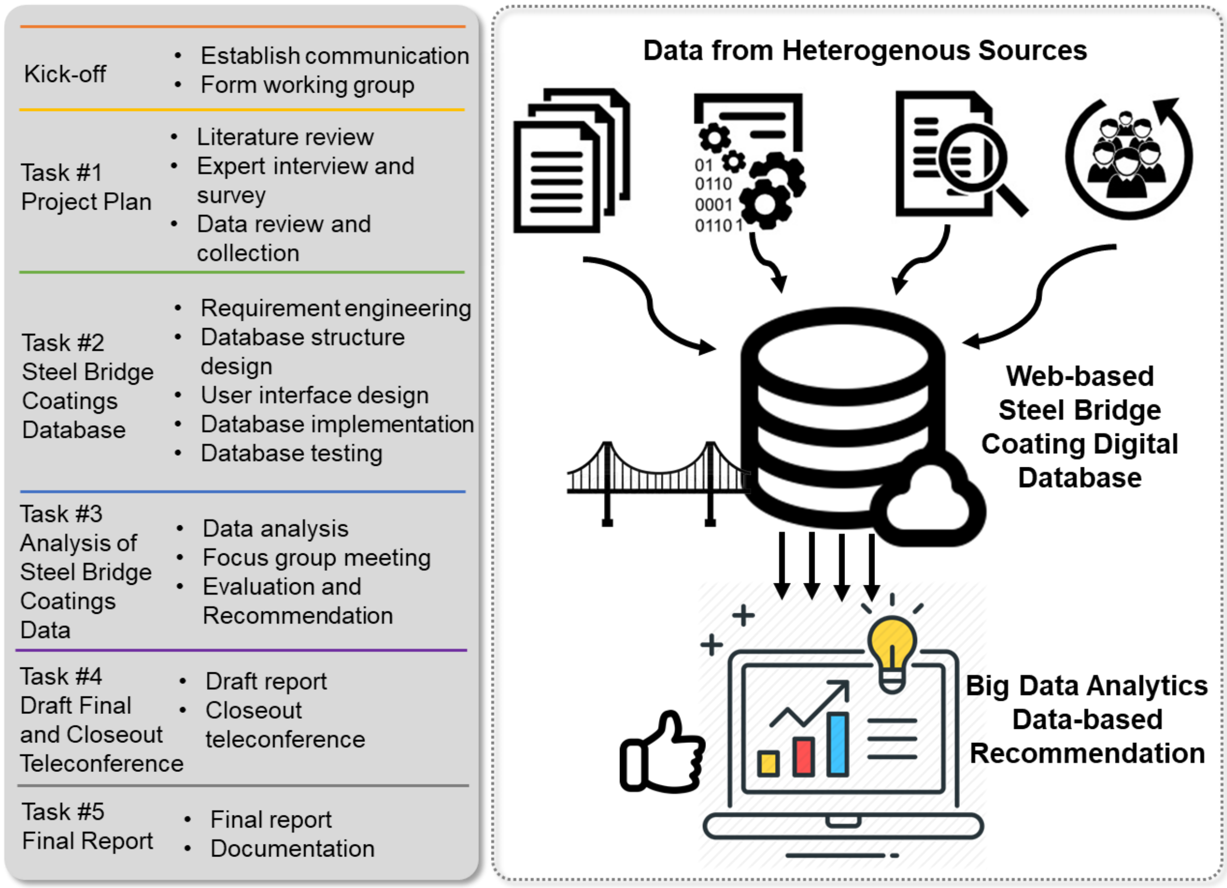

Figure 1-5. Project Overview.

The project started by creating a detailed plan that includes the types of data and methods that would be used for data collection. The project team first identified and understood the historical steel bridge coating data available at the FDOT District level. To do that, the project team adopted both theoretical and empirical approaches. For the theoretical approach, the project team conducted a comprehensive literature review focusing on factors that lead to premature coating failures. Potential contributing factors include the type of steel surface preparation, type of coating system, service conditions (environment), project-specific modifications to standard requirements, and repair methods for correcting non-conformances (e.g., Lau et al., 2018, Chang et al., 2000, Toubia and Emami, 2016). The Transportation Research International Documentation (TRID) and the Research in Progress (RIP) online databases were reviewed to identify and obtain relevant research projects, reports, and papers in the areas of steel bridge coating, coating premature failures, coating data analytics, coating performance assessment, coating performance forecasting, and policies and regulations pertaining to steel bridge coating systems. Besides the theoretical analysis on existing research and projects, the project team conducted empirical studies that involves systematic expert interviews and surveys with FDOT district engineers. These interviews and surveys aim to understand (1) the types of data available, and (2) the requirements of database design (e.g., expected database functions, expected user interface) by systematically soliciting input from district engineers. Structured surveys were used so the exact same questions in the same order were included to ensure systematic collection of input from FDOT engineers. The project team then reviewed the various types of data available at the FDOT district level. The data include all relevant information related to steel bridge coating, such as performance, environment, and cost. Such data may include existing bridge inventory data, surface preparation data, coating data, environmental data, inspection data, maintenance and repair record, maintenance and repair cost, and etc. These relevant data were gathered and catalogued for database design and data analytics.

In the next stage, the project team designed and developed a digital database of steel bridge coating (SBC) data. The SBC database has a graphical user interface to facilitate locating the data that are relevant to the state steel bridge coating systems. In addition, the database offers analytics functions that allow users to select, analyze, and visualize the data in different ways based on their needs. The database provides access to pertinent bridge identification information, relevant inspection and construction documents, historical coating conditions, bridge work plans, and coating cost. It also offers access to the relevant environmental data.

The SBC database was developed following a standard software development procedure, including requirements engineering, design, implementation, testing and release. The requirements engineering focused on identifying, analyzing, documenting, and checking the functions the proposed database can provide as well as their constraints. Based on the functional requirements, a conceptual schema for the database was first created in the form of an Entity-Relationship Model (ERM). The conceptual schema provides detailed descriptions of the data names, types, relationships, and constraints. The conceptual schema was mapped into a logical data model, which documents the structure of the data to be implemented in the database. The Microsoft Azure SQL server was adopted to transform the logical data model into a physical data model that specifies the internal storage structures, file organizations, indexes, access paths, and physical design parameters for the database. In terms of the user interface design, user and task analysis were conducted based on the gathered functional requirements first. An information architecture was then developed to capture the process of how users input, edit, search, and analyze the steel bridge coatings data in the database. A website wireframe was created and visual features (such as layouts, icons, fonts, color etc.) were added to it iteratively according to the feedbacks from the users. The proposed database and its user interface were first implemented in a prototype web application in a testing environment. In addition to standard application testing procedure, potential users also provided comments to the prototype system throughout the testing stage. Feedbacks were gathered and incorporated through prototype revisions before the final system is released.

After the development of the digital database, the project team analyzed the data and developed a machine learning (ML)-based deterioration model that predicts coating conditions based on selected data on highway steel bridge in Florida. In developing the model, bridge characteristic data, coating performance data, and environmental factor data were collected and pre-processed. Several ML models were implemented and evaluated including decision trees, k nearest neighbors, support vector regression, and deep neural networks. In addition to the deterioration model, the project team also evaluated the impact of using environmental factor data on the performance of coating deterioration prediction.

CHAPTER 2. LITERATURE REVIEW

The literature review presents the backgrounds on coating performance assessment and the identified factors that contribute to steel bridge premature coating failures, including types of coating systems, environmental factors, surface characteristics and preparation, application methods, and other factors.

2.1 Coating Performance Assessment

Coatings are integral elements in the preservations systems for bridge structures. They are applied to prevent corrosion and improve aesthetics of bridges. Protective coatings have a variety of forms, from the patina on weathering steel to 3-coat zinc-based coating systems applied to abrasive blasted steel (FDOT, 2018). The specifications for structural steel coatings are outlined in Sections 560, 561, and 975 of FDOT standard specifications for road and bridge construction for the categories of coating new structural steel, coating existing structural steel, and structural coating materials, respectively (FDOT, 2015). General structural coating materials requirements prescribe non-hazardous coatings that are visually uniform and adherent upon curing. Minimum performance requirements for coating test panels specified in Section 975 are listed in Table 2-1 (FDOT, 2015). FDOT-specified coating systems for new and existing structural steel that meet the requirements of Sections 560 and 561 (FDOT, 2015) are listed in the FDOT Approved Product List (FDOT, 2020).

Table 2-1. Minimum Performance Requirements for Coating Test Panels (FDOT, 2015)

Laboratory Testing		
Property	Test Method	Requirement
Slip Coefficient	AASHTO R-31	Min Class B (primer only)
Salt Fog Resistance	AASHTO R-31	Blister Size = 10 Average Rust Creep at the Scribe ≤ 0.1 inches
Cyclic Weathering Resistance	AASHTO R-31	Blister Size = 10 Average Rust Creep at Scribe ≤ 0.2 inches, Color retention ΔE ≤ 8, Gloss loss less than 30 units
Abrasion Resistance	AASHTO R-31	Wear index ≤ 2.7 mg/cycle
Adhesion	AASHTO R-31	Average system tensile strength ≥ 800 psi
Freeze Thaw Stability	AASHTO R-31	Avg. tensile strength ≥ 800 psi
Coatings Identification	Fourier Transform Infrared Spectroscopy	IR scan (2.5 to 15 um) for each base, catalyst, and mixed coating
Impact Resistance	ASTM D2794	Greater than 25 inch/lb, ½” impact intrusion
Flexibility	AASHTO R-31, ASTM D522, 1 inch cylindrical mandrel	No cracking
Outdoor Testing		
Property	Test Method	Requirement
Rusting	ASTM D610 ASTM D1654 (scribed) ASTM D1654 (unscribed)	≥ 9 after 5 years ≥ 9 after 5 years ≥ 9 after 5 years
Blistering	ASTM D714	10 after 5 years
Adhesion	ASTM D4541; annex A4	≥ 800 psi (unscribed area) after 5 years
Color Retention	ASTM D2244	ΔE ≤ 8 after 2 years
Gloss	ASTM D523	≤ 30 gloss units after 2 years

There are several reasons involved for the failure of protective coatings. The failure types can be divided into three broad categories: formulation-related failures, adhesion-related failures, and substrate-related failures. There are many failures of coatings due to the incompatibility of the resins, pigments, and other ingredients in the coating formulation to provide desirable characteristics. If the selected coating is formulated inadequately, the coating will most likely fail regardless of all efforts made in an optimal application. It has been estimated from past experience that 70% of all coating deterioration has resulted from poor or inadequate surface preparation (Dudley, 2003). This can in part lead to adhesion-related failures at the interface between the adhesive and the adherent, or the material to be bonded. Regular bridge inspections are vital to identify structural and material deficiencies of bridge systems to ensure public safety and bridge functionality. Furthermore, records of deficiencies can be useful to identify material performance and to assess future maintenance work and budget allocation. Type and extension of maintenance work depends on the level of coating degradation. ASTM established several methods to quantify the level of existing coating degradation. Typically, bridges are inspected every two years following a testing protocol as described in Figure 2-1 (Burgess, 2015). For making decisions about preservation and functional improvements of the structure, inspection records are maintained with the help of AASHTOWare™ Bridge Management software (BrM), formerly Pontis (FDOT switched to BrM in December 2016). Condition states are assigned for various bridge components based on the existing condition. The condition state ratings vary between 1 and 5, with an increasing rating value indicating higher damage level. Table 2-2 shows the condition state and corresponding remedy for painted steel girder (DelDOT, 2008).

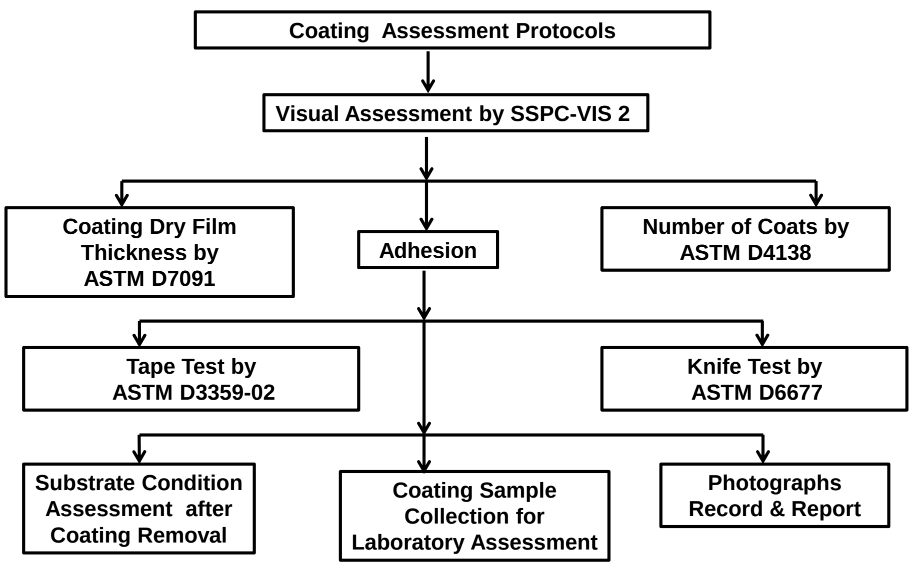

Figure 2-1. Bridge Coating Assessment Protocols (Burgess, 2015).

Table 2-2. Condition State and Remedy for Open Painted Steel Girder.

Condition State	Description	Preventive action
1	There is no evidence of active corrosion, and the paint system is sound and functioning as intended to protect the metal surface. ~No corrosion.	Do Nothing
2	There is little or no active corrosion. Surface corrosion has formed or is forming. The paint system may be chalking, peeling, curling, or showing other early evidence of paint system distress but there is no exposure of metal.~ Minor deterioration.	Do Nothing
3	Surface corrosion is prevalent. There may be exposed metal, but there is no active corrosion that is causing loss of section. ~Rust formation.	Do Nothing. Rehab connectors, Power Wash and Restore top coat.
4	Corrosion may be present but any section loss due to active corrosion does not yet warrant structural review of either the element or bridge. ~Moderate corrosion.	Do Nothing. Rehab connectors and Replace paint system.
5	Corrosion has caused section loss and is sufficient to warrant structural review to ascertain the impact on the ultimate strength and/or serviceability of either the element or the bridge. ~Advanced corrosion.	Do Nothing. Rehab connectors Replace paint system and Deck.

The level of maintenance is usually determined by the condition of the coating, but the maintenance strategy is influenced by the ease of access, removal of accumulated debris, and washing of contaminants. Based on the coating condition assessment, a repair decision is made that considers the cost of performing surface preparation and painting on the bridge. There are several strategies available for the maintenance of steel bridge coatings, such as spot painting, overcoating, and full removal or replacement of the existing coating system with the aim of maximizing service life while minimizing cost. The FDOT developed a process map (Figure 2-2) (Pouliotte, 2014). Selection of a compatible coating material is a critical parameter for providing proper protection from its exposure environment. Figure 2-3 shows survey results by Transportation Research Synthesis for typical coating system maintenance (KTA, 2014). FDOT-specified coating systems for existing structural steel in section 561 and materials are listed on the Department's Approved Product List (APL).

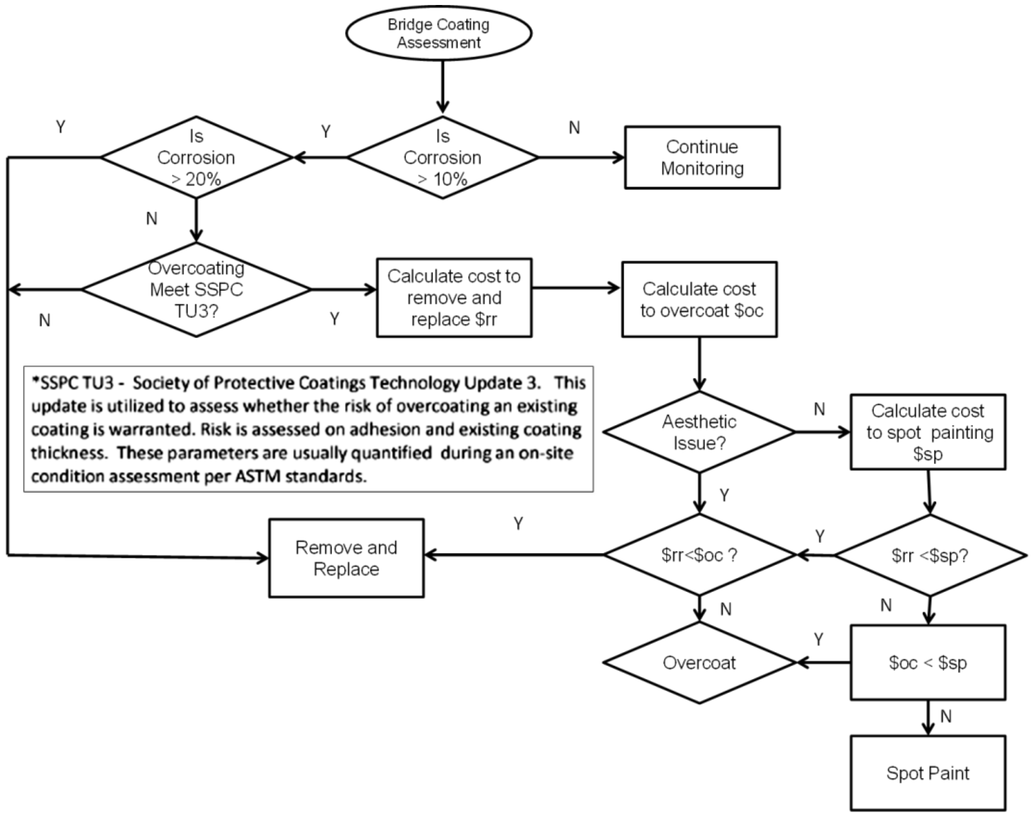

Figure 2-2. Flow Chart for Maintenance of Bridge Paintings (Pouliotte, 2014).

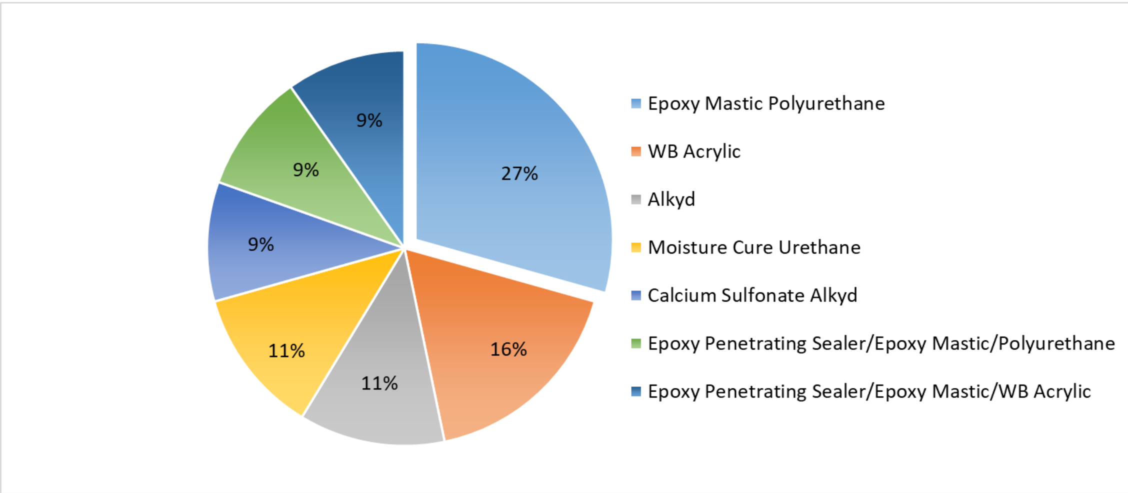

Figure 2-3. Typical Painting Systems Used for Maintenance (KTA, 2014).

2.2 Factors Contributing to Premature Coating Failures

2.2.1 Types of Coatings

The newer coating systems usually include three layers whereas only two coating layers are applied on the existing ones during maintenance. Primers are applied as the base coat to provide shielding properties followed by the intermediate coat which further serves as the corrosion barrier, and finally the finishing coat to withstand the external stresses, protect inner layers and add aesthetic colors to the structures (FDOT, 2018). Some of the primers used for bridge coating are acrylic primer, polyurethane primer, epoxy primer, enamel, oil-based, alkyd, and organic or inorganic zinc materials (Davies and Jackson, 2012; Kumar et al., 2006). However, FDOT maintains a diverse inventory of bridges with variations of aged coatings. Thus, the preventive maintenance of coating systems must be flexible to address the corrosion concerns of such diverse bridge coating systems.

Different types of coating materials may have different levels of performance in different environments. For example, Alkyd/oil-based coating is generally easy to apply, and it can be formulated with corrosion inhibitive pigments, but it can collect dust and dirt due to its sticky nature (Weldon 2005). Epoxy coating contains corrosion inhibitive elements, but it is susceptible to wearing in the presence of sunlight. High ratio calcium sulfonate that is used to prevent the detachment of coating layers has a tendency to remain damp and soft for a long time and requires a high level of accuracy during application. Moisture cure urethane (MCU) coating is able to overcome high moisture environments but could fail by developing bubbles or cracks if the application thickness is inappropriate. Waterborne acrylic contains low volatile compounds and is less affected by sunlight, but it requires multiple coats to prevent corrosion. Organic zinc-rich primer provides cathodic protection if it is applied on a freshly clean substrate. Low viscosity sealers are designed to improve the adhesion of other coatings and they require long curing time and in situ mixing. Corrosion preventing compounds (CPC) are capable of reaching the crevices and slow down the corrosion process. However, they are prone to be washed off and do not completely stop the corrosion on bridges (FDOT, 2018).

2.2.2 Environmental Factors

Coating performance and corrosion mitigation vary depending on the severity of the exposure environments. In Florida, bridge environments are classified as slightly aggressive, moderately aggressive, or extremely aggressive environments according to the chloride content in the environments, as shown in Figure 2-4 (FDOT, 2017). Structures located over or within 2,500 feet of a waterbody containing chloride above 2,000 ppm are designated as marine structures, and other structures are considered non-marine structures. Marine environments are generally considered the most corrosive environments due to the amount of sea salt carried by winds and deposited on bridge surfaces. The environment is dynamic and exerts various harmful elements on bridge surfaces leading to corrosion. The bridges' coatings need to be durable enough to deal with and withstand this changing nature of environments, such as contact with water, soil, pollution, chemicals, ultraviolet radiation, and etc. This versatility of environments poses a threat to the integrity of coating applied on steel bridges (Sørensen et al., 2009). Several environmental factors that could result in premature coating failures are discussed in the following subsections.

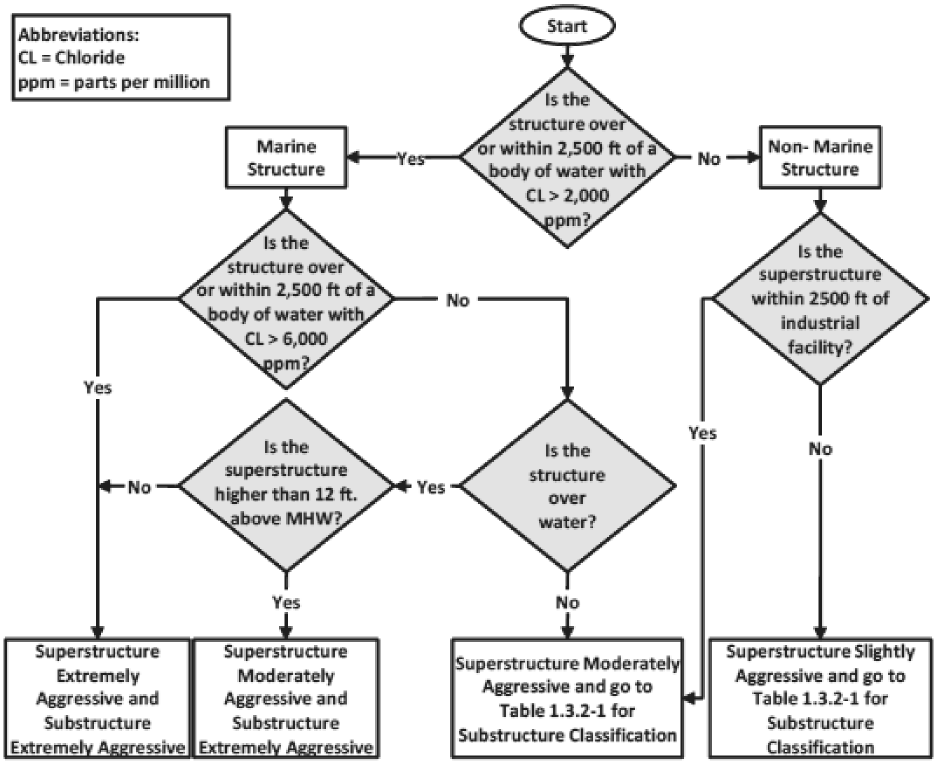

Figure 2-4. Environmental Exposure Classification of Structures (FDOT, 2017).

2.2.2.1 Atmospheric Exposure

The severity of corrosion depends on the atmospheric elements that coatings are exposed to, which vary from location to location. For example, corrosion observed in rural environments is less severe in comparison to those observed in industrial and marine environments (Sørensen et al., 2009). Atmosphere in industrial environments is composed of miniscule solid particles like sand, soot, dust particles and sulfates (Kallias et al., 2017), which interact with rainwater to form acidic rain (Sørensen et al. 2009). This eventually deteriorates the performance of coating material. In addition, the presence of pollution gases, such as SO_2, H_2S, and NH_3, in the atmosphere, particularly at high relative humidity, strongly accelerates the corrosion of metals (Dehri and Erbil, 2000). Atmosphere in marine environment contains huge amount of chloride ions, which are reactive and aggressive to metals and paints. Chlorides react chemically with steel and form corrosion cells that concentrate as pits on the steel and can cause accelerated degradation of the coating system (Appleman, 1987). Prasanna (2016) reported that high atmospheric humidity enhances condensation of moisture on the surface, and painting over the surface condensation often causes the formation of rust bloom on the metal surface, resulting in blistering, delamination, and consequently total coating failures.

2.2.2.2 Temperature

Temperature is an important environmental factor to consider when dealing with premature corrosion of steel bridge coating system. Studies show that the rate of corrosion process will double when the temperature increases 20 degrees (FDOT, 2015). Variations in temperature can cause adverse effects, such as brittleness, shrinking in volume, lessening of cohesive bond, overall weakening to impact, losing of protective properties, and eventually significant coating failures. The coating performance is also adversely affected when applying paint in extreme heat or cold climate (Gedeon, 1995).

2.2.2.3 Moisture

Moisture can seep through small cracks and crevices into the girder of a bridge and gets trapped, which eventually leads to corrosion. Presence of moisture not only leads to spreading of rust from crevices to cutting of the coating films, but also causes cracking and peeling (Machen et al., 2011). If the duration of moisture contact is long, water vapor can combine with pollution present in the atmosphere or on the surface to create a corrosive electrolyte (FDOT, 2015).

2.2.2.4 Immersion

When the structures of bridge are immersed in water or buried inside the soil, the possibility of corrosion is higher than exposed outside. Temperature, salinity, acidity, alkalinity, and presence of dissolved gases all play vital roles toward degradation of coating layers. Unlike fresh water, sea water contains huge amount of dissolved salt which are highly aggressive to anticorrosive coatings on the metal surface. Biofouling by marine organisms can also degrade protective coatings. Immersed or underneath structures are also acted upon by mechanical action of stones, pebbles, and sands, which can lead to removal of coatings from the substrate. Existing studies show that immersion in water for a long duration decreases the adhesive strength of organic coating and ultimately causes failures, such as blistering, delamination, adhesive deterioration, and cathodic disbondment (Gedeon 1995, Sørensen et al., 2009).

2.2.2.5 Soluble salts

Studies show that coating performance will be compromised when there are soluble salts between the layer of coating and the metal substrate. This is because the dissolution of salts beneath the coating layer gives rise to the volume occupied by them. Increment of volume naturally exerts more pressure and causes coating blisters if the pressure exceeds the adhesive/cohesive force (Morcillo, 1999; de la Fuente et al., 2006). de la Fuente et al. (2006) reported that the presence of hygroscopic salts, especially chlorides and sulfates, at the coating/steel interface promotes osmotic blistering of the coating and under-film metallic corrosion. Loss of adhesion, cathodic disbondment, scribe creep, and a decrease in the adhesion/cohesion strength of the coatings have also been reported as a consequence of painting over a rusty surface contaminated with soluble salts. These are detrimental to coating systems even if presenting for a short duration (Morcillo, 1999; de la Fuente et al., 2006).

2.2.2.6 Biological Factor

When coming in contact with moisture, litters from birds and other animals that accumulate on the surfaces of bridges are not only corrosive to the coating, but also hazardous to the health of the workers involved in repair and maintenance (Machen et al., 2011).

2.2.3 Surface Characteristics and Preparation

Beside the external factors, the steel surface on which the paint layer is applied could also be a trigger to corrosion (Lanterman, 2018). Past studies have discovered that corrosion spreads uniformly in flat surface and non-uniformly in surface with cuts, scratches, nuts or bolts. Regular flat surfaces corrode less compared with undulating surfaces like edges and welded points (FDOT

2015; Machen et al., 2011). It is very important to have good adhesion at the interface of coating and the substrate beneath it. The surface roughness plays a critical role during the coating application process. If the applied coating layer is not properly attached to the surface because of less roughness or irregularities, it would have lower impact resisting capacity and be prone to failures (Podgornik et al., 2004; Jamali and Mills, 2014).

Untreated surface contains rust, dust and dirt, or any loose particles, which is not favorable for the coating layer due to the loss of electrostatic bonds and interlocking between two surfaces (Jamali and Mills, 2014; de la Fuente et al., 2003). Research has shown that coatings applied on untreated or improperly treated surface fails by formation of blisters as a result of osmotic process. (de la Fuente et al., 2003). Some studies also show that surface preparation techniques such as water jet, wet sand blast or garnet blasting could lead to formation of oxide layers on the surface (Dong et al., 2009; Vesga et al., 2000). Coating delamination may occur when the oxide layers get in contact with chloride salts or other chloride carrier (Jamali and Mills, 2014).

The level of surface preparation is thus a critical factor for durable coating systems and their repair. The repair specification for Florida is described in the FDOT bridge maintenance and repair handbook. For coating application, surface preparation is the essential first step and the most important factor affecting the total success of a corrosion protection system. The performance of a coating is significantly influenced by its ability to adhere properly to the substrate material. The surface preparation process is not only to clean the steel, but also to introduce a suitable anchor profile for mechanical bonding of the coating. It has been estimated that 60% to 80% of all premature coating failures are the result of inadequate or improper surface preparation (Prasanna, 2016). According to the FDOT specification, all surfaces to be coated should be clean, dry, and free from oil, grease, dirt, dust, soluble salts, corrosion, peeling coating, caulking, weld spatter, mill scale, and any other surface contaminants according to the SSPC standard (Table 2-3).

Table 2-3. List of SSPC and NACE Standards Specifications for Surface Finish.

Types of Cleaning	SSPC Standard	NACE Standard
Solvent cleaning	SP 1	
Hand tool cleaning	SP 2	
Power tool cleaning	SP 3	
White metal blast cleaning	SP 5	NACE No. 1
Commercial blast cleaning	SP 6	NACE No. 3
Brush-off blast cleaning	SP 7	NACE No. 4
Near-white blast cleaning	SP 10	NACE No. 2
High and Ultrahigh Pressure Water Jetting	SP-12	NACE No. 5

SSPC = Society for Protective Coatings;

NACE = National Association of Corrosion Engineers International

2.2.4 Application Methods

Coatings on bridge structures can be applied in different ways such as by brushing, rolling or spraying. Brushing is a slow application method where brushes with synthetic bristle are used to do the painting. This method is mostly used when it is required for spot and stripe painting. Rolling is relatively faster than brushing, and it is commonly conducted in combination with brushing. Spraying is frequently used for painting large surfaces on bridges. Although it is the fastest process, it could potentially waste paints due to overspray and clean-up (FDOT, 2018). Also, it is not used when painted structures are near other existing facilities to avoid splash. In addition, coatings are generally applied in enclosure/containment to keep the paints from splashing and prevent the debris from entering the working area (NCHRP, 2016). Containment is constructed with the help of screens, scaffolds and supports (FDOT, 2018).

Premature coating failures have been associated with errors in the application process. Research shows inappropriate application method accounts for approximately 68% of all coating failures (Ravichandran and Nair, 2016). This may happen due to a lack of proper knowledge on coating paint technology and/or inappropriate use of coating application devices or tools. Paints are applied based on the manufacturer's protocols. They are applied at suitable temperatures within 4^{o}C and 50^{o}C, during dry conditions after mixing without creating lumps, and with the right tools (Alberta Transportation, 2017). In addition, multiple coats perform better than a single coat, and overlaps are necessary to cover any left-out areas (FHWA, 1997). Failing to do such could potentially result in corrosions. Moreover, when tools (e.g., brush, roller, spray) are not appropriately used in the painting process, defects are more commonly observed. These defects may include uneven thickness, mud cracking, dry spraying, sagging, and pin holing, all resulting in premature coating failures and more frequent repair. In practice, even the project managers are aware of the project specifications on coating application, the workers who actually apply the coatings could lack knowledge on the overall process and consequence of faulty application. This could be a trigger for premature coating failures (Ravichandran and Nair, 2016).

2.2.5 Other Factors

Some other factors such as mechanical factors and construction debris could also cause premature coating failures. Coatings are susceptible to any types of mechanical impacts and abrasive actions. For example, when nuts and bolts are being fitted, repaired, or replaced, there is friction between two metal surfaces, which can graze off the coating layer from the substrate (Lanterman, 2018). Metals are liable to expansion due to sudden impacts or force, and when coatings lack sufficient degree of flexibility, they rupture and fail (Gedeon, 1995). Abrasion and friction are not only the results of metals rubbing against each other, but also natural phenomena where dust and sand grains are drifted by blowing wind and flowing water over a long period of time (Gedeon, 1995).

In addition, construction debris on the bridge surface could also lead to premature coating failures. These debris may include small metal pieces produced due to drilling of holes in the girders, metallic dust particles due to grinding and friction, or unused nuts. The metallic particles deposited on the topcoat of painting can create pin-point rust appearance to bridges (Machen et al., 2011).

CHAPTER 3. EXPERT INTERVIEWS AND SURVEY

In order to systematically identify the historical data available at the FDOT district level, a web-based questionnaire survey was developed based on the literature review of factors that contribute to steel bridge premature coating failures. The following subsections describe the questionnaire design, implementation process, and preliminary findings.

3.1 Questionnaire Design

The survey focuses on addressing three main questions: (1) what are the available data related to steel bridge coatings? (2) What are the sources of the data? and (3) how to collect these data if they are available? The questionnaire is composed of three main sections: (1) Project Description, (2) Data Availability, and (3) Data Sources. The Project Description section provides a brief summary of the necessary background information and the purpose of the survey. The Data Availability section aims to identify the specific types of coating-related data that are available within FDOT district offices. In this section, a predefined hierarchy of coating-related data (Figure 3-1) is included based on the comprehensive literature review. As per Figure 3-1, six main data categories are included in the survey, including coating performance data, surface preparation data, environmental exposure data, coating application or repair data, and coating cost data. More specific types of data are then added under each of these data categories. For example, environmental exposure data include salt concentration, chloride exposure level, water pH level, temperature, relative humidity, distance from the shore, prevailing winds, airborne pollution, contaminant deposition, and ultraviolet light (UV) exposure. Respondents are then asked to select the types of data that are available within FDOT district offices. Based on their responses, the Data Sources section asks the respondents to specify the sources of the data they selected, and whether they are willing to share the data sources with the FIU team. If the respondents are willing to share the data sources, they are asked to provide their contact information for future data collection. In the end of the questionnaire, an open-ended question is included to ask the respondents to add any coating-related data that is not listed in the questionnaire. Appendix A presents the questionnaire designed for this study.

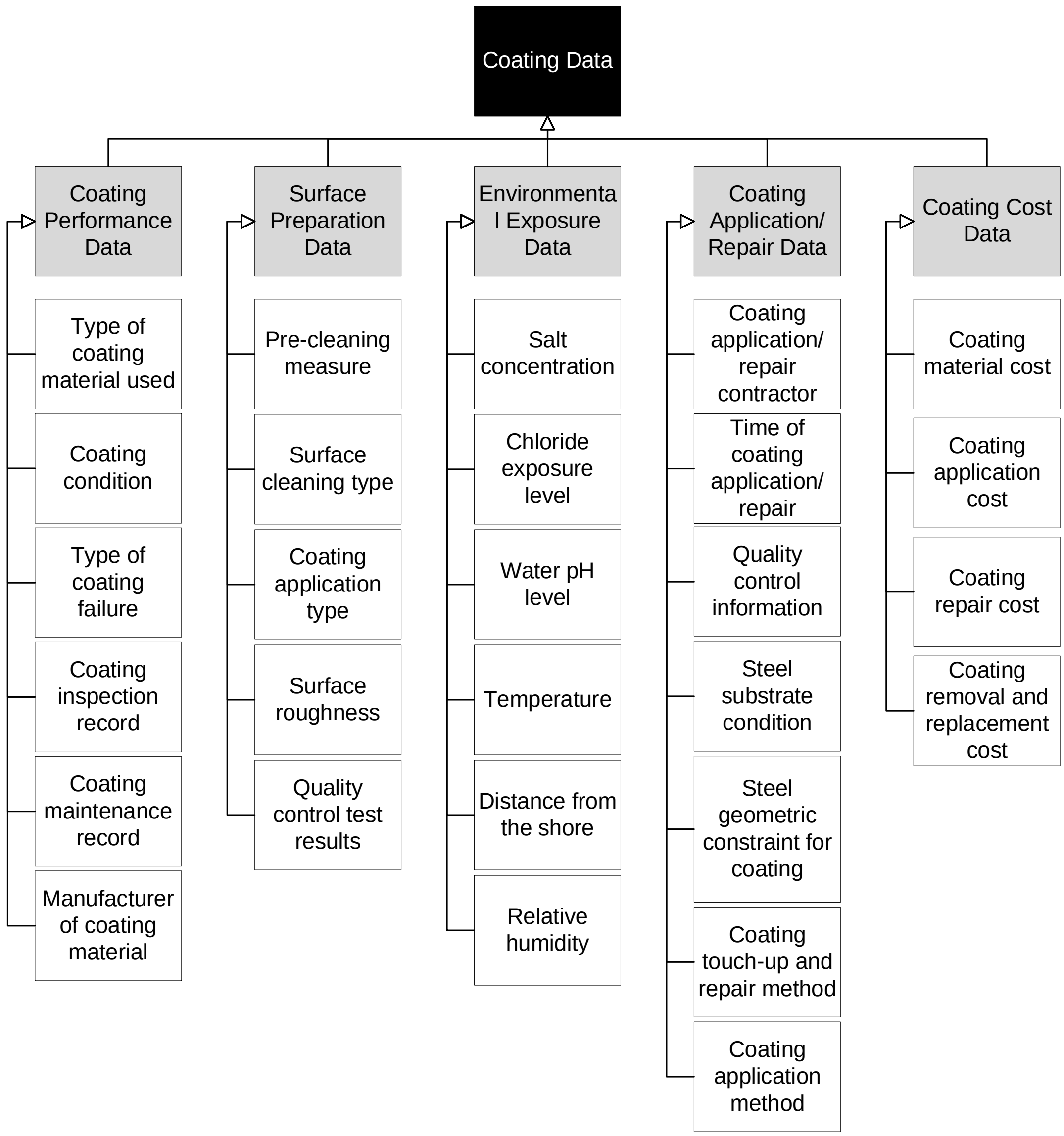

Figure 3-1. A Hierarchy of Coating-Related Data

3.2 Survey Implementation

The survey was conducted online using Qualtrics from May to June 2020, and the survey invitations with the link to the survey were sent out through email. The survey targeted the engineers and administrators at the FDOT Materials, Maintenance, Structural Design, and Construction Offices in Districts 2, 4, and 6. Potential respondents were sampled from the websites of FDOT district offices, and their contact information was collected.

3.3 Preliminary Findings

The survey invitations were sent out to approximately 146 potential respondents. A total of 29 responses (excluding five incomplete responses) were received during the reporting period of the first deliverable, representing about 20% response rate. This is on the lower end of "the norm of 20%-30%" response rate with most questionnaire surveys in the engineering field (Akintoye 2000), which could be due to the impacts of COVID-19. The analysis of the responses aimed at addressing the following questions:

(1) What coating data are available within FDOT district offices based on the responses?

(2) What are the sources of the available data based on the responses?

The following subsections provide a summary of the preliminary findings based on the responses.

3.3.1 Types of Data

Figures 3-2 to 3-7 summarize the types of data that are available within FDOT district offices based on the collected responses. As per the figures, the data are available in all five predefined categories. For coating performance data, the available data include the data on the type of coating material used, the coating condition, the type of coating failures, the coating inspection records, the coating maintenance records, and the manufacturers of coating materials. The data on debris accumulation information and level of coating degradation are not available. For surface preparation data, the available data include the data on the pre-cleaning measure, the surface cleaning type, the coating application delay, the surface roughness, and the quality control test results. For environmental exposure data, the available data include the data on salt concentration, chloride exposure level, water pH level, temperature, relative humidity and distance from the shore. The data on prevailing winds, airborne pollution, contaminant deposition, ultraviolet light (UV) exposure are not available. Similarly, for the coating application or repair data, the available data include the data of the coating application or repair contractor, the time of coating application or repair, quality control information, steel substrate condition, steel geometric constraint for coating, coating application method, and coating touch-up and repair method. Lastly, for coating cost data, the available data include the data of coating material cost, coating application cost, coating repair cost, and coating removal and replacement cost.

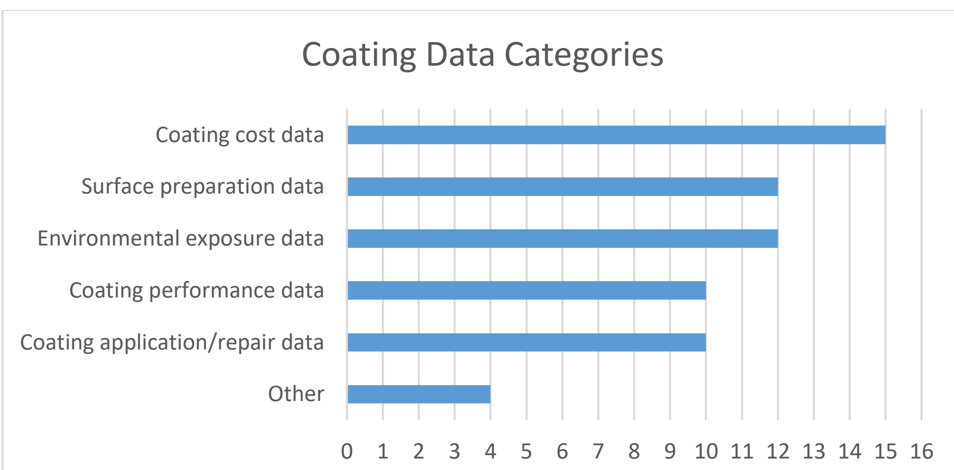

Figure 3-2. Summary of Availability of Coating-Related Data

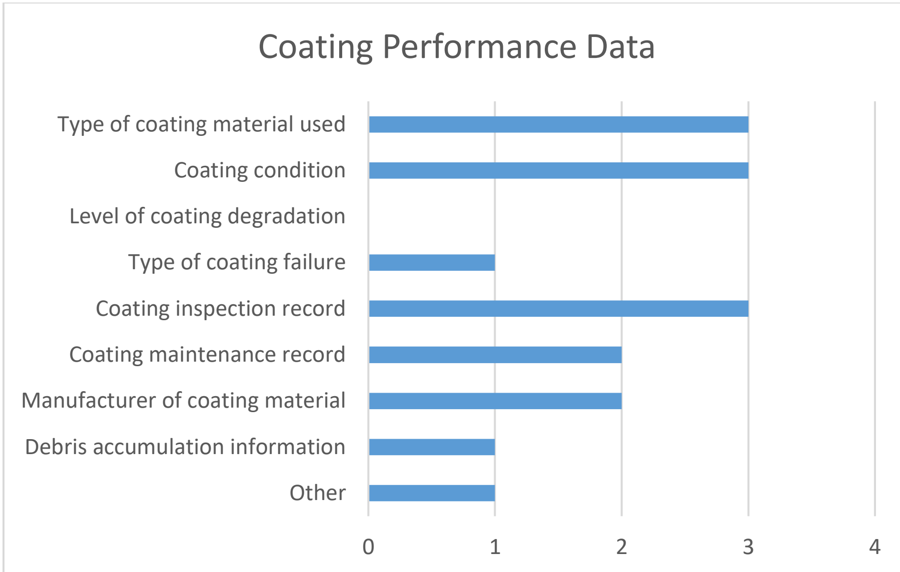

Figure 3-3. A Summary of Availability of Coating Performance Data

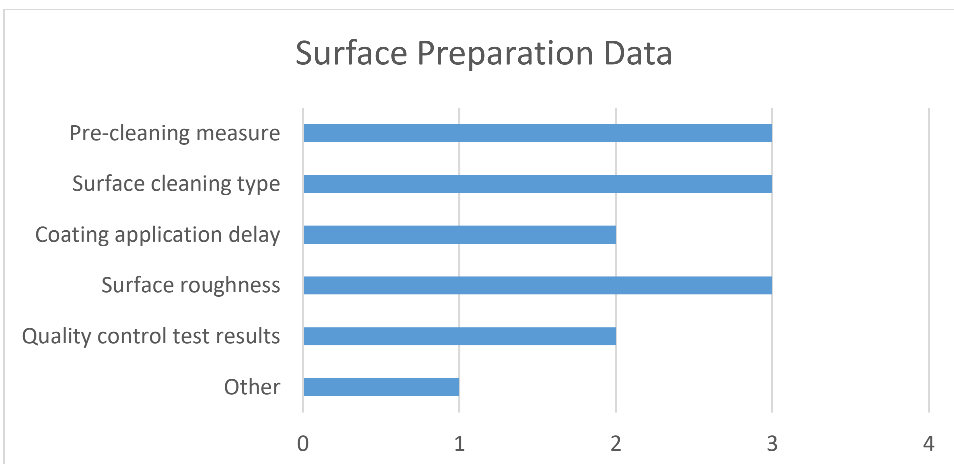

Figure 3-4. A Summary of Availability of Surface Preparation Data

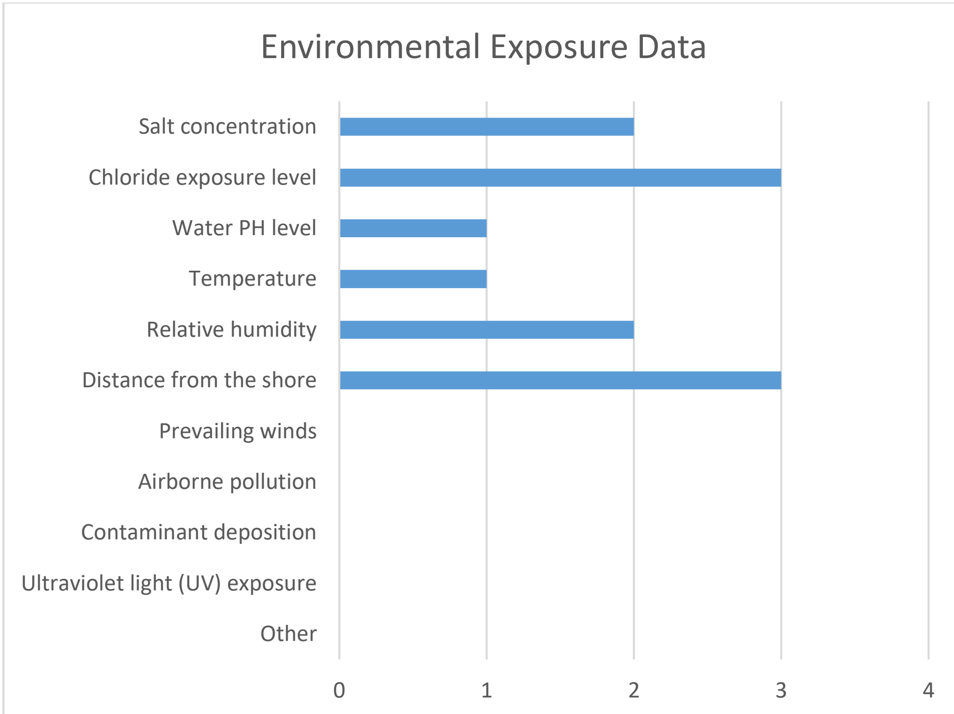

Figure 3-5. A Summary of Availability of Environmental Exposure Data

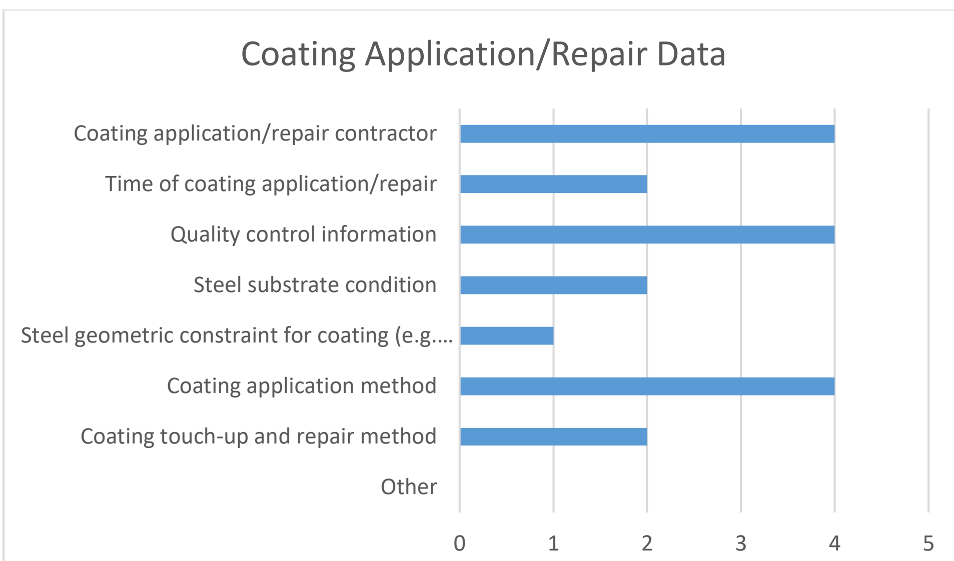

Figure 3-6. A Summary of Availability of Coating Application or Repair Data

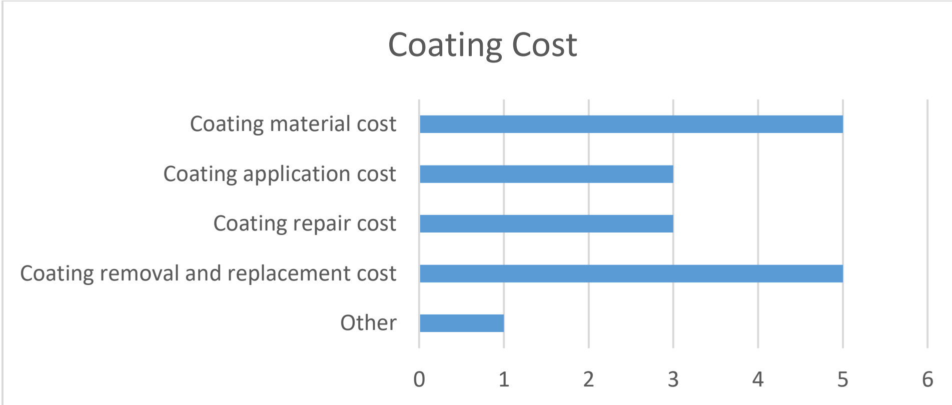

Figure 3-7. A Summary of Availability of Coating Cost Data

3.3.2 Sources of Data

Tables 3-1 to 3-5 summarize the sources of data based on the collected responses. As noted in the tables, some data are selected as available, but the respondents did not provide the sources of the data. For example, two respondents have selected "relative humidity" as available environmental exposure data. But none of the respondents provided the data sources. Some data sources are provided by the respondents, but they are not valid data sources. For example, some respondents mentioned "historic data" as the data source. "Historic data" is not a valid data source. This indicates follow-up meetings are needed to get more information and feedback form district engineers and administrators about the sources of data.

Table 3-1. Coating Performance Data and Their Sources

Coating performance	
Type of data	**Source of data**
Type of coating material used	Contract documents
	Office of maintenance (FDOT)
Coating condition	Inspection reports
	Office of maintenance (FDOT)
Level of coating degradation	N/A
Type of coating failure	N/A
Coating inspection record	Office of maintenance (FDOT)
Manufacturer of coating material	Contract documents
	Office of maintenance (FDOT)
Debris accumulation information	Inspection reports

Table 3-2. Surface Preparation Data and Their Sources

Surface preparation	
Type of data	**Source of data**
Pre-cleaning measure	Project documents
	Construction daily reports
	Project specifications
	SSPC standards
Surface cleaning type	Project documents
	Construction daily reports
	Project specifications
	SSPC standards
Coating application delay	Project documents
	Construction daily reports
Surface roughness	Project documents
	Construction daily reports
	Project specifications
	Product data sheet
Quality control test results	Project documents
	Construction daily reports
	Project specifications

Table 3-3. Environmental Exposure Data and Their Sources

Environmental exposure	
Type of data	**Source of data**
Salt concentration	Project records
Chloride exposure level	Bridge environmental database
	Environmental maps
Water PH level	Bridge environmental database
Temperature	N/A
Relative humidity	N/A
Distance from the shore	Bridge location maps
	Inspection reports
Prevailing winds	N/A
Airborne pollution	N/A
Contaminant deposition	N/A
Ultraviolet (UV) light exposure	N/A

Table 3-4. Coating Application Data and Their Sources

Coating application	
Type of data	**Source of data**
Coating application or repair contractor	Project records
	Project specifications
	Product data sheet
	Contract documents
	Construction office (FDOT)
Time of coating application or repair	Inspector's daily reports
	Construction office (FDOT)
Quality control information	Possibly project records
	FDOT database
	Construction office (FDOT)
Steel substrate condition	Possibly project records
	FDOT database
Steel geometric constraint for coating (e.g., bolts, cuts, edges)	Project plans
Coating application method	Project records
	Project specifications
	Product data sheet
	Contract documents
	Construction office (FDOT)
Coating touch-up and repair method	Possibly project records
	Construction office (FDOT)

Table 3-5. Coating Cost Data and Their Sources

Coating cost	
Type of data	**Source of data**
Coating material cost	Bid documents
	Construction office (FDOT)
Coating application cost	Historical cost
	Bid documents
Coating repair cost	Bid documents
	Construction office (FDOT)
Coating removal and replacement cost	Statewide averages
	Historical cost
	Bid documents
	Construction office (FDOT)

CHAPTER 4. DATA REVIEW AND COLLECTION

The project team has collected and reviewed sample data sources in the categories of (1) existing steel bridge inventory, (2) coatings performance assessment, (3) surface preparation, (4) environmental exposure, and (5) cost. The sample data was first collected for bridges managed by FDOT District 6 due to easiness of coordination and close proximity to the project team's working location. Upon successful development of a database with this data for the sample bridge set, the database can be expanded (ideally where the database can be fully supported, shared, and expanded within FDOT and/or with support from the research team). To prepare for the development of the database, the following categories of data were reviewed and collected:

4.1 Florida Bridge Inventory

Florida Bridge Inventory is part of the National Bridge Inventory (NBI), which is a unified database providing design and condition information of bridges to the general public. FDOT updates and publishes bridge inventory data quarterly, which includes information such as average daily traffic (ADT), last inspection date, sufficiency rating and health index. A snapshot of the collected Florida Bridge Inventory Data for the 2020 3rd quarter is shown in Figure 4-1.

DISTRICT	COUNTY	OWNER	BRIDGE	STRUCTURE NAME	ROADWAY	ADT	FACILITY CROSSED	YEAR BUILT	RECONSTRUCTED	LAST INSPECTION	SUFFICIENCY RATING	HEALTH INDEX	NBI RATING
South Florida	Miami-Dade	State Highway Agency	870311	I-195 OVER NW 1 AVE	I-195 (SR-112)	146,000	NW 1ST AVE.	1961	2012	10/8/2019	85	92.36	
South Florida	Miami-Dade	State Highway Agency	870312	I-195 OVER N MIAMI AVE	I-195	146,000	NORTH MIAMI AVE	1960	2012	7/12/2018	83	98.15	
South Florida	Miami-Dade	State Highway Agency	870313	I-195 OVER US-1	I-195 (SR-112)	146,000	SR-5 & FEC R/R	1961	2000	5/21/2020	81	89.20	FO
South Florida	Miami-Dade	State Highway Agency	870314	I-195 OVER WESTSHORE WW	I-195 (SR-112)	128,500	WESTSHORE WATERWAY	1961	1991	5/16/2019	72	88.42	
South Florida	Miami-Dade	State Highway Agency	870315	I-95 SB OVER NW 79 ST	I-95 SB (870431)	101,750	NW 79TH STREET	1961	1993	4/11/2019	90	97.46	FO
South Florida	Miami-Dade	State Highway Agency	870317	I-95 OVER LITTLE RIVER CNL	I-95 SB (870433)	108,500	LITTLE RIVER CANAL C-7	1961	1975	11/13/2018	91.1	87.59	
South Florida	Miami-Dade	State Highway Agency	870322	I-95 SB OVER SR-922	I-95 SB (870438)	31,500	SR-922 (NW 125 ST)	1962	1991	8/29/2019	92.5	99.42	
South Florida	Miami-Dade	State Highway Agency	870323	I-95 OVER NW 131ST ST	I-95 SB (870439)	106,500	NW 131ST ST	1963	2008	10/2/2018	95.5	99.47	
South Florida	Miami-Dade	State Highway Agency	870324	I-95 SB OVER I-195	I-95 SB	100,500	I-195 (SR-112)	1961		3/18/2020	83.6	96.75	FO
South Florida	Miami-Dade	State Highway Agency	870325	I-195 WB TO I-95 SB	I-195 WB TO I-95SB	29,500	I-195 (SR-112)	1961	2012	5/22/2019	83	97.75	FO
South Florida	Miami-Dade	State Highway Agency	870326	I-195 OVER NW 3 AVE	I-195	68,500	NW 3RD AVE	1961	2012	3/20/2019	81.8	98.43	
South Florida	Miami-Dade	State Highway Agency	870327	I-95 OVER SR112 RAMP	I-95	201,000	RAMP 112/195 EB - 95 NB	1959	1988	5/23/2019	82.8	97.18	
South Florida	Miami-Dade	State Highway Agency	870328	I-95 OVER NW 46 ST	I-95	187,500	NW 46 ST	1961	2020	1/21/2020	86.3	97.27	
South Florida	Miami-Dade	State Highway Agency	870329	I-195 WB TO I-95	I-195 WB TO I-95	29,500	NW 3RD AVE.	1961	2012	2/12/2020	86.7	96.42	
South Florida	Miami-Dade	State Highway Agency	870331	I-95 SB TO I-195 EB	I-95 SB TO I195 EB	24,500	I-195 & 1-95 & RAMPS	1959	2004	12/18/2018	84.3	97.16	FO
South Florida	Miami-Dade	State Highway Agency	870332	36 ST INTERCHANGE	I-95 NB TO I-195WB	13,500	I-95 & I-195 & RAMPS	1961	2010	9/11/2019	91.5	98.54	FO
South Florida	Miami-Dade	State Highway Agency	870333	I-195 EB RAMP OVER NW 3 AVE	I-95 NB TO I-195EB	68,500	NW 3 AVE	1961	2012	3/20/2019	89.9	99.47	
South Florida	Miami-Dade	State Highway Agency	870334	SR-112 EB TO I-95	SR-112 EB TO I-95	19,000	NW 10TH AVE	1962	1989	1/13/2020	95.1	99.02	
South Florida	Miami-Dade	State Highway Agency	870335	I-95 SB TO SR-112 WB	I-95SB TO SR-112WB	7,100	NW 10TH AVE	1962	1989	1/13/2020	95.7	99.54	
South Florida	Miami-Dade	State Highway Agency	870336	I-195(SR-112)EB TO I-95SB	I-195EB TO I-95SB	12,000	US-27(NW 36 ST)&NW 35 ST	1960	2020	1/21/2020	90.9	98.66	FO
South Florida	Miami-Dade	State Highway Agency	870337	I-195 TO I-95 SB	I-195EB TO I-95SB	31,500	NW 32ND ST	1960	1994	2/11/2020	93.3	98.46	
South Florida	Miami-Dade	State Highway Agency	870339	I95SB/US-27(NW 36 ST)&NW 35 ST	I-95 SB (870533)	100,500	US-27(NW36ST) & NW 35 ST	1962	2010	10/9/2019	80	98.06	FO
South Florida	Miami-Dade	State Highway Agency	870340	I-95 OVER I-195 RAMP	I-95	201,000	I-195 WB TO I-95 SB	1962	2010	3/18/2020	81	98.48	FO
South Florida	Miami-Dade	State Highway Agency	870341	I-95 NB TO I-195 EB	I-95NB TO I-195EB	26,500	US 27(NW 36 ST)& NW35 ST	1962	2020	1/21/2020	70.2	99.49	FO
South Florida	Miami-Dade	State Highway Agency	870342	I-195 WB TO I-95 SB	I-195 WB TO I-95SB	29,500	US-27 (SR948/NW36 ST)	1960	2020	1/21/2020	72.4	97.13	
South Florida	Miami-Dade	State Highway Agency	870343	I-195 EB TO I-95 SB	I-195 EB TO I-95SB	12,000	US 441 (NW 7 AVE)	1962	2020	1/21/2020	91.7	99.52	
South Florida	Miami-Dade	State Highway Agency	870344	I-95 OVER NW 135TH ST	I-95 SB (870443)	31,500	NW 135TH ST	1963	1994	6/19/2019	96	99.35	
South Florida	Miami-Dade	State Highway Agency	870347	I-95 SB OVER NW 151 ST	I-95 SB (870446)	134,500	NW 151 ST	1963	1976	6/21/2019	91	99.57	
South Florida	Miami-Dade	State Highway Agency	870348	I-95 OVER BISCAYNE CANAL	I-95	269,000	BISCAYNE CANAL C-8	1961	1975	7/12/2018	86.6	96.67	
South Florida	Miami-Dade	State Highway Agency	870349	I-95 NB TO TPX	I-95 NB to TPX	52,500	I-95 SB	1963		8/29/2019	56.7	98.65	FO
South Florida	Miami-Dade	State Highway Agency	870350	US-1 NB TO I-95 NB	US-1 NB TO I-95 NB	33,250	US-1 (SR-5) SB	1964	2000	2/11/2020	93	94.23	
South Florida	Miami-Dade	State Highway Agency	870352	I-95 SB OVER SR-860	I-95 SB (870449)	91,500	SR-860 & I-95 SB RAMPS	1962	1988	3/23/2020	77.1	99.87	FO
South Florida	Miami-Dade	State Highway Agency	870354	I-95 SB OVER SW 1ST AVE	I-95 SB (870451)	33,250	SW 1ST AVE	1966		5/21/2019	84.2	99.84	
South Florida	Miami-Dade	State Highway Agency	870355	I-95SB/SW 3RD AVE & BROADWAY	I-95 SB (870452)	33,250	SW 15 RD & SW 3RD AVE	1965	2000	6/9/2020	93.4	96.16	
South Florida	Miami-Dade	State Highway Agency	870356	I-95SB OVER DOWNTOWN & MIAMI R	I-95 SB (870453)	33,250	SW/NW 8TH ST - MIAMI RV	1967		5/31/2020	80.1	98.61	
South Florida	Miami-Dade	State Highway Agency	870357	I-95 OVER 10TH&11THST&11TH TER	I-95 SB	87,250	NW 10&11TH ST& NW 11 TER	1968	1993	5/9/2020	88.8	87.72	
South Florida	Miami-Dade	State Highway Agency	870358	I-95 OVER NW 17TH ST	I-95 SB (870455)	100,500	NW 17TH ST	1968		4/8/2019	81	96.46	
South Florida	Miami-Dade	State Highway Agency	870359	I-95 SB OVER NW 20 ST	I-95 SB (870548)	201,000	NW 20 ST	1965	1994	6/8/2020	71.7	99.87	FO
South Florida	Miami-Dade	State Highway Agency	870360	I-95 NB TO I-395	I-95 NB TO I395 EB	14,500	NW 8 ST TO NW 11 TERR	1968		9/10/2019	73.7	95.88	FO
South Florida	Miami-Dade	State Highway Agency	870361	I-95 NB TO I-395 EB	I-95 NB TO I-395EB	15,000	NW 14 ST	1968		2/12/2019	89.4	97.18	
South Florida	Miami-Dade	State Highway Agency	870362	I-95 SB TO SR-836 WB	I-95SB TO SR-836WB	39,500	NW 17TH ST	1960	1990	10/1/2018	96	97.88	
South Florida	Miami-Dade	State Highway Agency	870363	I-95 TO SR-836 WB	I-95 TO SR-836 WB	39,500	NW 7TH AVE & SALRR	1969	1994	11/2/2019	50.1	94.59	FO
South Florida	Miami-Dade	State Highway Agency	870364	I-95 NB TO SR-836 WB	I-95NB TO SR836WB	21,500	NW 14 ST I-395 I-95	1968		3/25/2019	80.8	91.38	FO
South Florida	Miami-Dade	State Highway Agency	870365	NW 14 ST OVER I-95(SR-9A) SB	NW 14 ST	6,246	I-95 SB (SR-9A)	1968		5/23/2019	92.1	99.48	FO
South Florida	Miami-Dade	State Toll Authority	870366	EB SR 836 over SR 7 and I-95 Mailine and Ram	SR 836 WB	61,500	SR 7/I-95 Main and Ramps	1968		3/29/2019	87.7	95.25	
South Florida	Miami-Dade	State Highway Agency	870367	SR836EB W/S CONN TO I 95	SR-836EB TO I-95SB	28,500	NW 14 ST & NW 8TH EXIT	1969	1993	2/24/2020	95.8	98.25	
South Florida	Miami-Dade	State Highway Agency	870368	I-395 WB TO I-95 NB	I-395WB TO I95NB	23,500	LAND ONLY	1969		2/11/2020	77.9	98.25	
South Florida	Miami-Dade	State Highway Agency	870369	SR-836 WB TO I-95 NB	SR-836WB TO I-95NB	23,500	NW 17TH ST	1969		5/14/2020	78.5	99.86	
South Florida	Miami-Dade	State Highway Agency	870370	SR-836 EB TO I-95 NB	SR836EB - I-95NB	25,000	I-95 SB & I-395 EB RAMP	1969		6/10/2020	87	95.74	
South Florida	Miami-Dade	State Highway Agency	870371	SR-836 WB TO I-95 SB	SR836 WB TO I95 SB	16,500	I95 & I95 RAMPS &14TH ST	1969		12/18/2019	91.5	80.73	FO
South Florida	Miami-Dade	State Highway Agency	870373	I-395 FROM US1 TO NW 3RD AVE	I-395 EB (870575)	72,000	NW 3RD AVE TO US-1 (SR5)	1970		10/30/2018	88.4	98.91	FO
South Florida	Miami-Dade	State Highway Agency	870374	I-395 WB/N BAYSHORE DR	I-395 WB (870574)	72,000	N BAYSHORE DR	1971	2014	1/23/2019	93.6	95.45	
South Florida	Miami-Dade	State Highway Agency	870375	I-195 WB TO NE 38 ST	I-195 WB RAMP	14,000	WESTSHORE WATERWAY	1959	1990	5/16/2019	92.4	80.71	
South Florida	Miami-Dade	State Highway Agency	870376	NW 36TH ST TO I-195 EB	I-195 EB ON RAMP	14,000	WESTSHORE WATERWAY	1959	1990	5/16/2019	97.5	85.77	
South Florida	Miami-Dade	State Highway Agency	870377	EAST TO NORTH RAMP ALTON	COMP I-195	17,000	NORTHBOUND ALTON ROAD	1959	1991	10/9/2019	81.7	94.59	FO
South Florida	Miami-Dade	State Highway Agency	870380	I-95 NB CONN TO SR91&SR826WB	I-95 NB TO SR91	52,500	CSX RR	1957	2011	7/11/2019	94.5	100.00	

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NBI=National Bridge Inventory
ADT=Average Daily Traffic
SD=Structurally Deficient
FO=Functionally Obsolete

Figure 4-1. A Snapshot of the Collected 2020 3rd Quarter Florida Bridge Inventory Data

4.2 Coating Performance

The information on coating performance can be obtained from (1) bridge management system (BMS), which has a summary on types of coatings and amounts of coatings in Condition States 1, 2, 3, and 4 for each bridge; (2) bridge inspection reports, which include detailed inspection records on the bridge conditions, including coating conditions, (3) bridge work plan, which lists the work needs for the next five year work program as identified by each district maintenance office. The following paragraphs discuss these data sources in more details:

Bridge Coating Conditions from BMS: The most recent information on bridge coating conditions for all bridges managed by FDOT was collected from the BMS. The collected information includes bridge number, district number, custodian number, facility carried, feature intersected, bridge locations (latitudes and longitudes), material types, design types, coating types, and the amount of coatings in Condition States 1, 2, 3, and 4, based on the most recent inspections on the bridges. A snapshot of the sample set of bridge coating conditions data are presented in Figure 4-2.

1	Bridge Numbe	Distr	Custodi	Facility Carried	Feature Intersected	Latitude	Longitude	Material Type	Design Type	Year Buil	Steel Elemen	Coating Type	Quantity Condition State	Quantity Condition State	Quantity Condition State	Quantity Condition State
100	134005	1	2	49th St E EXP FARM	TERRA CEIA CREEK	273328.36	823308.27	3	2	1960	107	8516	483	0	494	24
180	260001	2	1	US-301 (SR-200)	SR-24 & CSXRR	294724	821003	3	2	1964	107	8516	0	6117	5383	380
183	260027	2	2	CR 325	CROSS CREEK	292911	820955	4	2	1940	107	8516	0	0	1623	854
184	260086	2	2	CR 241	SANTA FE RIVER	295635	823024	3	2	1950	107	8516	0	0	6720	1680
193	273002	2	2	SAND HILL ROAD	GUM SWAMP CREEK	302542	822112	4	2	1973	107	8516	0	0	925	925
194	290027	2	2	CR 6	SUWANNEE RIVER	303027	824300	4	3	1951	107	8516	0	0	960	563
195	290027	2	2	CR 6	SUWANNEE RIVER	303027	824300	4	3	1951	113	8516	0	0	1820	835
196	290027	2	2	CR 6	SUWANNEE RIVER	303027	824300	4	3	1951	152	8516	0	0	460	1526
197	290027	2	2	CR 6	SUWANNEE RIVER	303027	824300	4	3	1951	107	8516	0	0	6730	1530
203	300022	2	2	CR 357 (HINES RD)	EIGHT MILE CREEK	294746.32	831344.25	4	2	1954	107	8516	0	0	797	24
204	300053	2	2	CR 357 (HINES RD)	EIGHT MILE CREEK	294748.84	831343.15	4	2	1955	107	8516	0	0	4348	16
212	320016	2	1	SR-6	WITHLACOOCHEE RIVER	302856.12	831436.52	4	3	1950	107	8516	0	35874	301	261
225	334001	2	2	Camp Grade Road	Steinhatchee River	295033.11	831830.13	3	10	1921	120	8516	0	481	85	1
234	380011	2	1	US-221 (SR-55)	TWO PINES CREEK	301158.44	833622.09	4	2	1939	107	8516	1138	0	1	113
238	380034	2	2	CR 361	WARRIOR CREEK	295627.2	833510.1	3	2	1940	107	8516	2115	0	4	81
249	720003	2	1	US-90 (SR-10)	MARIETTA BRANCH	301922.14	814623.4	3	2	1931	107	8516	0	91	52	26
253	720022	2	1	US-1 (MAIN ST.)	ST. JOHNS RIVER	301919.56	813931.07	3	15	1941	120	8516	128891	121	23	665
260	720022	2	1	US-1 (MAIN ST.)	ST. JOHNS RIVER	301919.56	813931.07	3	15	1941	162	8516	2488	413	9	16
264	720044	2	1	SR-10 E.B.	SAN PABLO RIVER (IWW)	301924	812621	4	2	1965	107	8516	17678	0	221	3221
265	720063	2	1	SR-105	HAULOVER CREEK	302430.37	812530.29	3	2	1948	107	8516	0	1678	3825	3825
266	720071	2	1	SR-105	MYRTLE CREEK	302740.9	812529.32	3	2	1949	107	8516	0	201	198	801

Figure 4-2. A Snapshot of the Bridge Coating Conditions.

Bridge Work Plan (BWP) Report: the BWP represents the work needs identified by each district maintenance office for the next five-year work program. These include repair, rehabilitation and replacement projects for bridges and ancillary structures such as overhead sign structures, traffic signal mast arms, and high mast light poles. The BWP report is prepared by the Office of Maintenance annually, and the reports from years 2016 to 2020 are collected. A snapshot of the collected 2020 BWP is shown in Figure 4-3.

Florida Department of Transportation Bridge Repair and Replacement Program

District 6

2020 Bridge Work Plan Report

Bridge No.	FM No.	Maint Resp	Fed Aid	Op Stat	Struct Type	Route	Feature Intersected	DECK	SUPS	SUBS	CHAN	CULV	Act Cat	Act Type	Act Status	Def Disc Date	Def Rate	Suff Rate
870019	43654015201	1	FA	A	302	1	CORAL GABLES CANAL	7	7	7	7	N	PM	45	C	20142015	ND	81
870028	44479815201	1	FA	A	501	1	FCD CANAL 12-B	7	7	8	8	N	RH	57	C	20182019	FO	58
870031	44479915201	1	FA	A	501	1	SPILLWAY 12-D	7	7	8	8	N	RH	57	C	20182019	FO	60
870055	44618915201	1	FA	A	302	1	INDIAN CREEK CANAL	7	7	7	7	N	PM	45	6	20192020	FO	76
870071	43337815201	1	FA	A	403	1	BAKERS HAULOVER INLET	6	5	5	7	N	RH	57	C	20122013	ND	70.7
870077	43652215201	1	FA	A	302	1	EAST CHANNEL	5	5	6	8	N	PM	43	C	20142015	ND	72
870082	43652615201	1	FA	A	316	1	Intracoastal Waterway	7	5	6	8	N	RM	38	C	20142015	ND	53
870085	44480415201	1	FA	A	316	1	East Biscayne Bay	7	7	7	7	N	RP	12	C	20182019	ND	67.3
870085	43652615201	1	FA	A	316	1	East Biscayne Bay	7	7	7	7	N	RM	38	C	20142015	ND	67.3
870162	44480115201	1	FA	A	402	1	US1&S MIAMI AVE&SW 25 RD	7	7	7	N	N	PM	45	C	20182019	ND	94.7
870163	44480215201	1	FA	A	402	1	S MIAMI AVE & SW 26TH RD	7	7	7	N	N	PM	45	6	20182019	FO	94
870301	43119315201	1	FA	A	302	1	INTRACOASTAL WATERWAY	6	5	6	7	N	PM	44	C	20112012	ND	73.9
870302	43653315201	1	FA	A	502	1	BISCAYNE BAY	6	7	6	7	N	PM	44	C	20142015	ND	85
870314	44196715201	1	FA	A	101	1	WESTSHORE WATERWAY	6	6	5	8	N	PM	44	C	20172018	ND	72
870472	43652815201	1	FA	A	302	1	SW 2ND ST TO SE 1ST AVE	7	7	7	N	N	PM	45	C	20142015	FO	86.6
870551	44480415201	1	FA	A	316	1	East Biscayne Bay	7	7	5	8	N	RP	12	C	20182019	ND	57.9
870551	43652615201	1	FA	A	316	1	East Biscayne Bay	7	7	5	8	N	RM	38	C	20142015	ND	57.9
870554	43652615201	1	FA	A	316	1	Intracoastal Waterway	7	5	6	8	N	RM	38	C	20142015	FO	50.9
870592	43652515201	1	FA	A	316	1	Intracoastal Waterway	6	7	7	6	N	RH	57	C	20142015	ND	81.4
870593	43652515201	1	FA	A	316	1	Intracoastal Waterway	6	7	7	6	N	RH	57	C	20142015	ND	83.3
870600	44480515201	1	FA	A	402	0	I-75 (SR-93)	7	7	7	N	N	PM	45	C	20182019	ND	99.3
870603	44196515201	1	FA	A	402	1	SR A1A TO SR 856 N TO W	7	7	7	N	N	PM	45	C	20172018	ND	90
870604	42999615201	1	FA	A	402	1	I-75	7	7	7	N	N	PM	45	C	20112012	ND	77.3
870606	43653915201	1	FA	A	402	0	Intracoastal Waterway	7	7	7	8	N	PM	45	C	20142015	ND	89.1
870607	43653915201	1	FA	A	402	0	Intracoastal Waterway	7	7	7	8	N	PM	45	C	20152016	ND	76
870621	44196315201	1	FA	A	501	0	RIO VISTA CANAL	5	5	5	7	N	RH	57	C	20172018	FO	78
870624	43653815201	1	FA	A	302	0	SNAKE CREEK CANAL C-9	7	6	7	8	N	PM	45	C	20142015	ND	72.8
870628	44196115201	1	FA	A	501	0	CANAL C-102	4	4	7	8	N	RH	57	C	20172018	SD	40.7
870651	44196615201	1	FA	A	502	0	Snapper Creek CANAL C-2	7	7	7	8	N	PM	43	C	20172018	ND	87
870657	42877315201	1	FA	A	302	1	SCL R/R	7	7	7	N	N	PM	45	C	20102011	FO	78

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Figure 4-3. A Snapshot of the Collected 2020 Bridge Work Plan

Bridge Inspection Reports: Bridge inspection reports document bridge conditions (including coating conditions) in detail based on the inspections; they protect the public's safety and offer basis for investment in bridge structures. Typically, bridges are inspected every two years following a testing protocol (Burgess, 2015). A sample bridge inspection report was collected for the Rickenbacker Causeway Bridge located in Miami Dade County, and two spreadsheets containing inspection records for all the bridges in District 6 over the past 10 years were collected. The inspection record spreadsheets were extracted from the BMS. In addition, the project team collected the full inspection reports over the last 10 years for the following bridges (Table 4-1). These bridges were identified as requiring "replace paint system" according to the Bridge Work Plan.

Table 4-1. A List of Bridges for the Request of Full Inspection Reports.

Bridge Number	FM Number
870019	43654015201
870055	44618915201
870071	43325415201
870082	24923925201
870162	44480115201
870162	44480115201
870163	44480115201
870305	43119415201
870349	42796415201
870371	43653115201
870451	42999915201
870455	43119115201
870470	42999515201
870472	43652815201
870473	43119015201
870474	43119215201
870600	44480515201
870603	44196515201
870604	42999615201
870606	43653915201
870607	43653915201
870624	43653815201
870657	42877315201
870724	44619315201
870731	44619015201
870759	43652715201
870763	44619015201
871001	44480515201
879004	42878015201
879007	43652915201
900077	43653215201

4.3 Surface Preparation and Coating Application

The information on the surface preparation and coating application refers to accepted and standard protocols at the time of application. Information is available in FDOT material specifications, Bridge Maintenance Reference Manual, as well as accepted guidelines from institutions such as AASHTO, SSPC, and NACE. These documents were collected form the websites of FDOT and other agencies.

Information on project-specific modifications and repair applications such as time delay to coating application, surface cleaning and non-ideal applications to joints and bridge hardware can be obtained from specific construction documents such as construction contracts, technical specifications, and construction daily reports. These documents are still being collected from the district Construction Offices. The project team collected the construction documents for bridge construction/maintenance projects that involve the activities of “coating new structural steel” and “coating existing structural steel” over the last 10 years in District 6. To be more specific, the construction documents for the contracts listed in Table 4-2 were collected.

Table 4-2. Contract Numbers for the Request of Construction Documents.

Contract Number
T6262
E6F47
E6G10
E6G62
E6H12
E6H38
E6H39
E6H55
E6H56
E6H59
E6H60
E6H61
E6I57
E6I58
E6I74
E6J52
E6J75
E6J76
E6K72
E6K74
E6K87
E6K88
E6J44
E6J51
E6K86
E6L23
E8Q16

4.4 Environmental Exposure

The project team has collected several datasets on potential environmental factors that affect steel bridge coating from publicly available sources. The collected datasets include outdoor air quality data, ocean temperature data, and water quality data. The outdoor air quality data was obtained from the website of U.S. Environmental Protection Agency (USEPA 2020) and includes ambient concentrations of pollutions measured by monitoring stations in Florida. The measured pollutions are Ozone, Particular Matter (PM10 and PM2.5), Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Sulfur Dioxide (SO2), and Lead (Pb). The ocean temperature data was collected from the website of National Oceanic and Atmospheric Administration (NOAA 2020) and includes historical ocean temperature information measured from 12 monitoring stations in Florida. The water quality data was collected from the website of Water Quality Portal (USGS et al. 2020) and includes physical properties (such as pH, light attenuation, and dissolved oxygen) of water sites in Florida.

4.5 Cost

Coating cost information was also collected to allow the users to correlate cost information with coating performance. Cost information on coatings can be obtained from historical cost summary reports, bidding documents from contractors, or construction documents for each project.

The project team has collected a sample of bidding documents for bridge rehabilitation projects. The sample data includes the bidding documents for all the bridge rehabilitation projects in District 6 over the past 10 years. Each bidding document contains the following information for each cost item: quantity, unit price and bid amount (total price) from each contractor, and average bid amount. For steel coating-related cost data, the lowest responsive bidders and their bidding price for the cost item “COATING EXISTING STRUCTURAL STEEL” with cost item number “0561” were extracted and were integrated with the proposed database.

Table 4-3 summarizes the collected data sources with their data information.

Table 4-3. A List of Data Sources and Data Types

Data Category	Data Source	Data Type
Bridge Inventory Data	Florida Bridge Inventory	District, County, Owner, Bridge Number, Structure Name, Roadway, Average Daily Traffic, Facility Crossed, Year Built, Reconstructed, Last Inspection, Sufficiency Rating, Health Index, NBI Rating
Coating Performance Data	Bridge Work Plan (BWP) Report	Bridge Number, Financial Management Project Number, Maintenance Responsibility, Federal Aid System, Operational Status, Structure Type, Route, Feature Intersected, Deck Numerical Condition Ratings (NCR), Superstructure NCR, Substructure NCR, Channel/Waterway NCR, Culvert NCR Action Category, Action Type, Deficiency Discovery Date, Action Status, Deficiency Rating, Sufficiency Rating
	Bridge Coating Conditions	Bridge Number, District, Custodian, Facility Carried, Feature Intersected, Latitude, Longitude, Material Type, Design Type, Year Built, Steel Element, Coating Type, Quantity Condition State 1, Quantity Condition State 2, Quantity Condition State 3, Quantity Condition State 4, Structure Unit
	Bridge Inspection Reports	Inspection Report ID, Bridge Number, District, Inspection Date, Inspection Operator, Year Built, Owner, Maintained By, Structure Name, Structure Type, Location, Route, Facility Carried, Service Type On, Service Type Under, Feature Intersected Above Water, Under Water, Location Map, Sufficiency Rating, Health Index, Element/Env Element Category, Condition State, Description, Quantity
Surface Preparation and Coating Application Data	Bridge Maintenance Reference Manual	Industry Standards for Surface Preparation, Surface Preparation Key Criteria, Surface Cleaning Level, Coating Application Method and Description
Environmental Exposure Data	Environmental Information Databases	Ozone, Particular Matter (PM10 And PM2.5), Carbon Monoxide (CO), Nitrogen Dioxide (NO2), Sulfur Dioxide (SO2), Lead (Pb), Ocean Temperature, Water pH Level, Light Attenuation, Dissolved Oxygen
Cost Data	Bidding Documents	Quantity, Unit Price, Total Price, Average Bidding Price

CHAPTER 5. DATABASE DEVELOPMENT PROCESS

A digital database of steel bridge coating (SBC) data was developed. The SBC database has a graphical user interface to facilitate locating the data that are relevant to the state steel bridge coating systems. In addition, the database offers analytics functions that allow users to select, analyze, and visualize the data in different ways based on their needs. The database provides access to pertinent bridge identification information, relevant inspection and construction documents, historical coating conditions, bridge work plans, and coating cost. It also offers access to the relevant environmental data. The following sections provide (1) a description of the database development process, (2) a description of the data contained in the database, and (3) an introduction of the main functions of the database.

5.1 Database Structure Design

This subtask aims to design the structure of the SBC database that stores and correlates data on bridge inventory, coating conditions, bridge inspection, bridge construction, environmental exposure, and coating cost. A conceptual schema for the database was created in the form of an entity-relationship (ER) model. The conceptual schema provides detailed descriptions of the entity types, relationships, and constraints (Elmasri and Navathe, 2017). An entity is an object that exists in the real world. It can be an object with a physical existence (e.g., a steel bridge or a coating) or an object with a conceptual existence (e.g., a coating cost or a coating inspection). Each entity has attributes that represent its properties. For example, a Steel Bridge entity is described by the bridge number, facility intersected, facility crossed, year of construction, year of reconstruction, latitude, longitude, location, custodian, district, and design. The entity-attribute list was generated based on the data requirements obtained from the previous task and was checked for errors or oversights (e.g., synonyms, redundant information, mutually exclusive data). The ER model of the SBC database is shown in Figure 5-1.

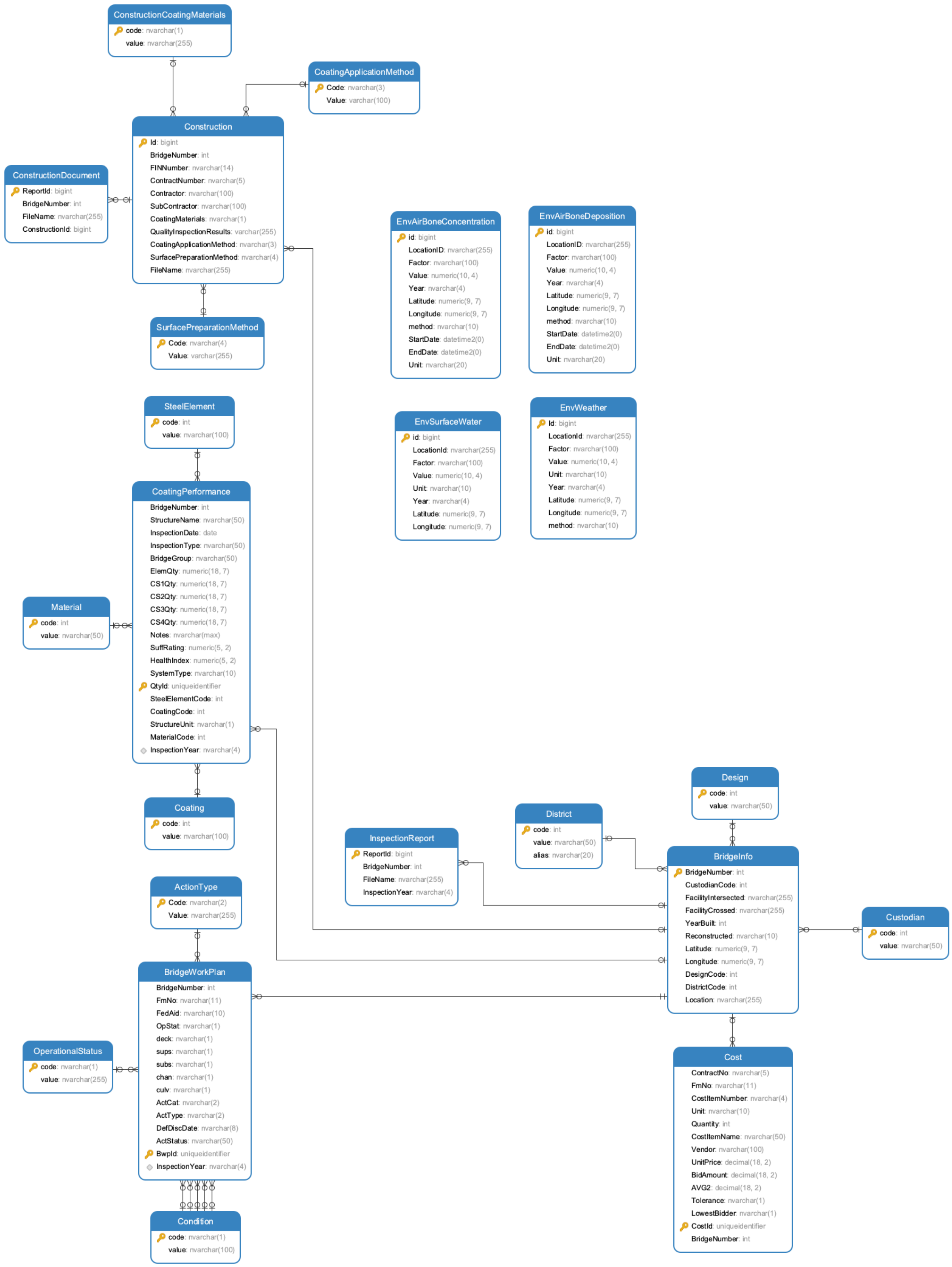


Figure 5-1. ER Model for the Steel Bridge Coating Database

In order to implement the conceptual schema in a relational database, the logical design was initiated to map the ER model into a logical data model, which documents the structure of the data to be implemented in the database. The mapping process was conducted using the normalization technique, which synthesizes individual data elements into normalized tables after analyzing the data element interdependencies (Hogan, 2018).

5.2 User Interface (UI) Design

This subtask aims to design the web UI of the SBC database. User and task analysis were conducted based on the gathered functional requirements from the project manager. An information architecture was then developed to capture the process of how users search, view, add, edit, and delete the steel bridge coating data in the database. An information architecture is the structured design of shared information environments, and provides a blueprint to organize information, content, and functionality of a website that maximizes user experience (Rosenfield, 2015). Figure 5-2 shows the information architecture diagram for the steel bridge coating database system. A website wireframe was created and visual features (such as layouts, icons, fonts, color etc.) were added to it iteratively according to the feedbacks from the project manager and potential users. The UI was also integrated with GIS mapping to correlate environmental and geographic factors relevant to the bridge coating information.

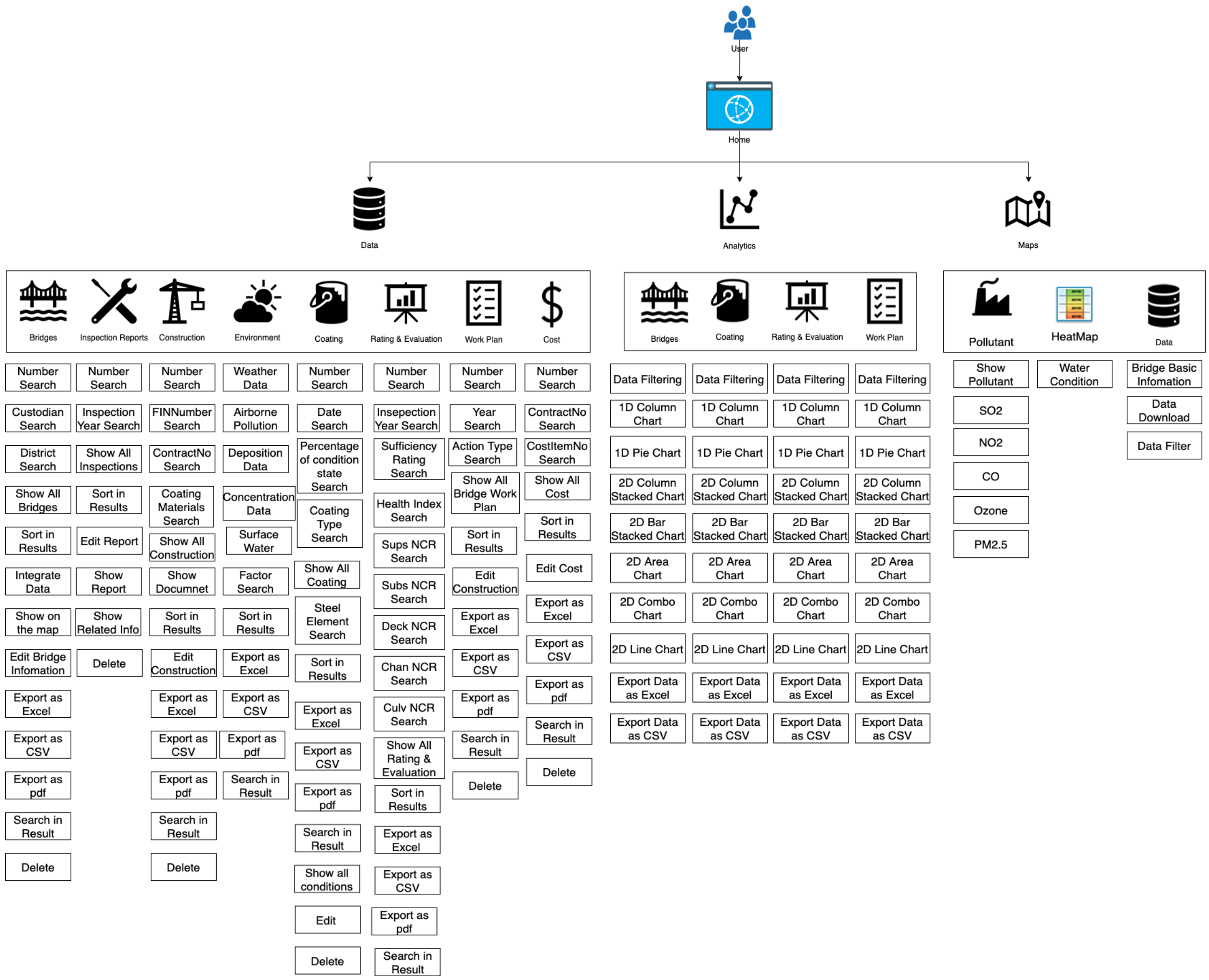


Figure 5-2. Information Architecture Diagram of the Database System

5.3 Database Implementation

This subtask aims to implement the SBC database and its UI in a prototype system. The prototype system allows users to search, view, add, edit, and delete the data in the database through a web UI. Per the FDOT Application Development Standards (FDOT, 2019), the prototype system was developed using Microsoft ASP.NET framework in a testing environment. To build an actual, optimized database, the logical data model created was transformed into a database-management-system-specific physical data model. The physical data model specifies the internal storage structures, file organizations, indexes, access paths, and physical design parameters for the database (Elmasri and Navathe, 2017). In this project, the physical data was created using Microsoft Azure SQL server. The web UI was created using web development techniques such as HTML, CSS, and JavaScript based on the final design from subtask 2.2.

CHAPTER 6. DATA DESCRIPTION

The SBC database includes eight categories of data: bridge identification and basic information, bridge coating condition, overall rating and evaluation, bridge inspection, coating cost, bridge work plan, bridge construction, and environmental data. The specific data included in each category is described as follows:

(1) **Bridge Identification and Basic Information Data**: These data were collected from FDOT Bridge Management System, and the data types include Bridge Number, Facility Intersected. Facility Crossed, Year Built, Reconstructed, Latitude, Longitude, Location, Custodian, Design, and District. The description of the data is summarized in Table 6-1.

Table 6-1: Bridge Identification and Basic Information Data

Data Type	Data Description
Bridge Number	A six-digit ID assigned to each bridge project
Facility Intersected	The name of the facility intersected by the bridge
Facility Crossed	A narrative description of the facility carried by the bridge
Year Built	A 4-digit number that represents the year when the construction of the bridge was completed
Reconstructed	A 4-digit number that represents the year when the reconstruction of the bridge was completed
Latitude and Longitude	The geographic coordinates of the bridge in degrees, minutes, seconds, and hundredths of a second
Location	A narrative description of the bridge location, which should be keyed to a distinguishable feature (e.g., road junctions, topographical features), of an official FDOT map
Custodian	The type of the agency that has primary responsibility for maintaining the bridge
Design	A description of the predominant type of design and/or type of construction of the bridge
District	The number and name of the FDOT highway district in which the bridge is located

(2) **Bridge Inspection Data**: These data types include bridge number, inspection year, and inspection reports in the PDF format. The description of the data is summarized in Table 6-2.

Table 6-2: Bridge Inspection Data

Data Type	Data Description
Bridge Number	A six-digit ID assigned to each bridge project
Inspection Year	A 4-digit number that represents the year when the inspection was completed
Inspection Report	A report in PDF format that contains detailed information on bridge inspection

(3) Bridge Construction Data: These data should be collected from construction documents such as contract documents, project specifications, or field reports, and the data types include Bridge Number, Financial Management Project Number, Contract Number, Coating Material, and Construction Document. The description of the data is summarized in **Error! Reference source not found.** 6-3.

Table 6-3: Bridge Construction Data

Data Type	Data Description
Bridge Number	A six-digit ID assigned to each bridge project
Financial Management Project Number	A 11-digit numerical code that represents the financial project ID for each bridge project
Contract Number	An alphanumeric code that identifies the contract of the project
Coating Material	The specific type of coating material used for the bridge element
Construction Document	The name of the group the bridge belongs to if one exists. Bridge groups are used to group bridges for a specific inspection contract

(4) Bridge Coating Condition Data: These data were collected from the Bridge Management System, and the data types include Bridge Number, Bridge Element Number, Inspection Date, Inspection Type, Bridge Group, Element Quantity, Condition State 1 Quantity, Condition State 2 Quantity, Condition State 3 Quantity, Condition State 4 Quantity, Percentage of CS1qty, Percentage of CS2qty, Percentage of CS3qty, Percentage of CS4qty, Inspection Notes, Coating Number, and Material Number. The description of the data is summarized in Table 6-4.

Table 6-4: Bridge Coating Condition Data

Data Type	Data Description
Bridge Number	A six-digit ID assigned to each bridge project
Bridge Element Number	A numerical code represents the structural component of the bridge. Only steel elements of the bridge are included in the database
Inspection Date	The month, day, and year when the last routine inspection of the bridge was performed. The Inspection Date is coded as MM/DD/YYYY
Inspection Type	The type of inspection that was performed
Bridge Group	The name of the group the bridge belongs to if one exists. Bridge groups are used to group bridges for a specific inspection contract
Element Quantity	The quantity of the bridge element in inspection. In the database, Element Quantity refers to the quantity of steel coating, which includes the entire protected surface of the steel element
Condition State 1 Quantity	The quantity of steel coating in condition state 1
Condition State 2 Quantity	The quantity of steel coating in condition state 2
Condition State 3 Quantity	The quantity of steel coating in condition state 3.
Condition State 4 Quantity	The quantity of steel coating in condition state 4
Percentage of CS1qty	The percentage of steel coating in condition state 1
Percentage of CS2qty	The percentage of steel coating in condition state 2
Percentage of CS3qty	The percentage of steel coating in condition state 3
Percentage of CS4qty	The percentage of steel coating in condition state 4
Inspection Notes	The remarks on the inspection results.
Coating Number	A numerical code that represents the type of steel coating in inspection
Material Number	A numerical code that represents the material of the bridge element

(5) **Overall Rating and Evaluation Data**: These data were collected from FDOT's bridge work plan reports, and the data types include Bridge Number, Inspection Date, Steel Element Code, Sufficiency Rating, Health Index, Superstructure NCR, Substructure NCR, Deck NCR, Channel/Waterway NCR, Culvert NCR, and System. The description of the data is summarized in Table 6-5.

Table 6-5: Overall Rating and Evaluation Data

Data Type	Data Description
Steel Element Code	A numerical code represents the type of steel element
Sufficiency Rating	A numeric value that describes the bridge's capability to remain in service
Health Index	A numeric value that describes the functional and structural health of the bridge
Numerical Condition Ratings (NCR)	A numeric rating that is used to describe the existing physical conditions as compared to the as-built conditions
Superstructure NCR	A numerical condition rating that describes the physical conditions of superstructure elements (e.g., girder, truss)
Substructure NCR	A numerical condition rating that describes the physical conditions of substructure elements (e.g., piers, abutments, piles, fenders, footings)
Deck NCR	A numerical condition rating that describes the physical conditions of decks
Culvert NCR	A numerical condition rating that describes that describes the physical conditions of the alignment, settlement, joints, structural condition, scour, and other items associated with culverts
Channel/Waterway NCR	A numerical condition rating that describes the physical conditions associated with the flow of water through the bridge such as stream stability and the conditions of the channel, riprap, slope protection, or stream control devices including spur dikes
System	The name of the bridge information system where the data were collected

(6) Bridge Work Plan Data: These data were collected from FDOT's bridge work plan reports, and the data types include Bridge Work Plan Year, Bridge Number, Financial Management Project Number, Federal Aid System, Operation Status, Action Category, Action Type, Acton Status, and Deficiency Discovery Date. The description of the data is summarized in Table 6-6.

Table 6-6: Bridge Work Plan Data

Data Type	Data Description
Bridge Work Plan Year	A 4-digit number represents the year the bridge work plan was published
Financial Management Project Number	A 11-digit number created by the Work Program office that identifies the financial project ID for the work to be performed
Federal Aid System	A yes/no alpha character indicates whether the bridge is on the Federal-aid Highway System (Y) or not (N)
Operation status	A single alpha code that provides information about the actual operational status of the structure
Action Category	A general designation for the nature of work to be performed under a particular Financial Management Project Number
Action Type	A description of the work to be performed by the Financial Management Project Number on the bridge structure listed
Deficiency Discovery Date	To record the fiscal year in which the structural deficiency or deterioration, that causes the bridge to be placed on the bridge work plan, is first discovered

(7) **Coating Cost Data:** These data were collected from the bidding documents, and the data types include Contract Number, Financial Management Project Number, Cost Item Number, Unit, Quantity, Vender, Unit Price, Bid Amount, and Lowest Bidder. The description of the data is summarized in Table 6-7.

Table 6-7: Coating Cost Data

Data Type	Data Description
Contract Number	An alphanumeric code that identifies the contract of the project
Financial Management Project Number	A 11-digit number created by the Work Program office that identifies the Financial Project number for the work to be performed
Cost Item Number	A numerical code represents costs associated with a specific task. In the database, only the cost information for the cost item "COATING EXISTING STRUCTURAL STEEL" with cost item number "0561" are included
Quantity	The quantity of the cost item
Vendor	The name of the contractor that submitted the bid
Unite Price	The price of the cost item per unit
Bid Amount	The bid value for the cost item
Lowest Bidder	A yes/no alpha character indicates whether the bid amount is from the lowest bidder (Y) or not (N)

(8) Environmental Data: These data include three types of data: weather data, airborne pollution data, and surface water data. The weather data were collected from the website of Florida Automated Weather Network (FAWN 2020), and the data types include annual average values of eight factors from 2010 to 2019. Table 6-8 shows the names and definitions of all eight factors included in the weather data.

Table 6-8: Name and Definition of Weather Factors

Data Type	Data Description
temp_dp_2m	Dew point temperature at 2 meters above the ground
temp_soil_10cm	Temperature of the soil at a depth of 10 cm
wind_speed_10m	Wind speed at 10 meters above the ground
temp_air_2m	Temperature of the air at 2 meters above the ground
temp_air_10m	Temperature of the air at 10 meters above the ground
temp_air_60cm	Temperature of the air at 60 cm above the ground
rh_2m	Relative humidity at 2 meters above the ground
rain_2m	Depth of rainfall measured by a tipping bucket gauge at 2 meters above the ground

The airborne pollution data were collected from the website of National Atmospheric Deposition Program (NADP 2020), and the data types include deposition of airborne pollution and concentration of airborne pollution. The deposition measures the amount of chemical that is transferred to a square meter of ground via precipitation. The concentration measures how much of a given chemical is mixed with precipitation. Table 6-9 shows all the deposition and concentration factors included in the airborne pollution data.

Table 6-9: Deposition and Concentration Factors

Deposition Factors	Concentration Factors
Total amount of precipitation in centimeters (ppt); Total volume of precipitation collected by the sampler (svol); Total inorganic nitrogen (totalN) deposition; Potassium (K) deposition; Chloride (CI) deposition; Free acidity (H) deposition; Sulfate (SO4) deposition; Calcium (Ca) deposition; Nitrate (NO3) deposition; Bromine (Br) deposition; Ammonium (NH4) deposition; Magnesium (Mg) deposition; Sodium (Na) deposition	Total amount of precipitation in centimeters (ppt); Potassium (K) concentration; Chloride (CI) concentration; Negative log of the hydrogen ion concentration (pH); Sulfate (SO4) concentration; Conductivity (Conduc); Calcium (Ca) concentration; Nitrate (NO3) concentration; Bromine (Br) concentration; Ammonium (NH4) concentration; Magnesium (Mg) concentration; Sodium (Na) concentration

The surface water data were collected from the website of Water Quality Portal (USGS et al. 2020), and the data types include Bicarbonate, Nitrogen, Nitrite, Nitrate, Magnesium, Sodium, pH, Acidity, Hydrogen ion, Alkalinity, Flow rate, instantaneous, Calcium, Temperature, air, deg C, Stream flow, instantaneous, Nitrogen, Orthophosphate, Biomass, periphyton, Hardness, non-carbonate, Cyanide, Oxygen, Carbon, Wind Velocity, Fluoride, Sulfite, Carbonate, Precipitation, Organic Nitrogen, Potassium, Chloride, Temperature, water, Phosphorus, Sulfide, Salinity, Carbon dioxide, Temperature, water, deg F, Temperature, air, deg F, Hardness, Ca, Mg, Stream flow, mean. daily, Sulfate, and Phosphate-phosphorus.

CHAPTER 7. DATABASE FUNCTIONS

The SBC database provides multiple functions, including searching, viewing, editing, adding, or deleting the data. The following subsections provide an introduction of these functions and the relevant screenshots of the database. Figure 7-1 shows the main menu page of the SBC database.

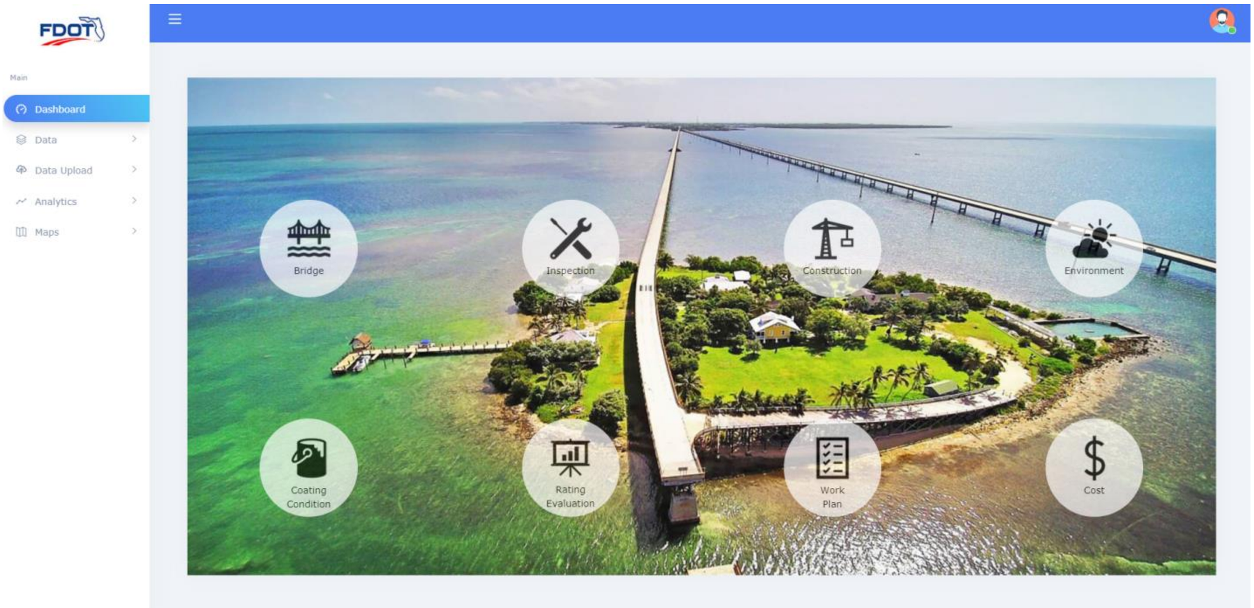


Figure 7-1. Main Menu Page of the Steel Bridge Coating Database

7.1 Search Functions

The SBC database allows users to search for relevant data in the following categories: Bridge Identification and Basic Information, Bridge Inspection, Bridge Construction, Bridge Coating Condition, Overall Rating and Evaluation, Bridge Work Plan, and Coating Cost. In each category, users can either search and view all information or customize their search. Figure 7-2 shows the custom search page for Bridge Identification and Basic Information, where users can search or filter the results based on the (1) Bridge Number, (2) Custodian, and/or (3) District.

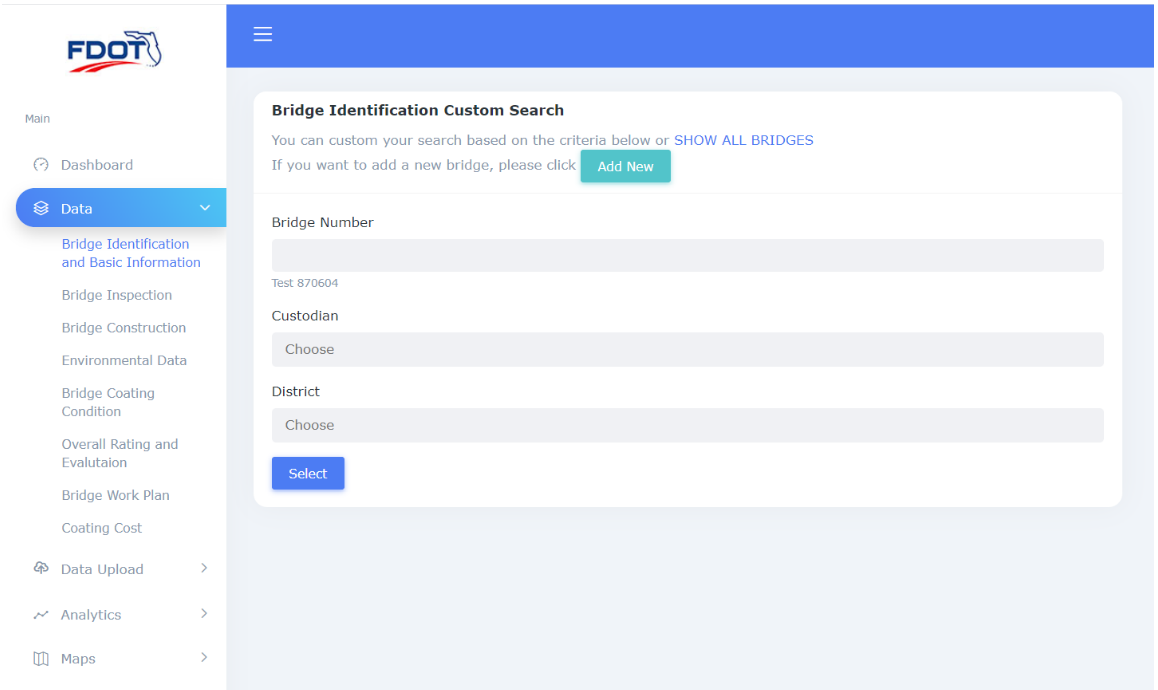


Figure 7-2. Bridge Identification Custom Search Page

Figure 7-3 shows the custom search page for Bridge Inspection Report, where users can search or filter the results based on the (1) Bridge Number, and/or (2) Inspection Year.

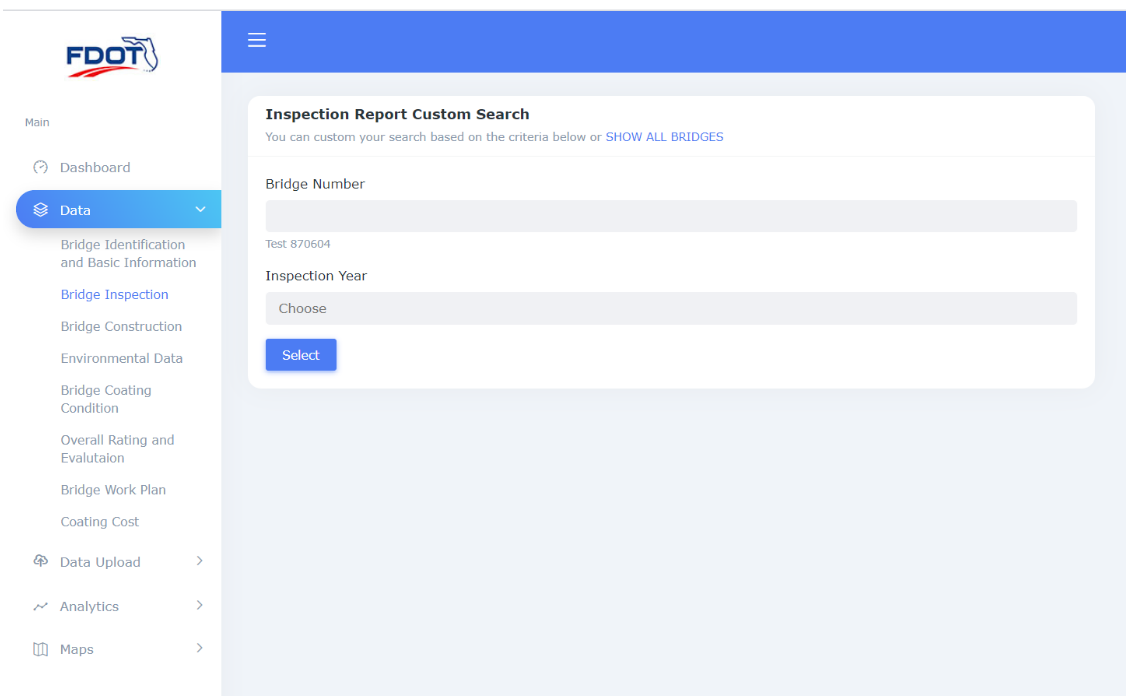


Figure 7-3. Bridge Inspection Custom Search Page

Figure 7-4 shows the custom search page for Bridge Construction, where users can search or filter the results based on the (1) Bridge Number, (2) Financial Management Project Number, (3) Contract Number, and/or (4) Coating Material.

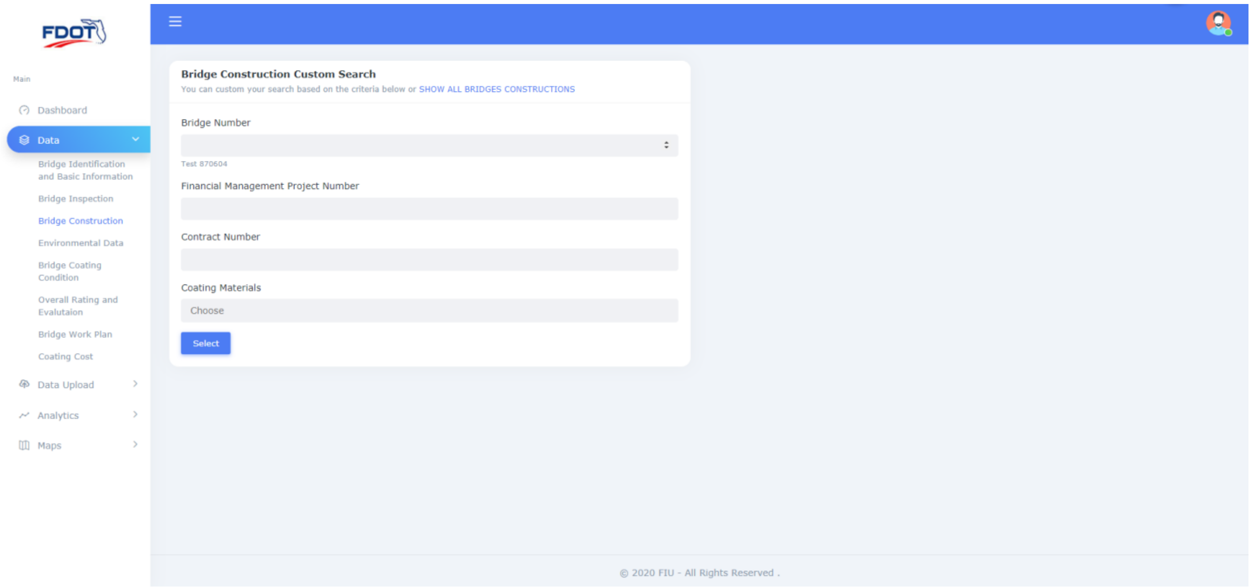


Figure 7-4. Bridge Construction Custom Search Page

Figure 7-5 shows the custom search page for Bridge Coating Condition, where users can search or filter the results based on the (1) Bridge Number, (2) Inspection Date, (3) Percentage of Coating System in Condition State 1, 2, 3, or 4, (4) Coating Type, and/or (5) Steel Element.

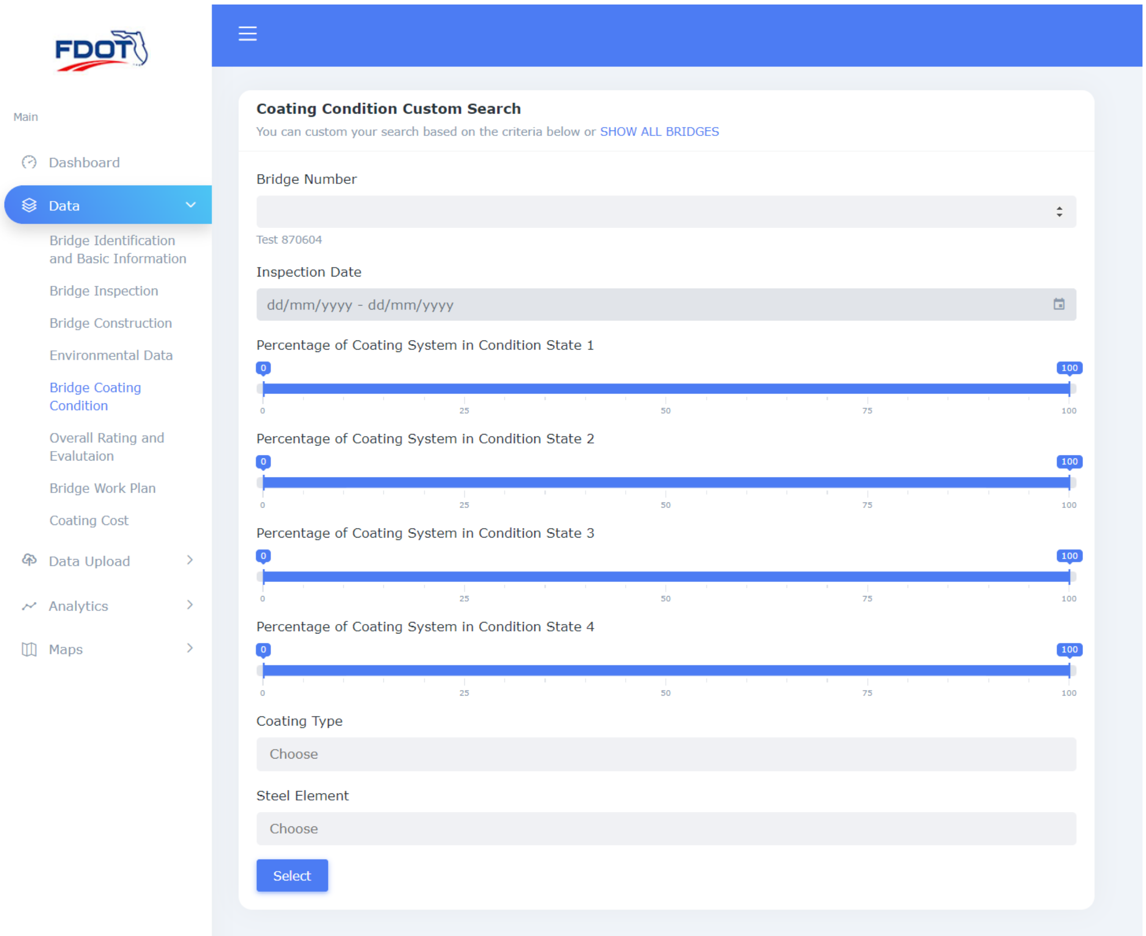


Figure 7-5. Coating Condition Custom Search Page

Figure 7-6 shows the custom search page for Overall Rating and Evaluation, where users can search or filter the results based on the (1) Bridge Number, (2) Inspection Year, (3) Sufficiency Rating, (4) Health Index, and/or (5) Superstructure, Deck, Channel/Waterway, or Culvert NCR.

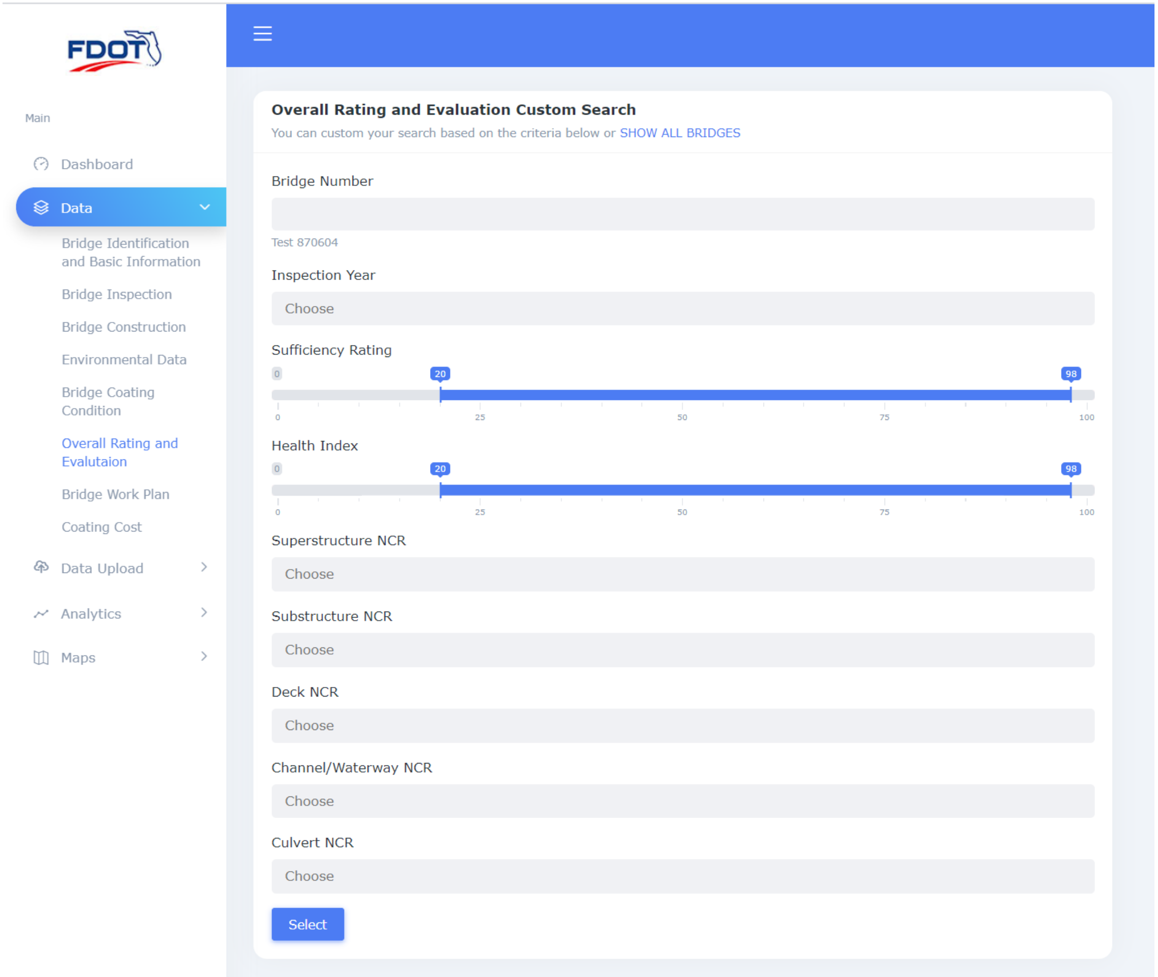


Figure 7-6. Overall Rating and Evaluation Custom Search Page

Figure 7-7 shows the custom search page for Bridge Work Plan, where users can search or filter the results based on the (1) Bridge Number, and/or (2) Bridge Work Plan Year.

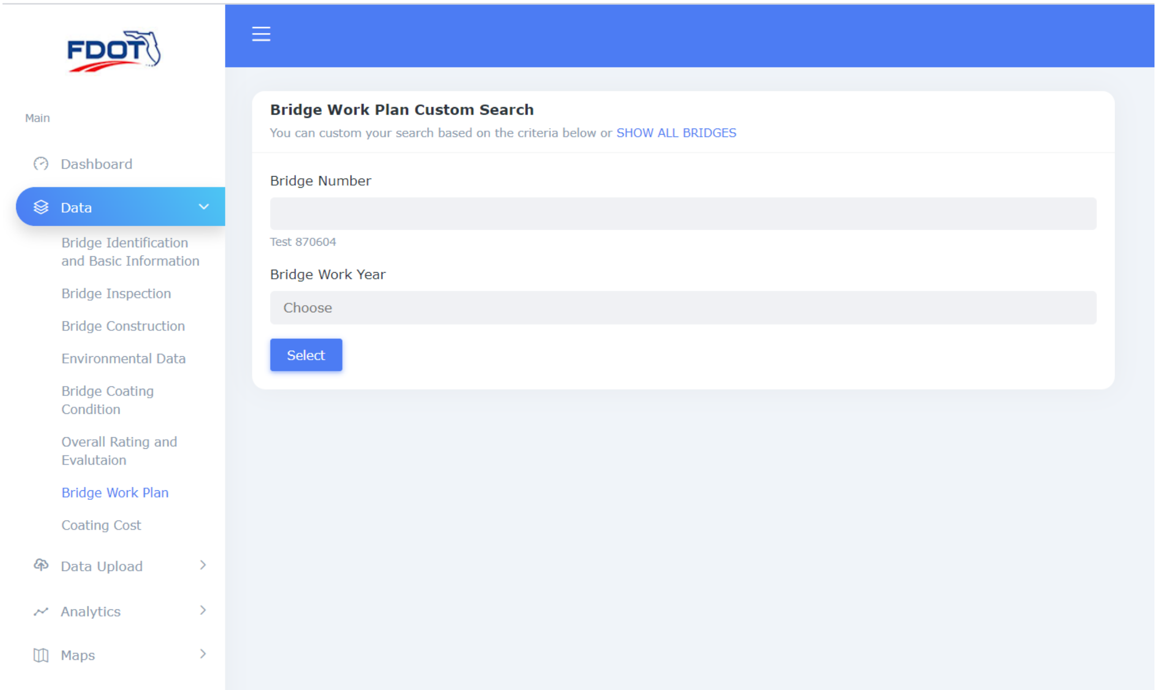


Figure 7-7. Bridge Work Plan Custom Search Page

Figure 7-8 shows the custom search page for Coating Cost, where users can search or filter the results based on the (1) Bridge Number, (2) Contract Number, and/or (3) Cost Item Number.

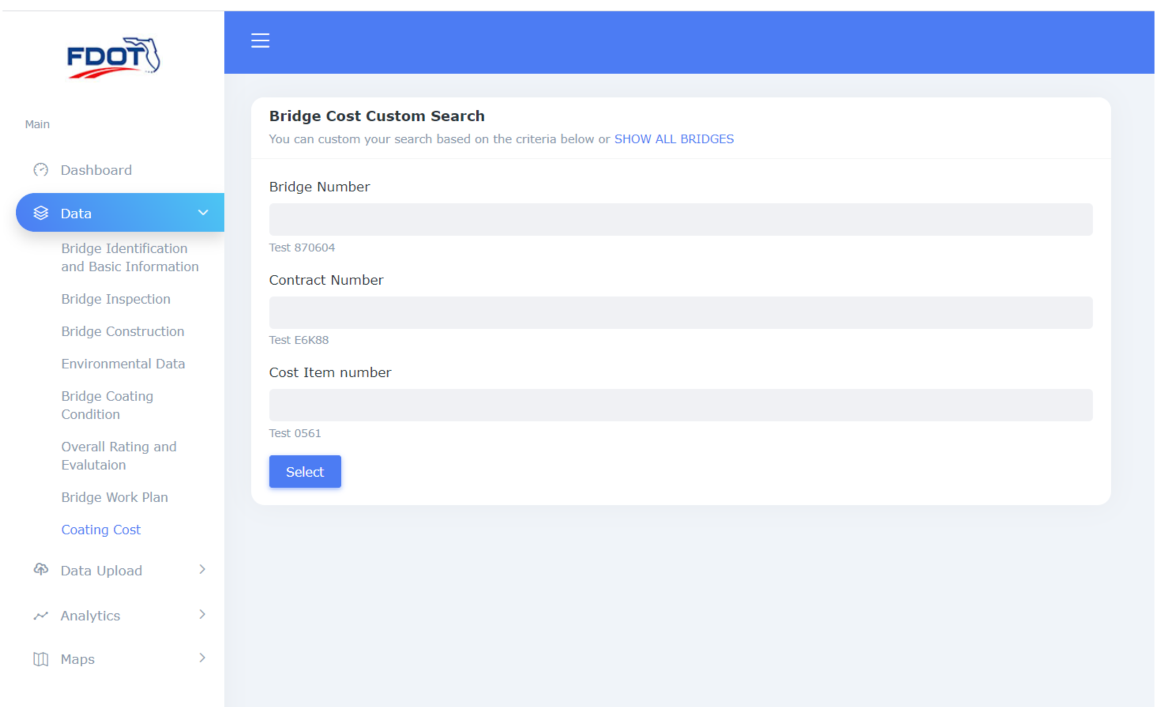


Figure 7-8. Coating Cost Custom Search Page

7.2 View, Edit, Add, and Delete Functions in Data Record Page

Based on the search criteria, the relevant bridge information is displayed in a table format. For example, Figure 7-9 shows all the relevant bridge identification information after searching for all the bridges in "District 6" in the Bridge Identification Custom Search Page. For each returned record, there is a "Operation" field that provides three functions to allow users to view, edit, or delete this record. Users can click the "view" button (blue button) to view the detailed bridge information page. For example, Figure 7-10 shows the detailed information page for the bridge with the bridge number of 870019. Users can also choose to edit this data record by clicking the "edit" button (yellow button). For example, Figure 7-11 shows the editing page for the bridge with the bridge number of 870019. Users can also click the "delete button" (red button) to delete this data record. A confirmation page will show up to confirm whether users want to delete the data record or not (Figure 7-12).

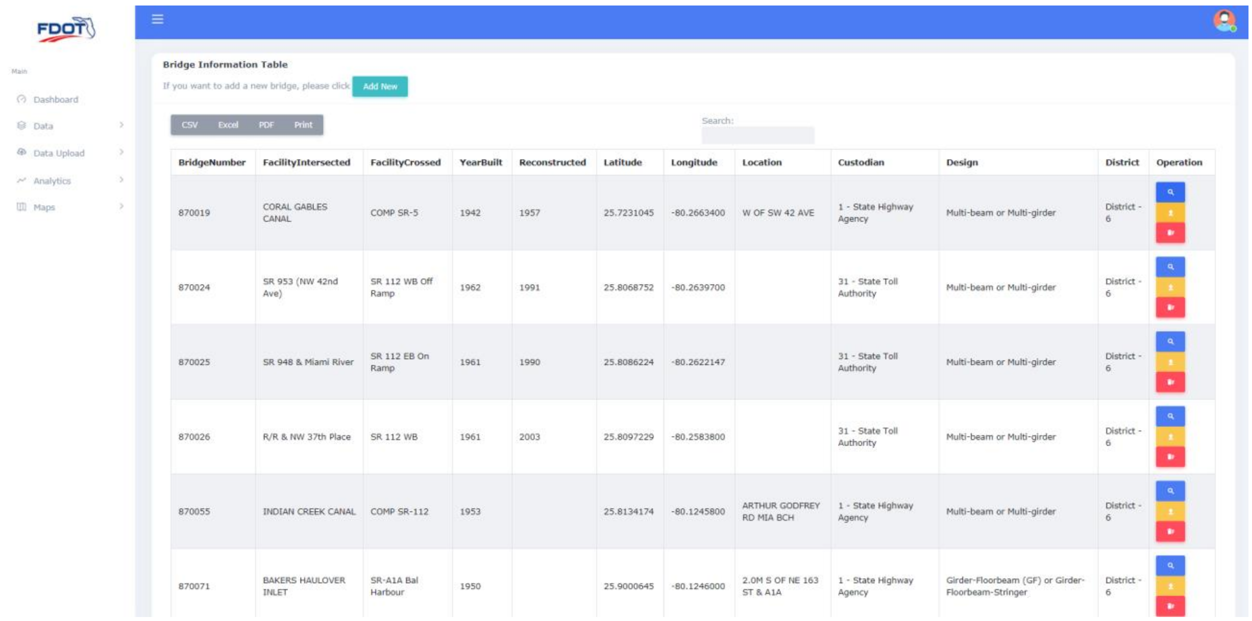


Figure 7-9. Sample Bridge Coating Condition Search Results

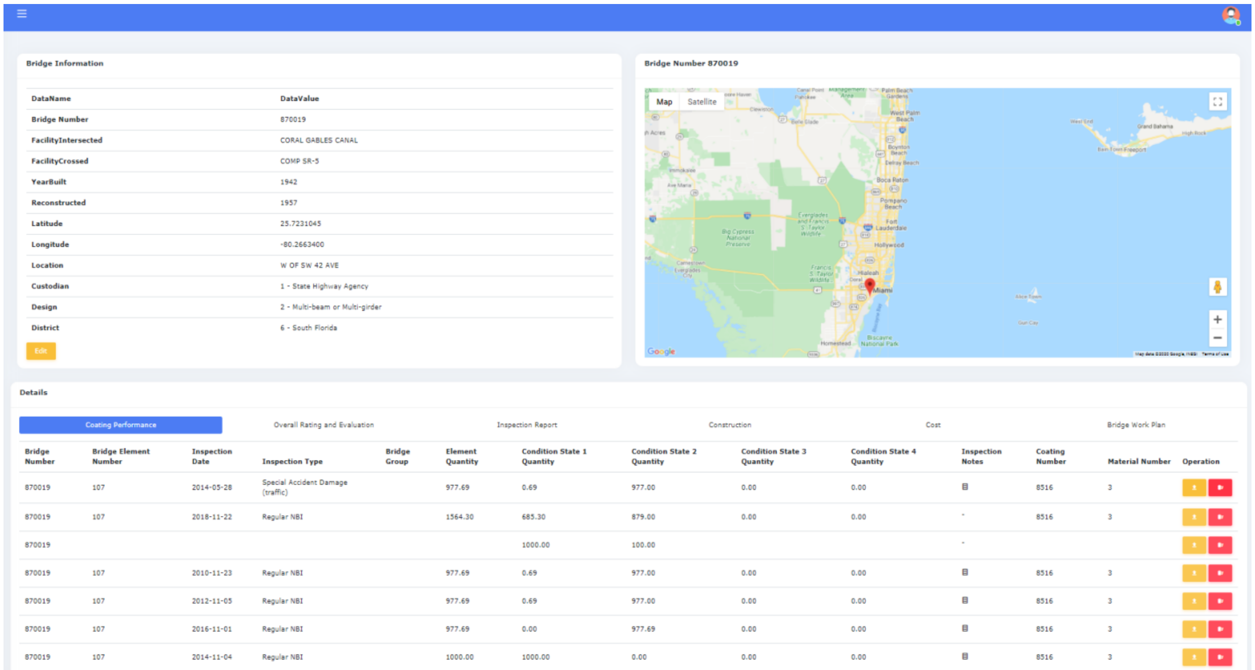


Figure 7-10. Detailed Information Page for Bridge 870019

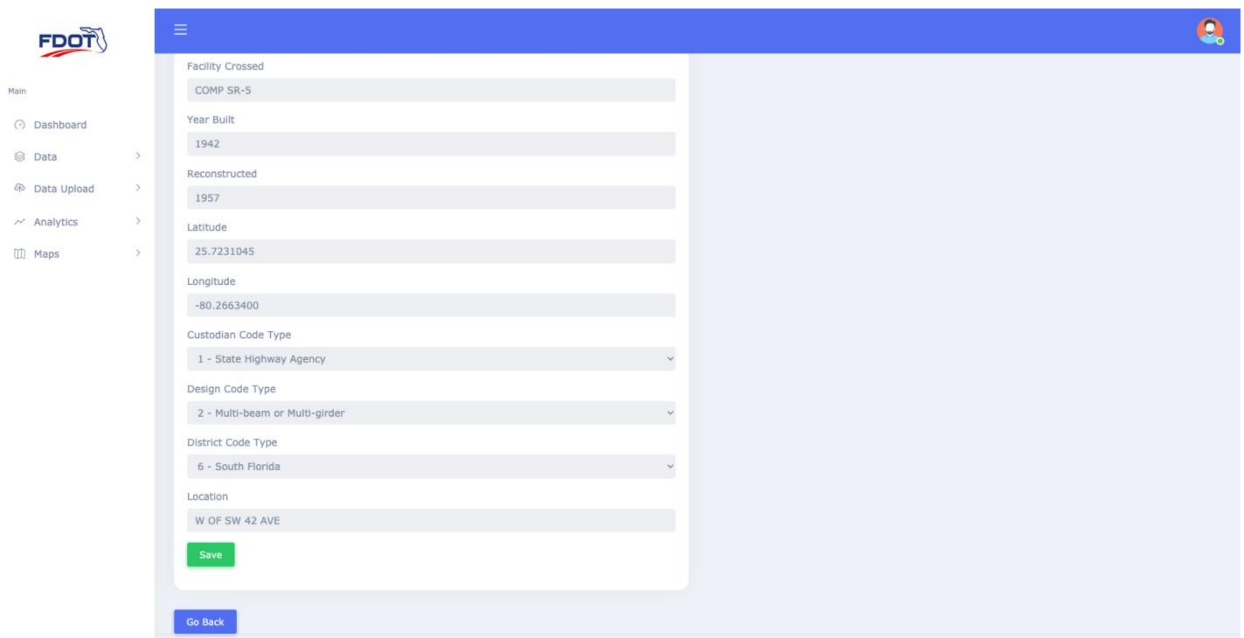


Figure 7-11. Editing Page for Bridge 870019

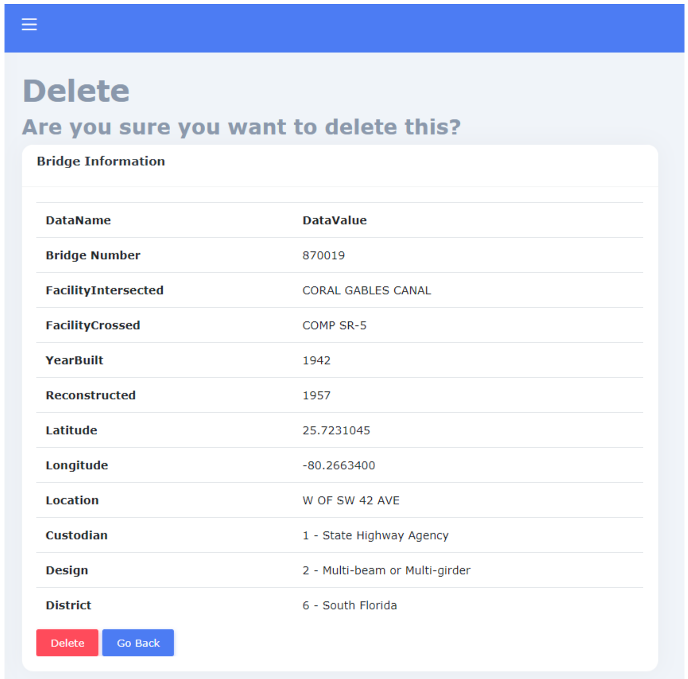


Figure 7-12. Delete Confirmation for Bridge 870019

The SBC database also allows users to add new data records to the system. To add a new bridge into the database, users need to click "Add New" button in the search results page (Figure 7-9). Users will then be directed to the "Create New Bridge" page (Figure 7-13), which provides a template for inputting basic information on a new bridge. The basic information includes Bridge Number, Facility Intersected, Facility Crossed, Year Built, Reconstructed, Latitude, Longitude, Custodian Code Type, Design Code Type, District Code Type, and Location.

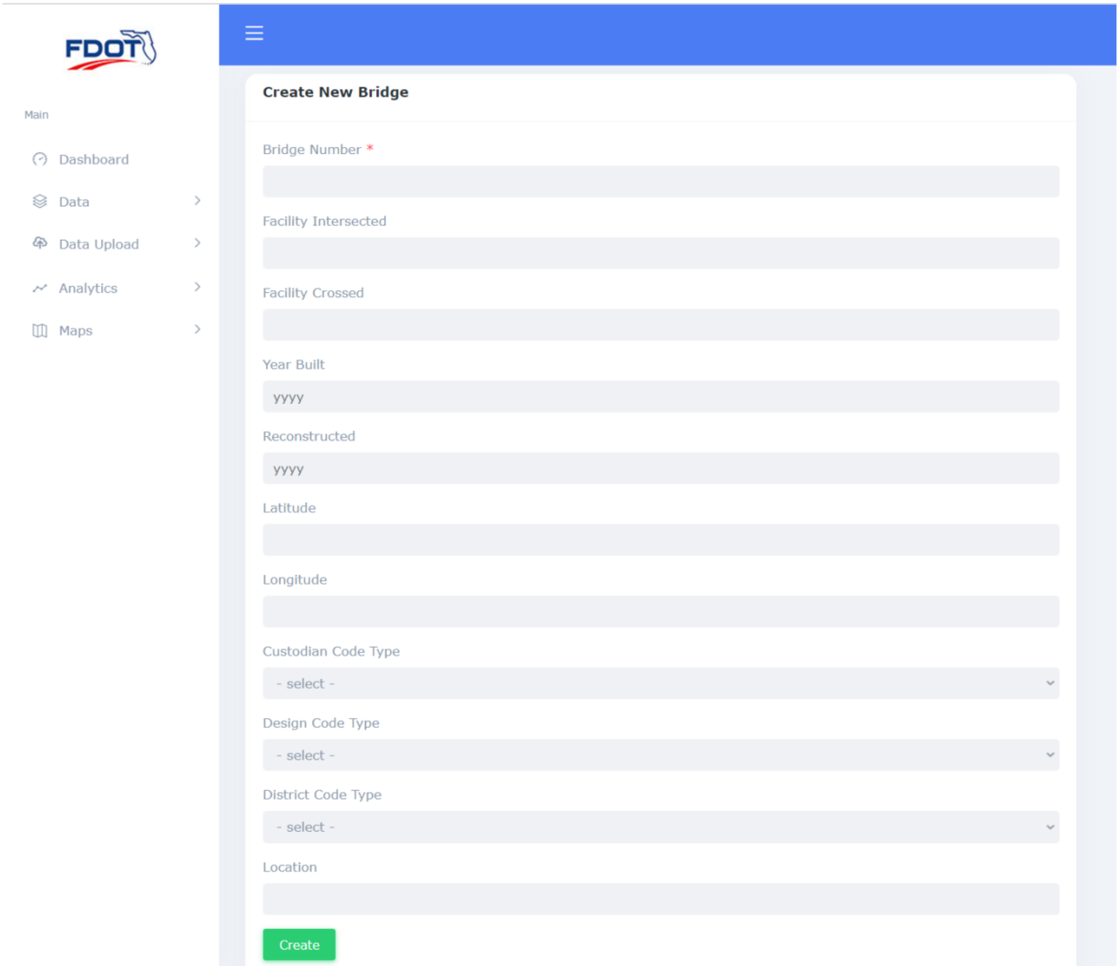


Figure 7-13. Create New Bridge Page

7.3 Edit, Add, and Delete Functions in Detailed Bridge Information Page

Each bridge has its own information page (e.g., Figure 7-10), which contains three sections: basic bridge information section, map section, and detailed information section. The basic bridge information section includes information such as Bridge Number, Facility Intersected, Year Built, etc. The map section displays the location of the bridge in the Google map. The detailed information section includes six tabs for information on Bridge Inspection, Bridge Construction, Coating Condition, Overall Rating and Evaluation, Bridge Work Plan, and Coating Cost.

To add detailed information in each data category, users can click the “Add Information” button at the bottom of each relevant tab under the detailed information section. For example, to add new coating condition information, users can click the “Add Coating Condition Data” button at the bottom of the Coating Condition tab. Users will then be directed to the “Create New Coating Condition” Page (Figure 7-14), which provides a template for inputting new coating condition information. Similarly, users can add new data for bridge inspection, construction, cost, and/or work plans.

In addition, in the detailed information section, users can either edit or delete a specific row of information by clicking the "Edit" button (yellow button) or the "Delete" button (red button) in the "Operation" column.

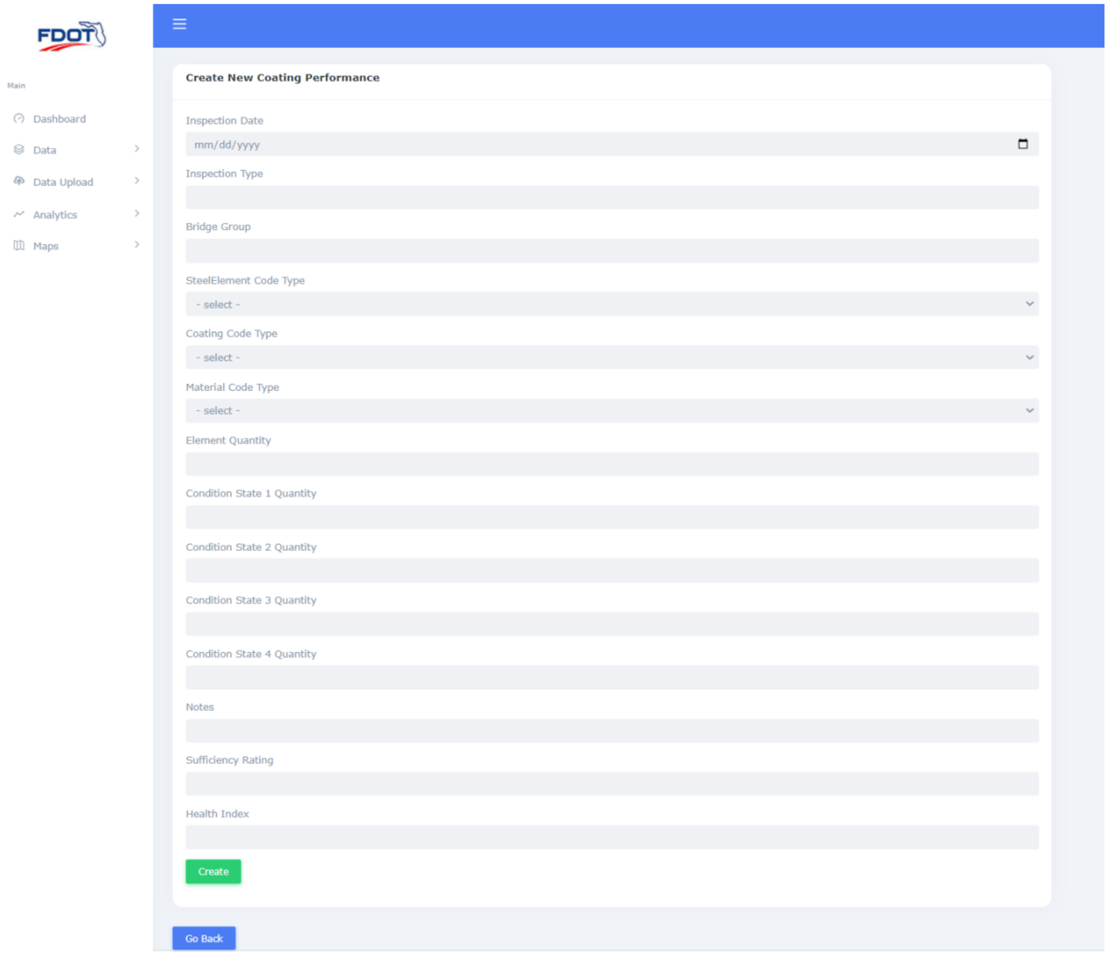


Figure 7-14. Create New Coating Performance Page

7.4 Environmental Data

The SBC database allow users to search for relevant environmental data that may affect coating performance. Three main categories of environmental data are included in the SBC database (as described in the section of "Data Description"): weather data, airborne pollution data, and surface water data. Users can search for relevant data in the environmental data page (Figure 7-15). For example, in the page of weather data, users can search for relevant environmental data by selecting the specific data through a dropdown list (Figure 7-16).

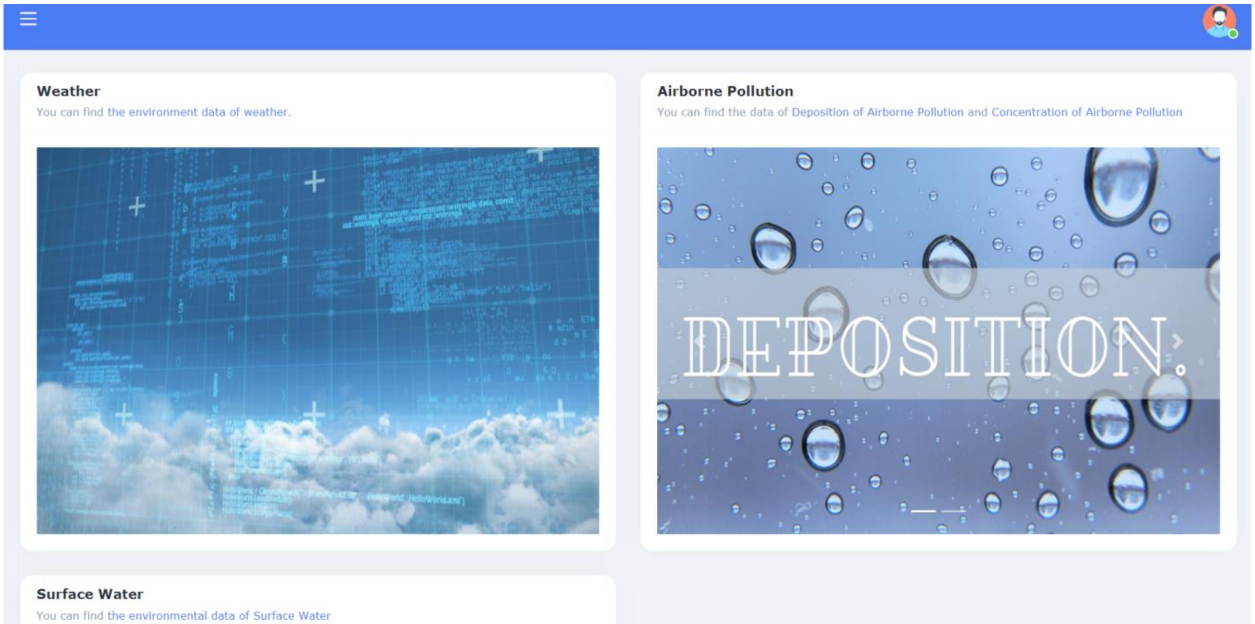


Figure 7-15. Environmental Data Page

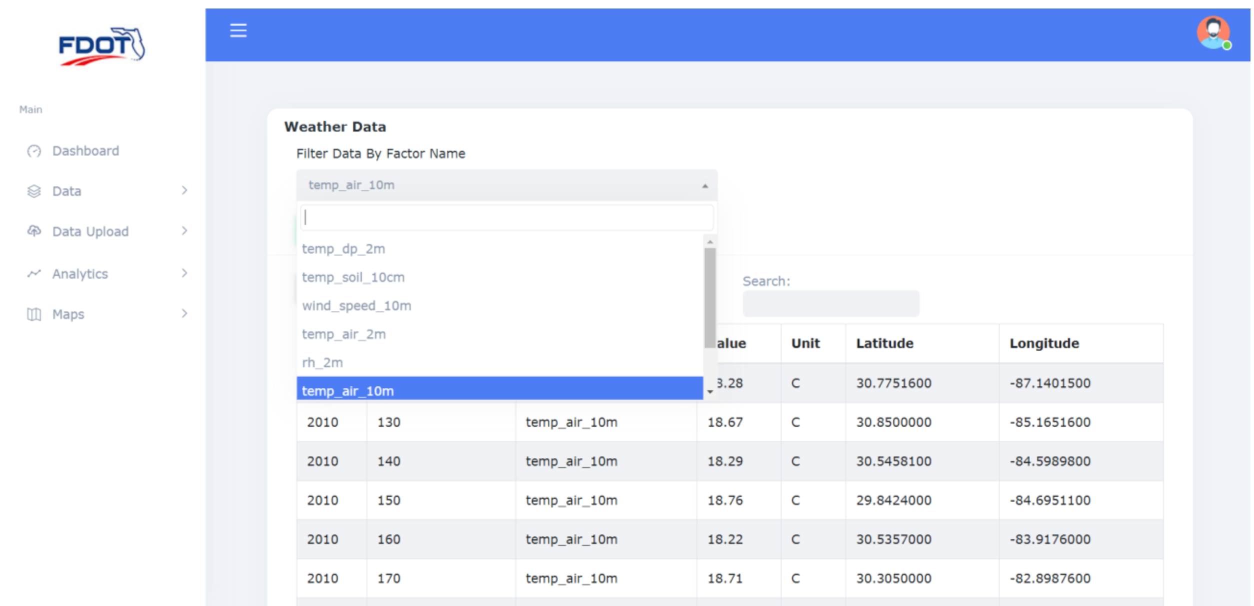


Figure 7-16. Weather Data Page

7.5 Bridge Maps

The SBC database allows users to view all the Florida steel bridges in the database through a Google map and an ArcGIS map. In the Google map (Figure 7-17), a steel bridge is represented as a red pin, which displays the basic bridge information when clicked. Users can also go to the detailed bridge information page by clicking the “Details” button below the basic information.

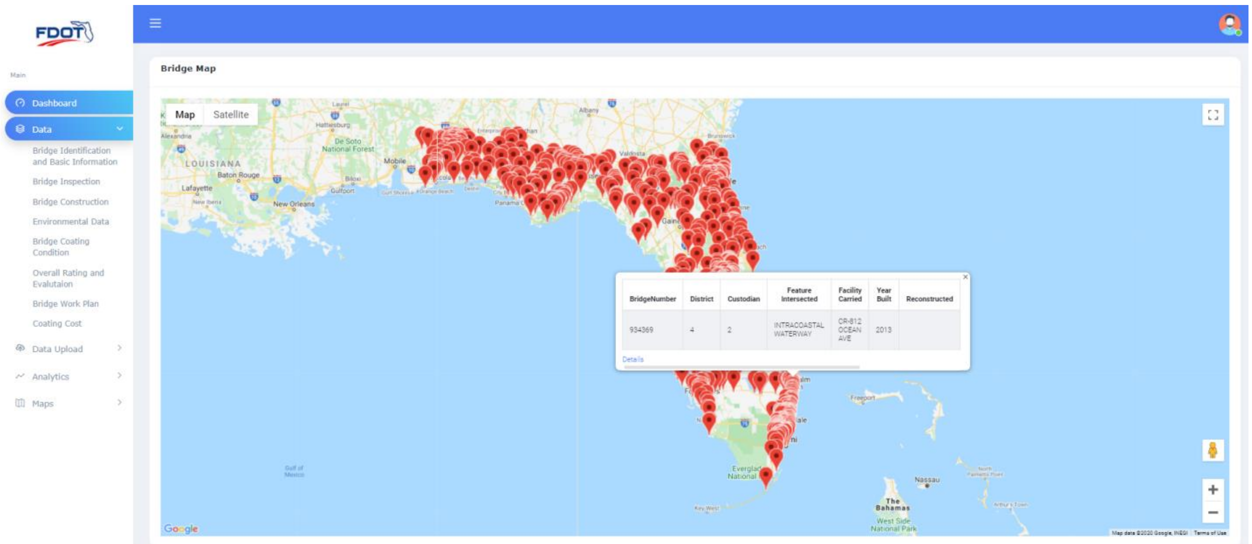


Figure 7-17. Florida Steel Bridges in Google Maps

In the ArcGIS map (Figure 7-18), a steel bridge is represented as a colored dot, the color of which is determined by its coating conditions: the red color indicates the bridge has the highest quantity of coating in Condition State 4 compared to the quantities of coating in other condition states; the orange color indicates the bridge has the highest quantity of coating in Condition State 3 compared to the quantities of coating in other condition states; the yellow color indicates the bridge has the highest quantity of coating in Condition State 2 compared to the quantities of coating in other condition states, and the green color indicates the bridge has the highest quantity of coating in Condition State 1 compared to the quantities of coating in other condition states. In addition, the ArcGIS map can display multiple layers of environmental information (such as air pollution, water quality) together with information of the steel bridges, which facilitates the identification of potential contributing factors that may result in premature coating failures.

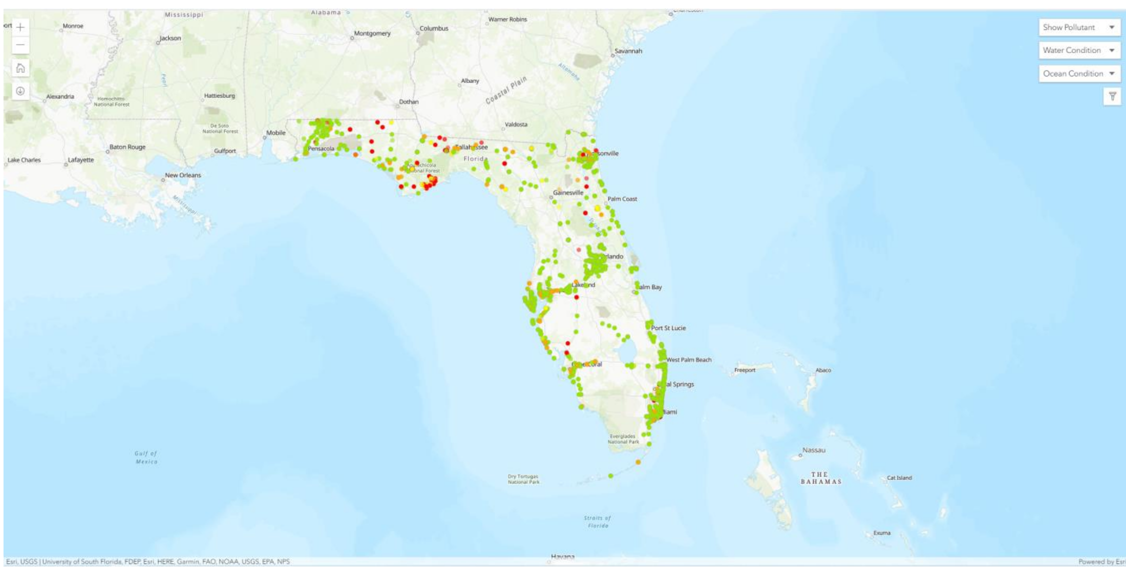


Figure 7-18. Florida Steel Bridges in ArcGIS Maps

7.6 Other Functions

The SBC database also has other functions that support data analytics. For example, it allows users to save the filtered data in csv, xlsx, pdf formats through the buttons located at the right-hand side corner of the data table (Figure 7-9). It also allows users to print all the filtered data. In the search results page (Figure 7-9), a search box is located at the top of the data table to allow users to further conduct onscreen keyword search. For example, if "I-75" is input in the search box, all the data records that include the keyword "I-75" are returned (Figure 7-19).

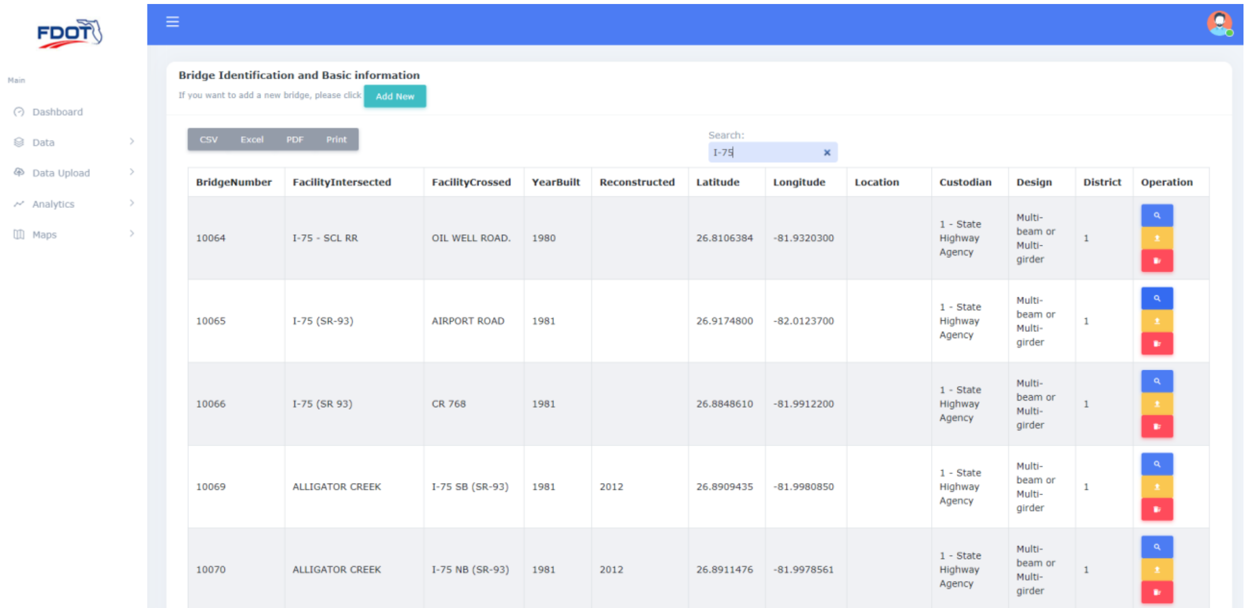


Figure 7-19. Onscreen Search by Inputting "I-75"

CHAPTER 8. ANALYTICS FUNCTIONS

The database offers interactive data analytics functions that allow users to select, analyze, and visualize the data in different ways based on the users' needs. Through these functions, the users are first asked to select or filter the set of data they want to analyze. They will then be offered to choose the criteria for analysis. The system offers the options to visualize the data in either 1-dimensional (1D) chart or 2-dimensional (2D) chart. The following subsections provide an introduction of these analytics functions and the relevant screenshots.

8.1 Bridge Identification Analytics

The Bridge Identification Analytics function first allows users to select and filter the data based on the following: (1) District, (2) Custodian, (3) Built Year, (4) Bridge Element, (5) Coating Type, and (6) Inspection Date. The users can then decide if they want to conduct a 1D analysis or a 2D analysis. For 1D analysis, the users will then select one criterion from among the following: (1) District, (2) Design, (3) Custodian, and (4) Bridge Age. The system will then visualize the data in different types of charts, including column chart and pie chart. For 2D analysis, the users will need to select a criterion A and a criterion B from among the following: (1) District, (2) Design, (3) Custodian, and (4) Bridge Age. Figure 8-1 shows the screenshot of the Bridge Identification Analytics function.

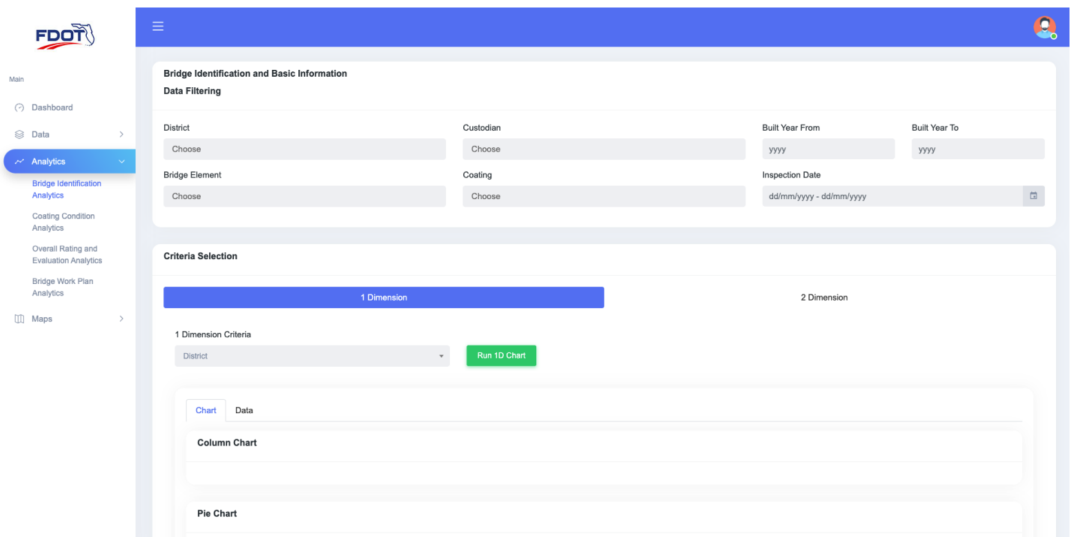


Figure 8-1. Bridge Identification Analytics Function

For example, for 1D data analytics/visualization, users can select "District" as a criterion for analysis. After clicking "Run 1D chart", the system can generate a column chart (Figure 8-2) and a pie chart (Figure 8-3) that show the number of bridges in each district.

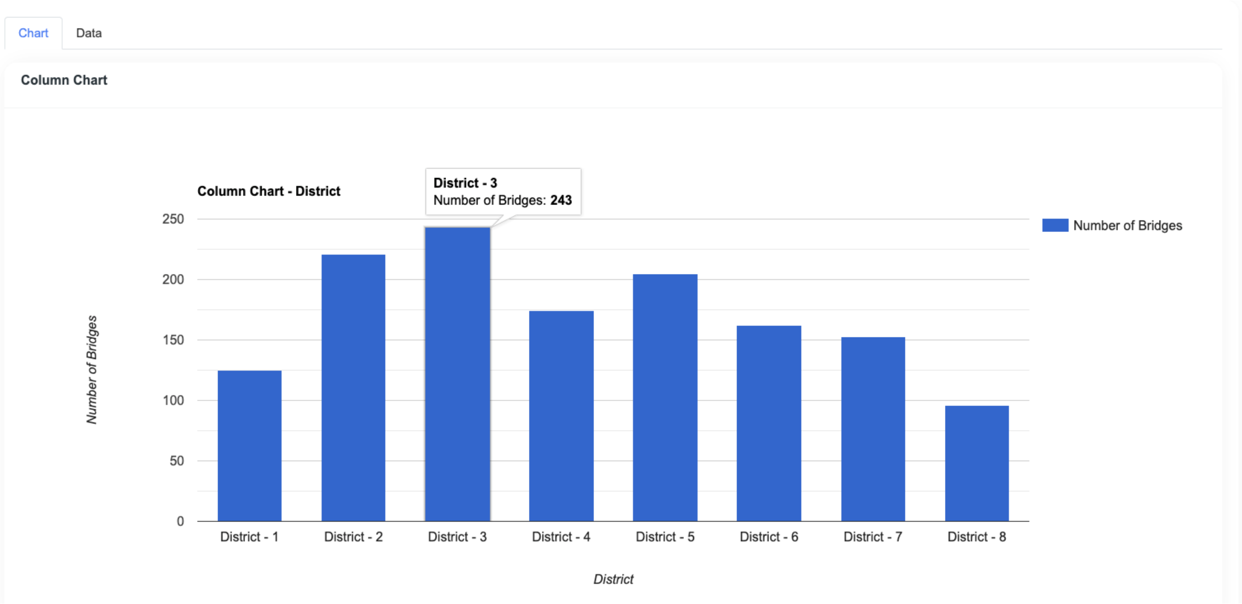


Figure 8-2. 1D Column Chart for Number of Bridges by District

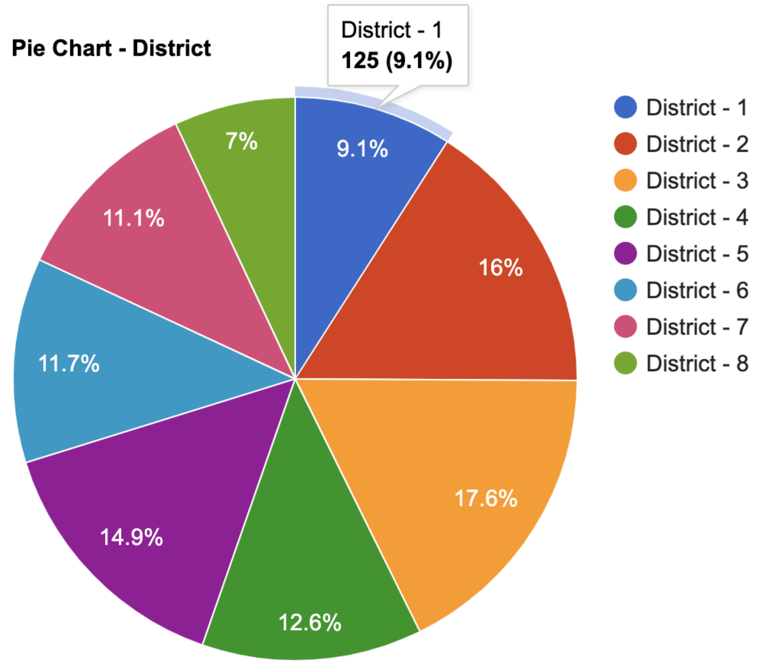


Figure 8-3. 1D Pie Chart for Number of Bridges by District

The system also provides the data that are used to generate the charts. Users can view the data by clicking the "Data" tab, which is located next to the "Chart" tab. Figure 8-4 shows the list of data that represent the number of bridges in each district. Users can then either save the data in csv or excel format, or print out the data.

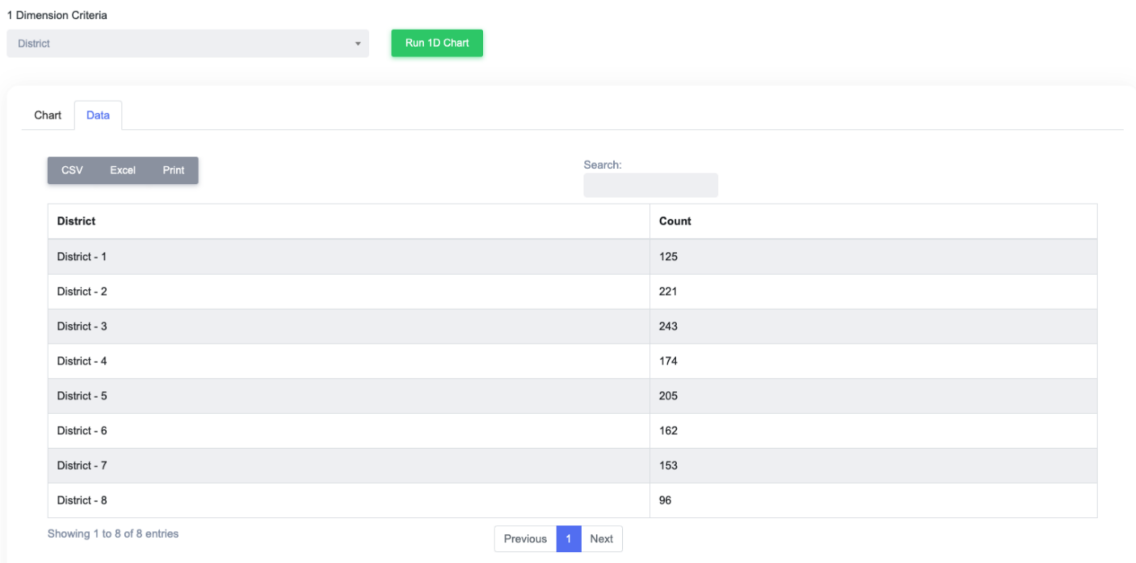


Figure 8-4. Data for Number of Bridges by District

For 2D data analytics/visualization, users can select a combination of criteria, including district, design, custodian, bridge age. The system can then generate 2D charts.

For example, when users select "District" and "Bridge Age" and click "Run 2D Chart", the system can generate a column stacked chart (Figure 8-5), a bar stacked chart (Figure 8-6), an area chart (Figure 8-7), a combo chart (Figure 8-8) and a line chart (Figure 8-9).

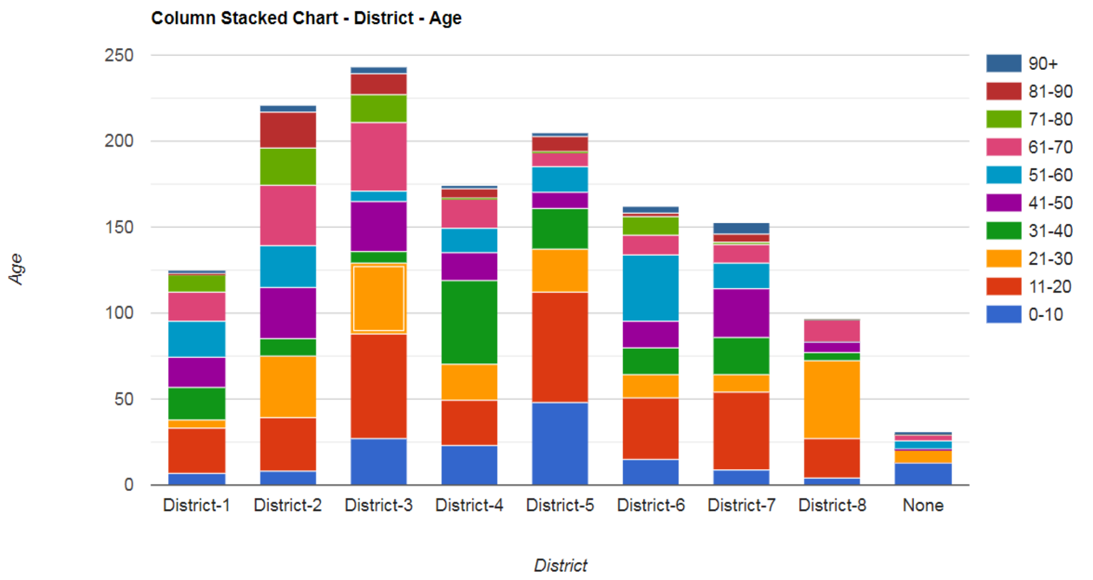


Figure 8-5. 2D Column Stacked Chart for Number of Bridges with Different Ages by District

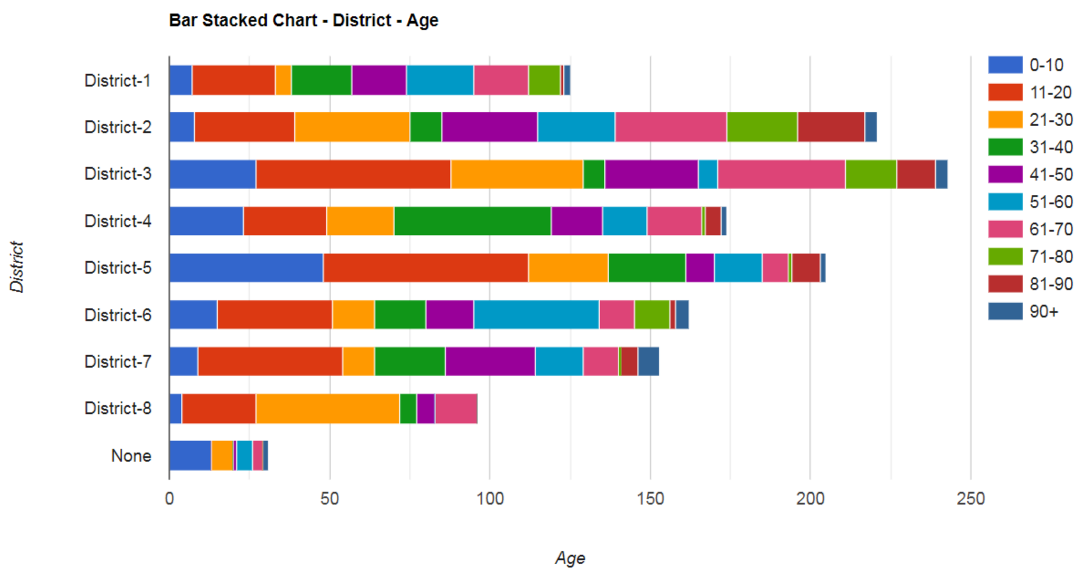


Figure 8-6. 2D Bar Stacked Chart for Number of Bridges with Different Ages by District

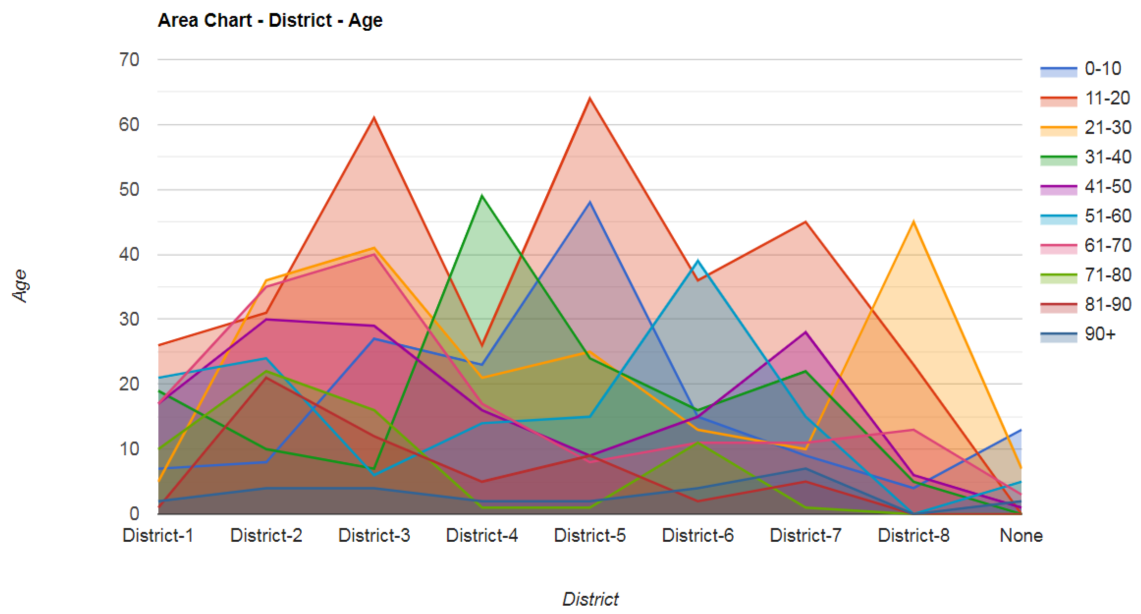


Figure 8-7. 2D Area Chart for Number of Bridges with Different Ages by District

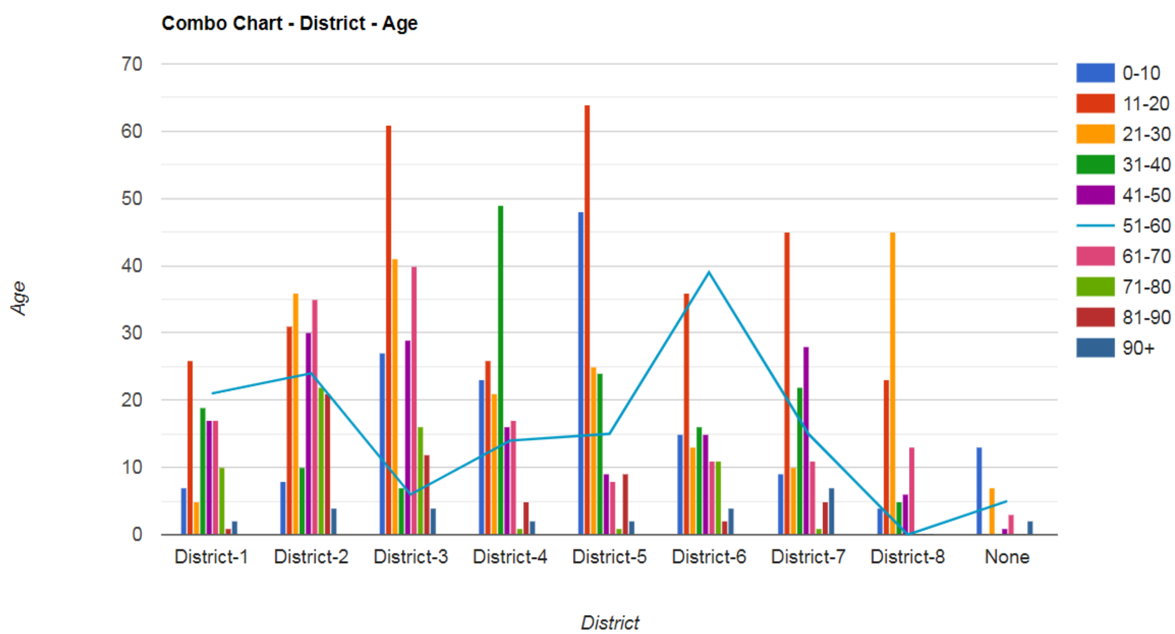


Figure 8-8. 2D Combo Chart for Number of Bridges with Different Ages by District

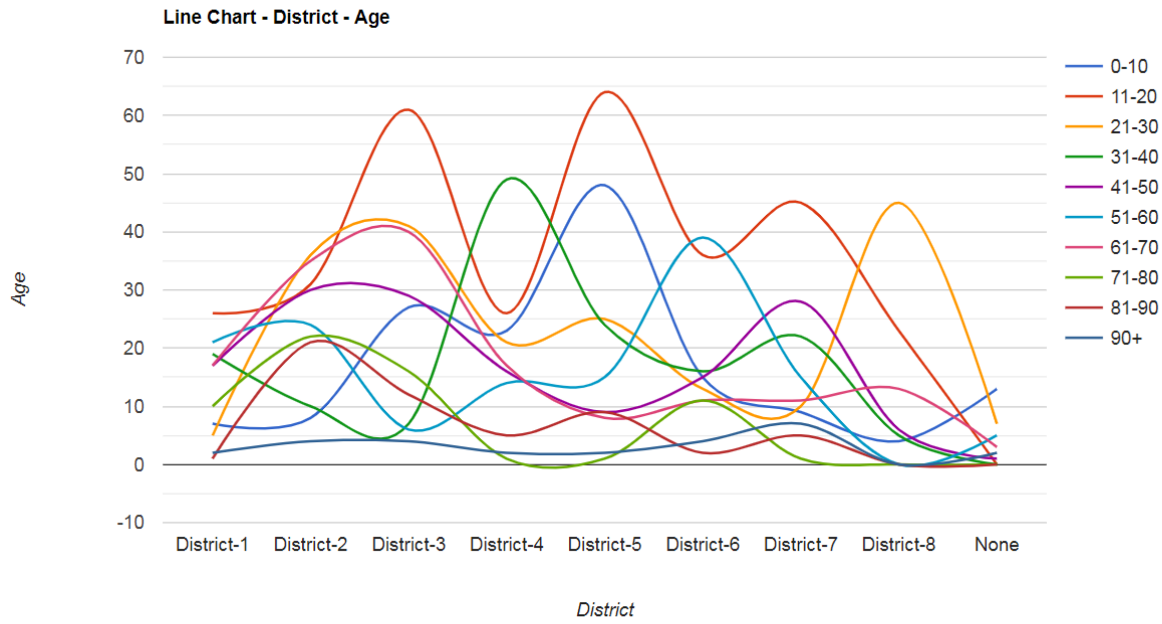


Figure 8-9. 2D Line Chart for Number of Bridges with Different Ages by District

8.2 Coating Condition Analytics

Similar to Bridge Identification Analytics function, the Coating Condition Analytics function first allows users to select and filter the data. The users can then decide if they want to conduct a 1D analysis or a 2D analysis. For 1D analysis, the users will then select one criterion from among the following: (1) Percentage of Coating in Condition State 1, (2) Percentage of Coating in Condition State 2, (3) Percentage of Coating in Condition State 3, and (4) Percentage of Coating in Condition State 4. The system will then visualize the data in different types of charts, including column chart and pie chart. For 2D analysis, the users will need to select a criterion A from among the following: (1) District, (2) Design, (3) Custodian, and (4) Bridge Age, and a criterion B from among the following: (1) Percentage of Coating in Condition State 1, (2) Percentage of Coating in Condition State 2, (3) Percentage of Coating in Condition State 3, and (4) Percentage of Coating in Condition State 4. Figure 8-10 shows the screenshot of the Coating Condition Analytics function.

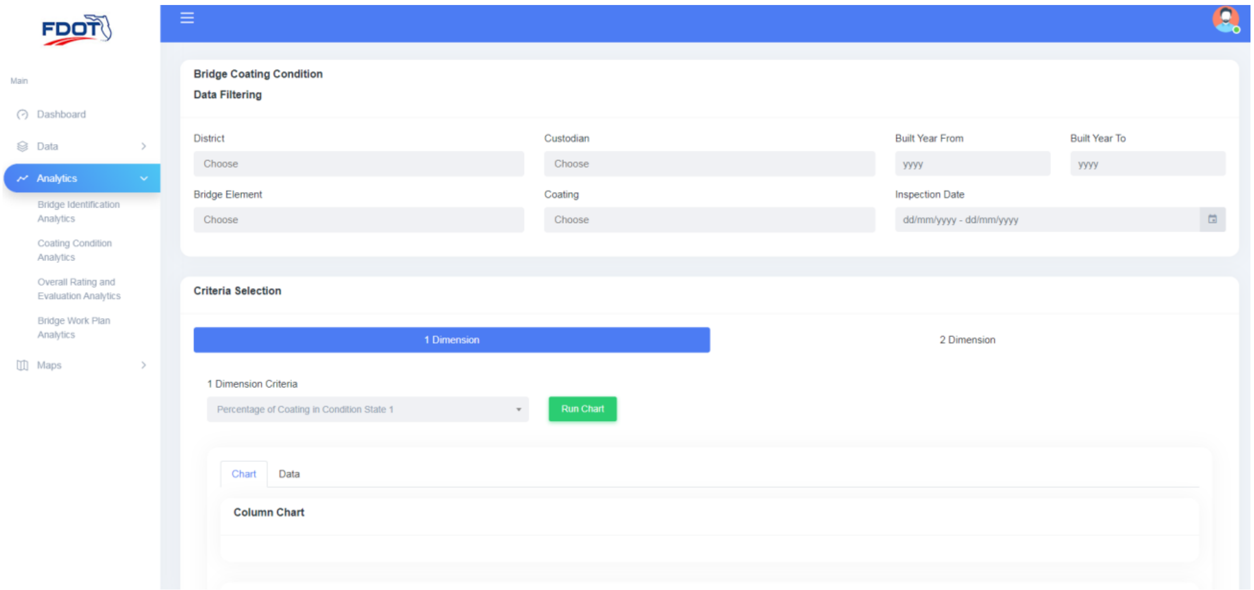


Figure 8-10. Coating Condition Analytics Function

For example, for 1D data analytics/visualization, users can select "Percentage of Coating in Condition State 1" as a criterion for analysis. After clicking "Run 1D chart", the system can generate a column chart (Figure 8-11) and a pie chart (Figure 8-12) that show the number of bridge elements with 1-25%, 25-50%, 50-75%, and 75-100% of coating in Condition State 1.

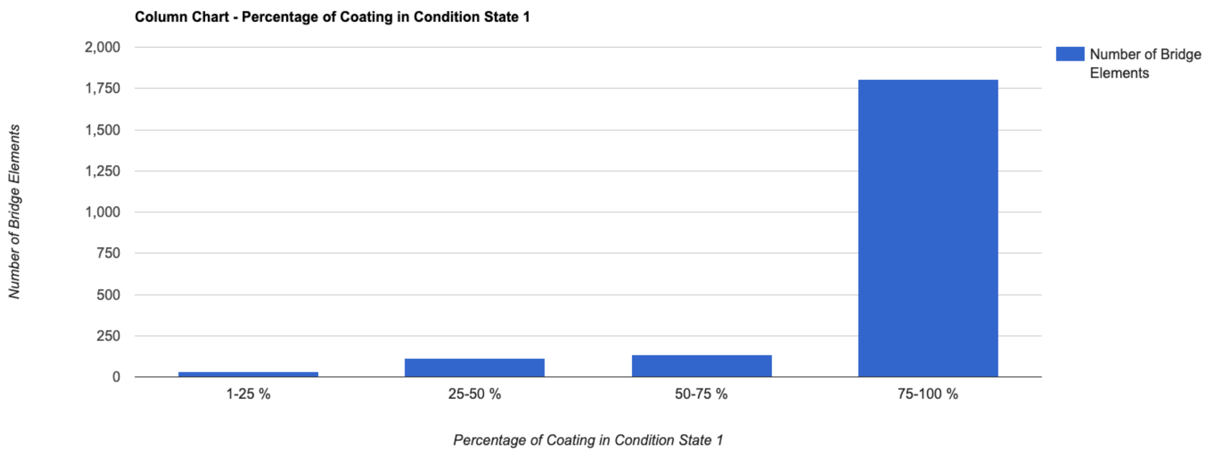


Figure 8-11. 1D Column Chart for Number of Bridge Elements by Percentage of Coating in Condition State 1

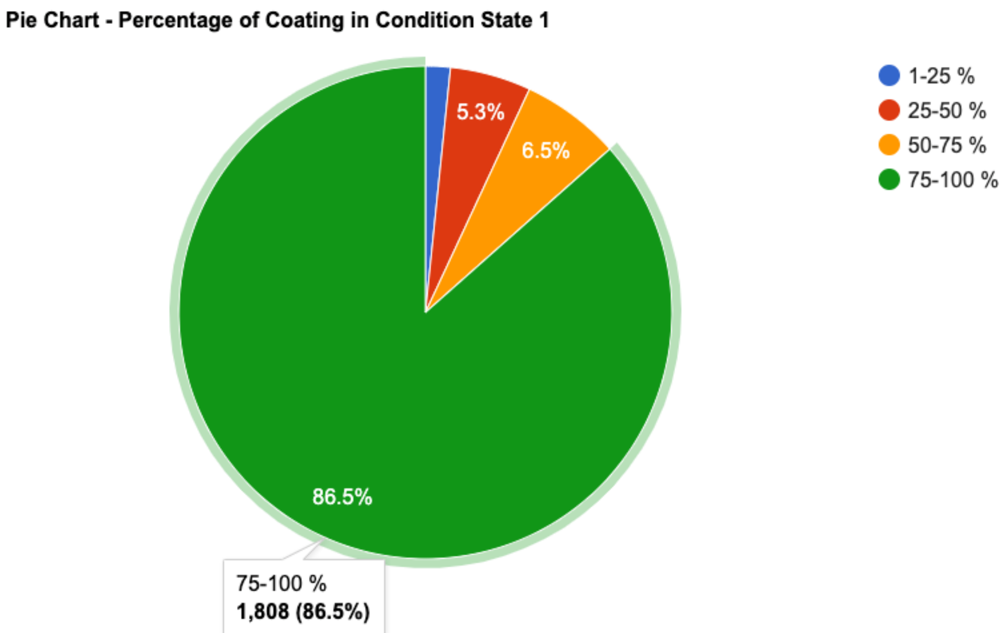


Figure 8-12. 1D Pie Chart for Number of Bridge Elements by Percentage of Coating in Condition State 1

The system also provides the data that are used to generate the charts. Users can view the data by clicking the "Data" tab, which is located next to the "Chart" tab. Figure 8-13 shows the list of data that represent the number of bridge elements with 1-25%, 25-50%, 50-75%, and 75-100% of coating in Condition State 1. Users can then either save the data in csv or excel format, or print out the data.

Chart Data

CSV Excel Print

Search:

Percentage of Coating in Condition State 1	Count
1-25 %	34
25-50 %	111
50-75 %	136
75-100 %	1808

Showing 1 to 4 of 4 entries

Previous 1 Next

Figure 8-13. Data for Number of Bridge Elements by Percentage of Coating in Condition State 1

For 2D data analytics/visualization, users can select a combination of (1) a criterion A, including District, Design, Custodian, Bridge Age, and (2) a criterion B, including Percentage of Coating in Condition State 1, 2, 3, and 4. The system can then generate 2D charts.

For example, when users select "District" and "Percentage of Coating in Condition State 4" and click "Run 2D Chart", the system can generate a column stacked chart (Figure 8-14), a bar stacked chart (Figure 8-15), an area chart (Figure 8-16), a combo chart (Figure 8-17), and a line chart (Figure 8-18) that represent the number of bridge elements with 1-25%, 25-50%, 50-75%, and 75-100% of coating in Condition State 4 in each district.

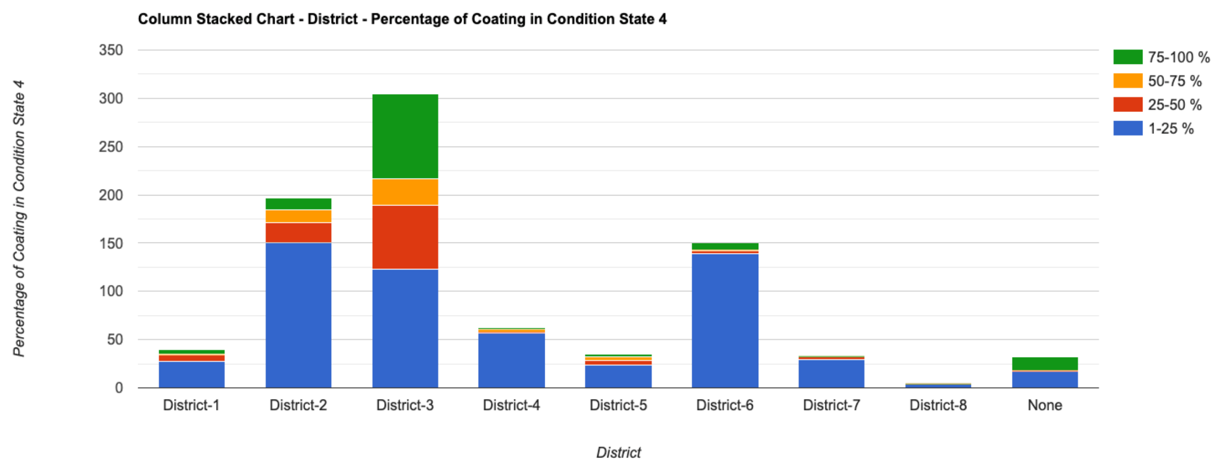


Figure 8-14. 2D Column Stacked Chart for Number of Bridge Elements in Different Ranges of Percentage of Coating in Condition State 4 by District

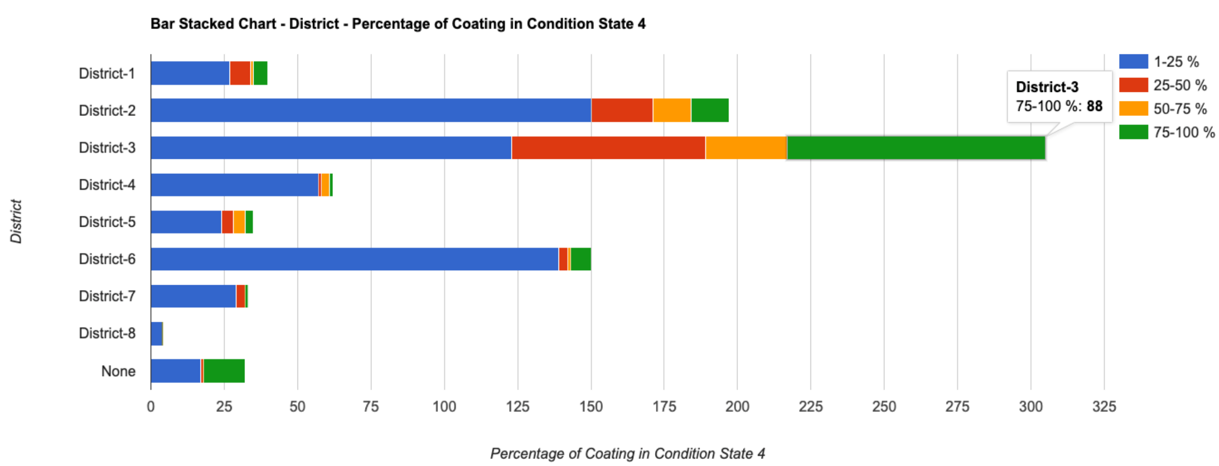


Figure 8-15. 2D Bar Stacked Chart for Number of Bridge Elements in Different Ranges of Percentage of Coating in Condition State 4 by District

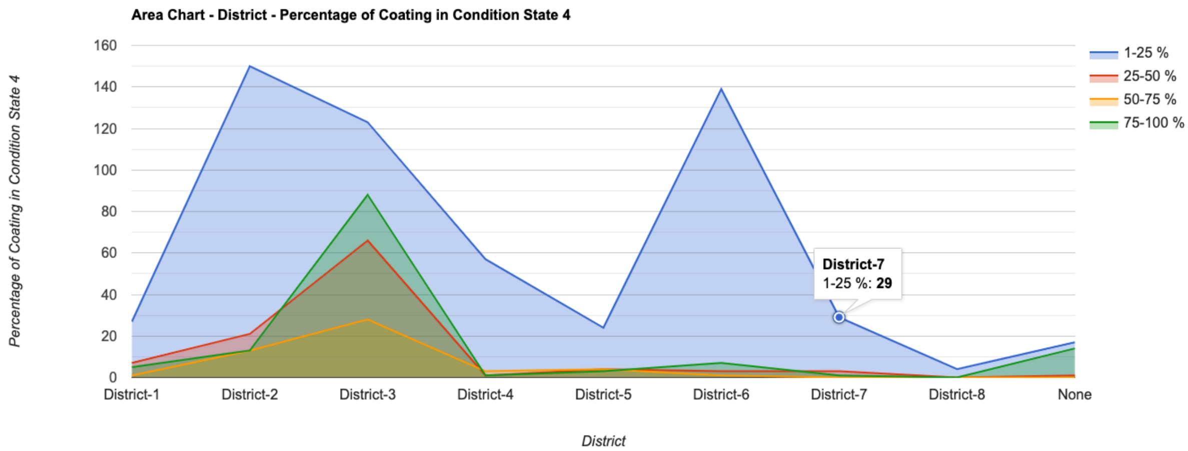


Figure 8-16. 2D Area Chart for Number of Bridge Elements in Different Ranges of Percentage of Coating in Condition State 4 by District

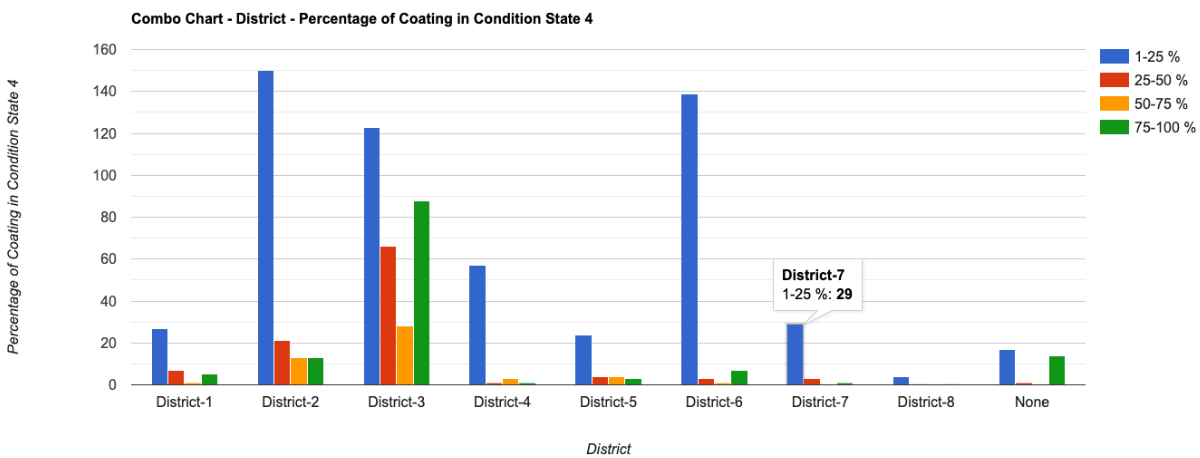


Figure 8-17. 2D Combo Chart for Number of Bridge Elements in Different Ranges of Percentage of Coating in Condition State 4 by District

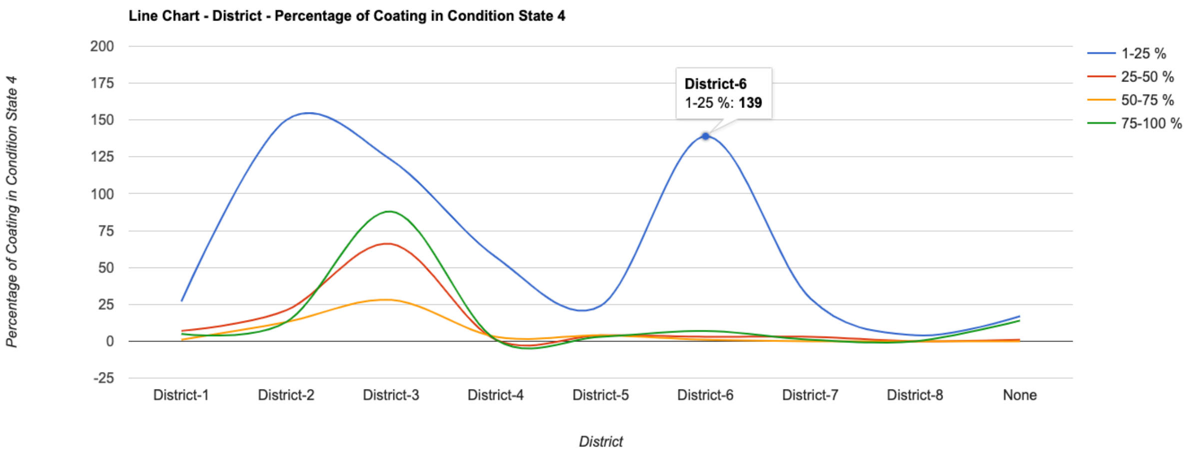


Figure 8-18. 2D Line Chart for Number of Bridge Elements in Different Ranges of Percentage of Coating in Condition State 4 by District

8.3 Overall Rating and Evaluation Analytics

The Overall Rating and Evaluation Analytics function first allows users to select and filter the data. The users can then decide if they want to conduct a 1D analysis or a 2D analysis. For 1D analysis, the users will then select one criterion from among the following: (1) Superstructure NCR Rating, (2) Substructure NCR Rating, (3) Deck NCR Rating, (4) Channel/Waterway NCR Rating, (5) Culvert NCR Rating, and (6) Superstructure NCR Rating. Figure 8-19 shows the screenshot of the Overall Rating and Evaluation Analytics function.

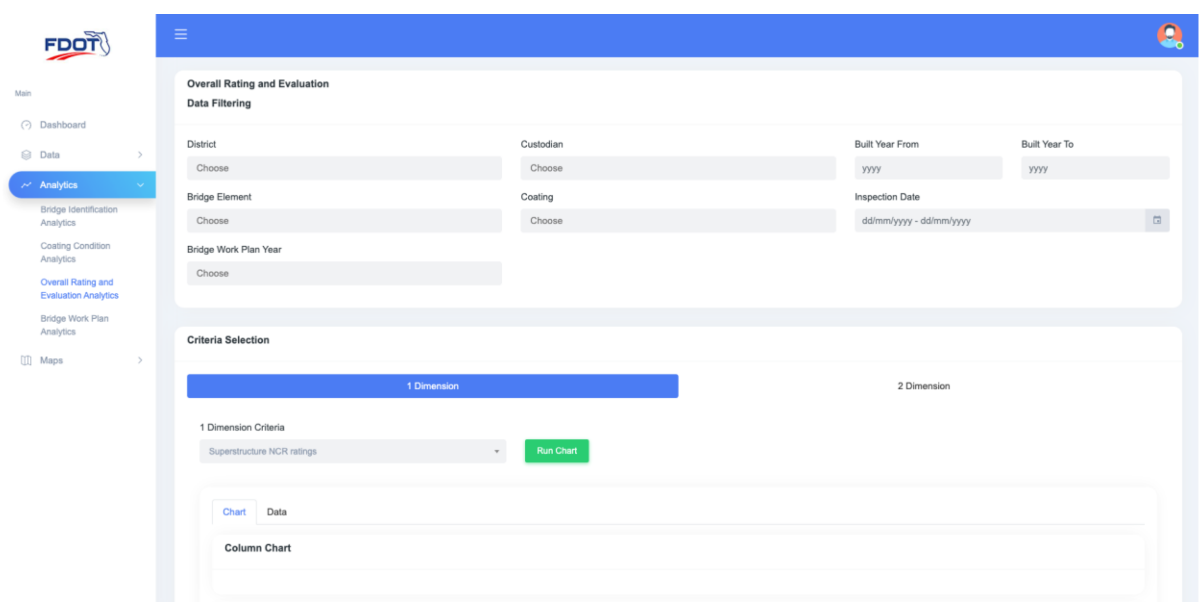


Figure 8-19. Overall Rating and Evaluation Analytics Function

For example, for 1D data analytics/visualization, users can select "Superstructure NCR Rating" as a criterion for analysis. After clicking "Run 1D chart", the system can generate a column chart (Figure 8-20) and a pie chart (Figure 8-21) that show the number of bridges with Good , Fair, and Poor conditions based on Superstructure NCR Ratings.

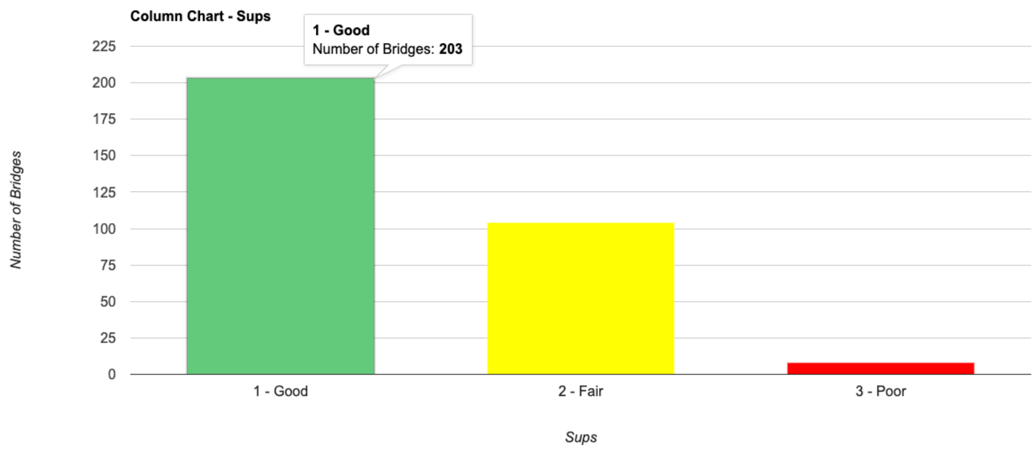


Figure 8-20. 1D Column Chart for Number of Bridges with Different Conditions Based on Superstructure NCR Ratings

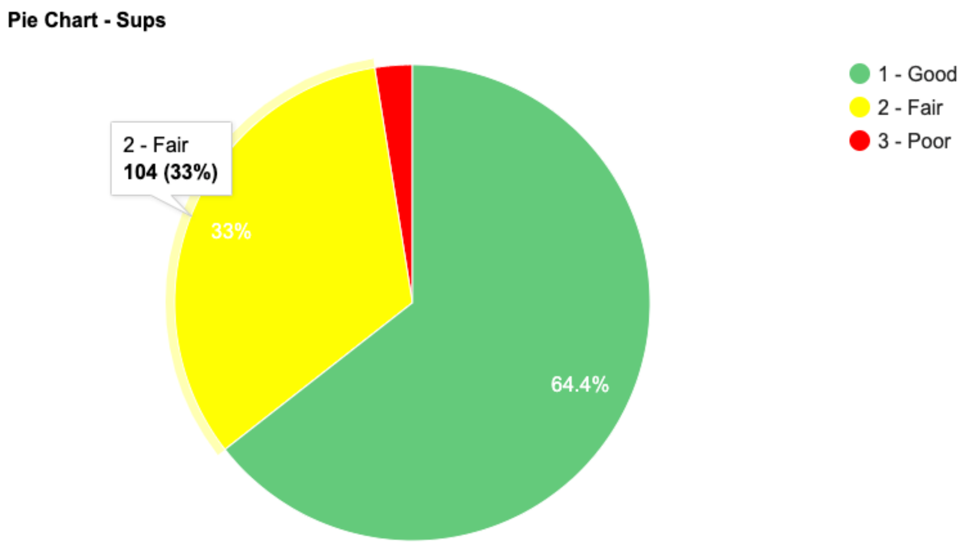
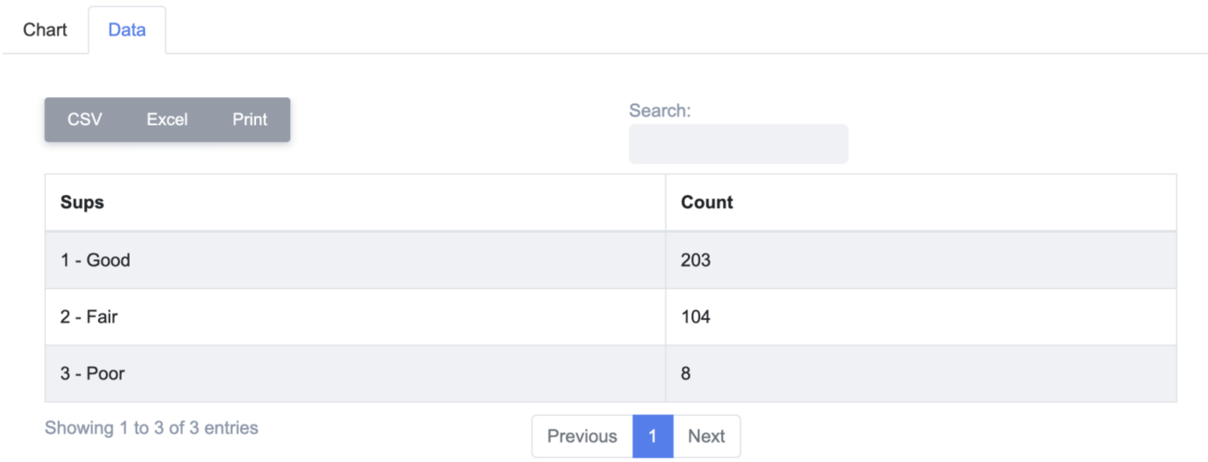


Figure 8-21. 1D Pie Chart for Number of Bridges with Different Conditions Based on Superstructure NCR Ratings

The system also provides the data that are used to generate the charts. Users can view the data by clicking the “Data” tab, which is located next to the “Chart” tab. Figure 8-22 shows the list of data that represent the number of bridge with Good, Fair, and Poor conditions based on Superstructure NCR Ratings. Users can then either save the data in csv or excel format, or print out the data.



Sups	Count
1 - Good	203
2 - Fair	104
3 - Poor	8

Figure 8-22. Data for Number of Bridges with Different Conditions Based on Superstructure NCR Ratings

For 2D data analytics/visualization, users can select a combination of (1) a criterion A, including District, Design, Custodian, Bridge Age, and (2) a criterion B, including Superstructure NCR Rating, Substructure NCR Rating, Deck NCR Rating, Channel/Waterway NCR Rating, Culvert NCR Rating, and Superstructure NCR Rating. The system can then generate the 2D charts.

For example, when users select “District” and “Superstructure NCR Rating”, and click “Run 2D Chart”, the system can generate a column stacked chart (Figure 8-23), a bar stacked chart (Figure 8-24), an area chart (Figure 8-25), a combo chart (Figure 8-26), and a line chart (Figure 8-27) that represent the number of bridges in Good, Fair, and Poor conditions in each district.

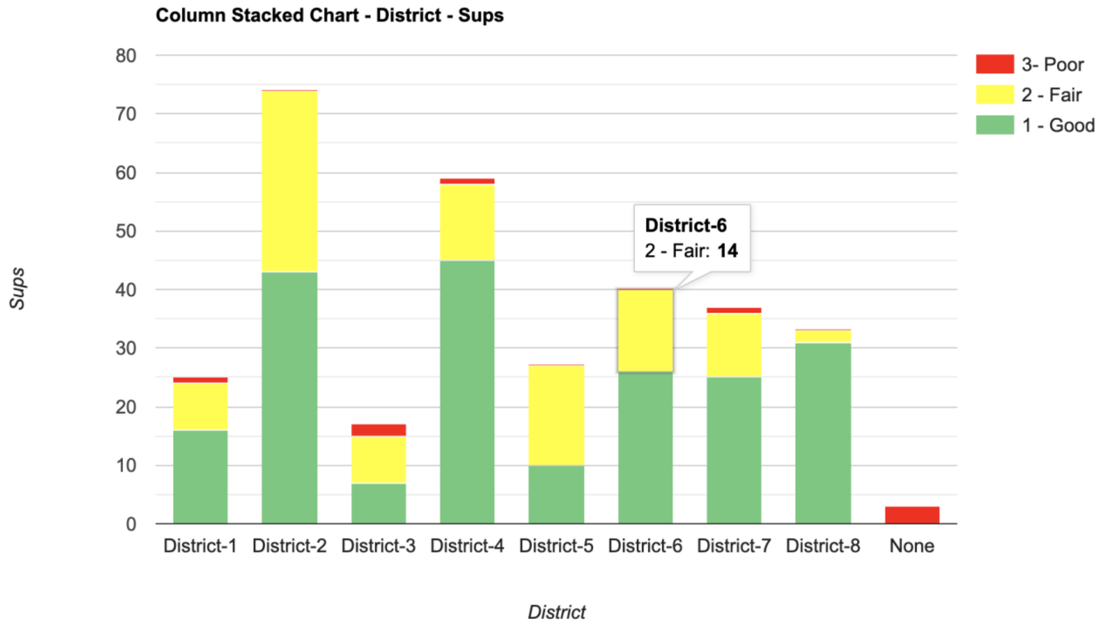


Figure 8-23. 2D Column Stacked Chart for Number of Bridges in Different Conditions Based on Superstructure NCR Ratings by District

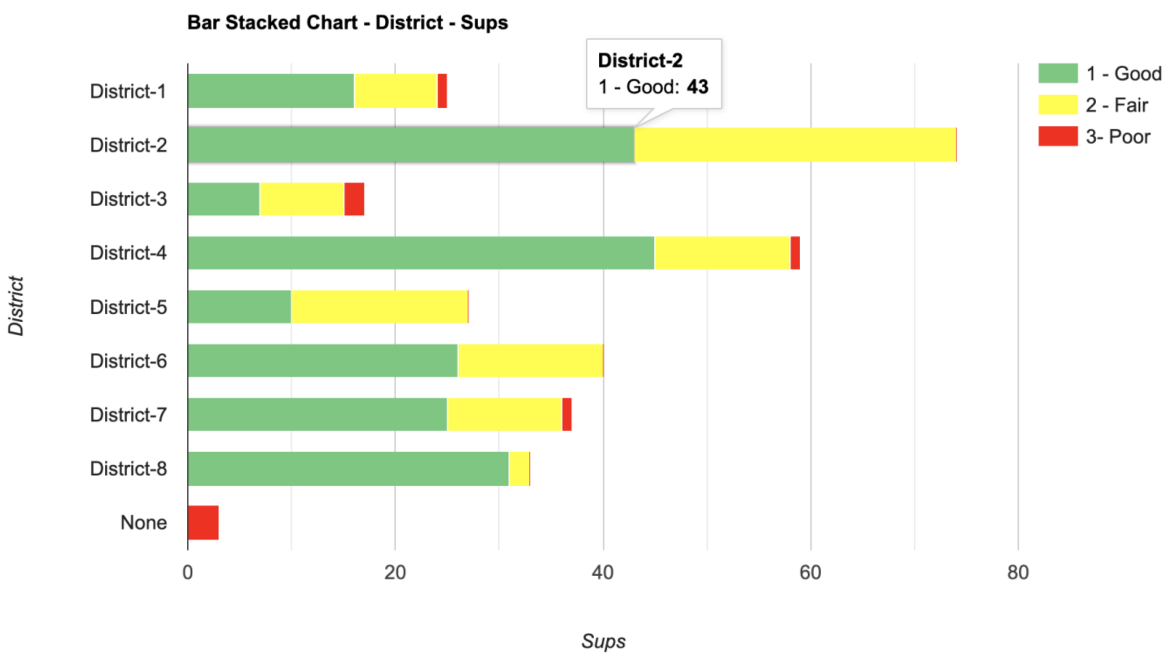


Figure 8-24. 2D Bar Stacked Chart for Number of Bridges in Different Conditions Based on Superstructure NCR Ratings by District

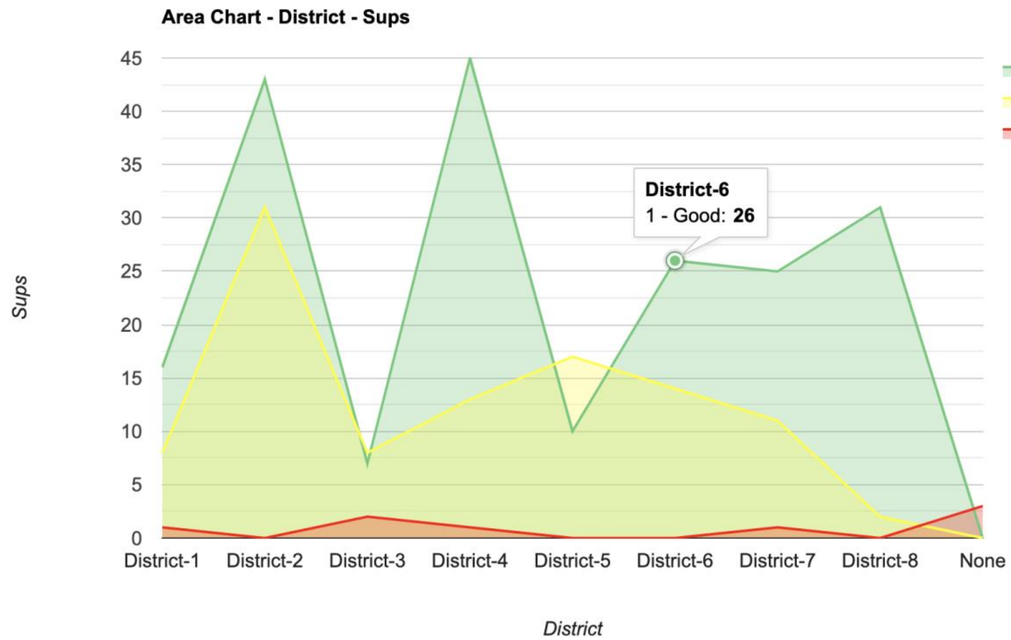


Figure 8-25. 2D Area Chart for Number of Bridges in Different Conditions Based on Superstructure NCR Ratings by District

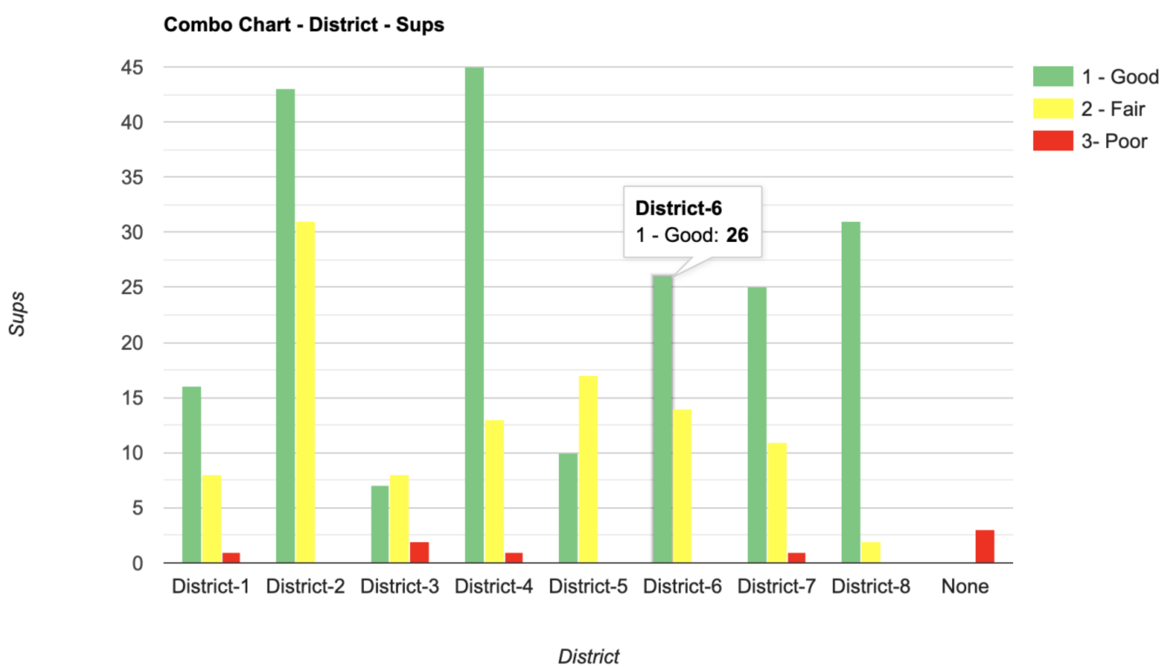


Figure 8-26. 2D Combo Chart for Number of Bridges in Different Conditions Based on Superstructure NCR Ratings by District

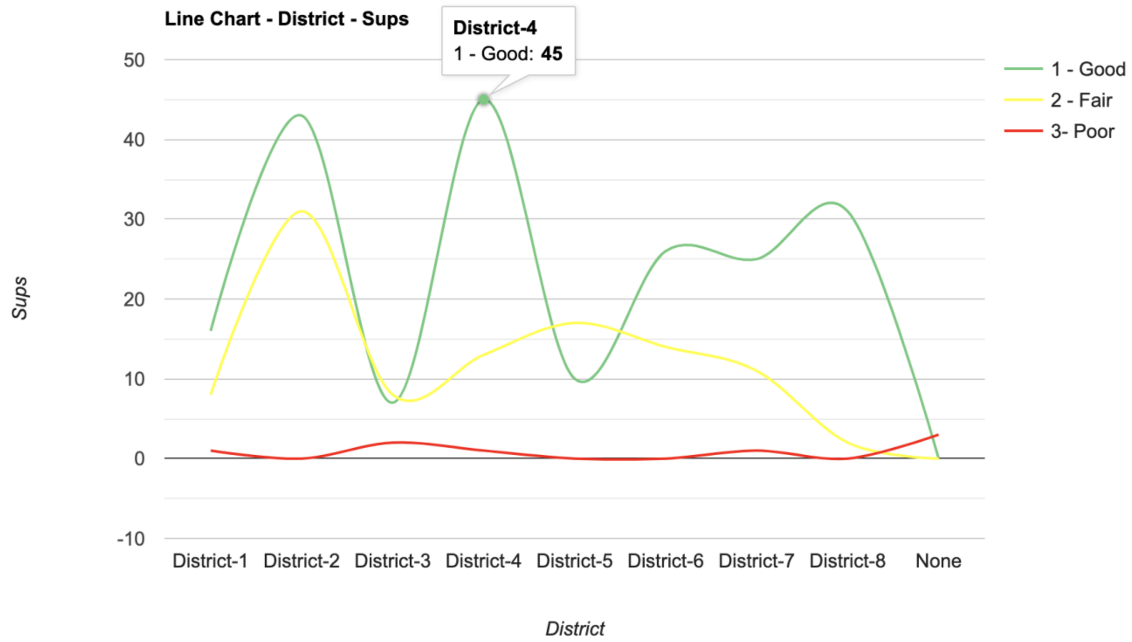


Figure 8-27. 2D Line Chart for Number of Bridges in Different Conditions Based on Superstructure NCR Ratings by District

8.4 Bridge Workplan Analytics

The Bridge Workplan Analytics function first allows users to select and filter the data. The users can then decide if they want to conduct a 1D analysis or 2D analysis. For 1D analysis, the users will then select the one criterion of Action Type. Figure 8-28 shows the screenshot of the Bridge Workplan Analytics function.

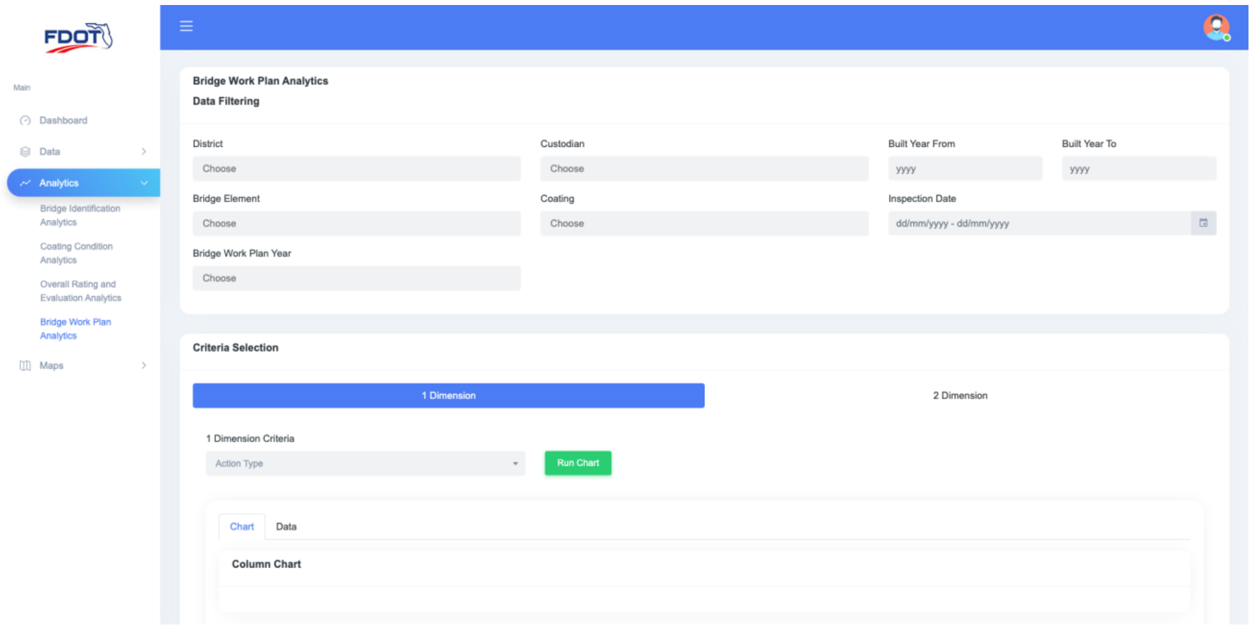


Figure 8-28. Bridge Work Plan Analytics Function

For 1D data analytics/visualization, users can select "Action Type" as a criterion for analysis. After clicking "Run 1D chart", the system can generate a column chart (Figure 8-29) and a pie chart (Figure 8-30) that show the number of bridges that require different types of actions.

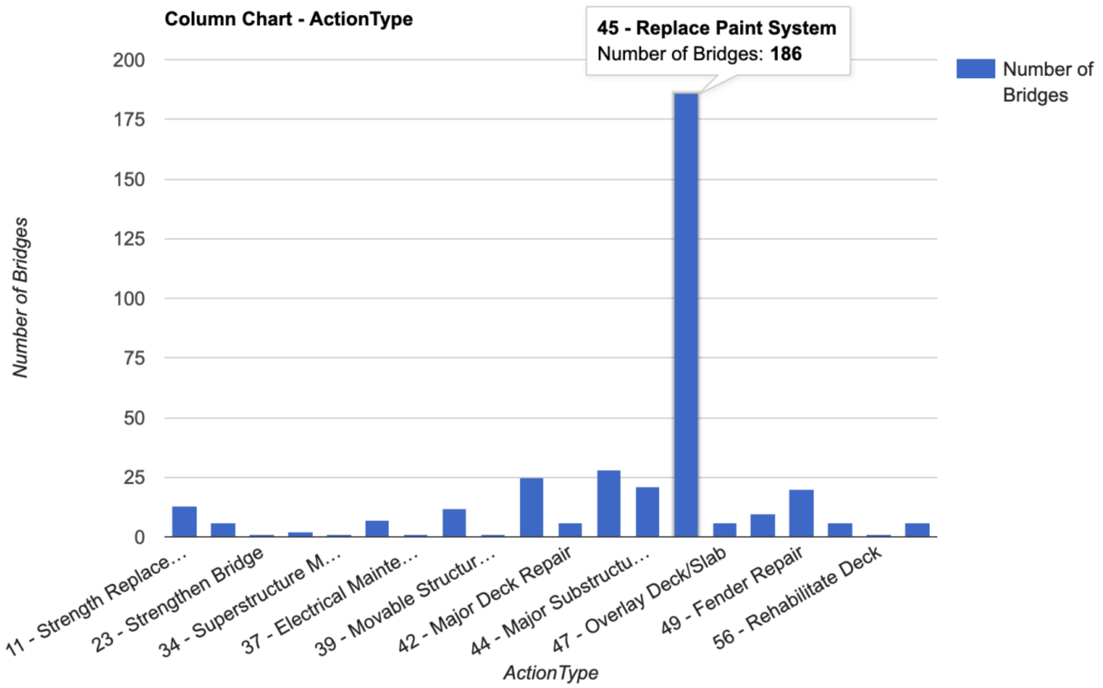


Figure 8-29. 1D Column Chart for Number of Bridges That Requires Different Types of Actions

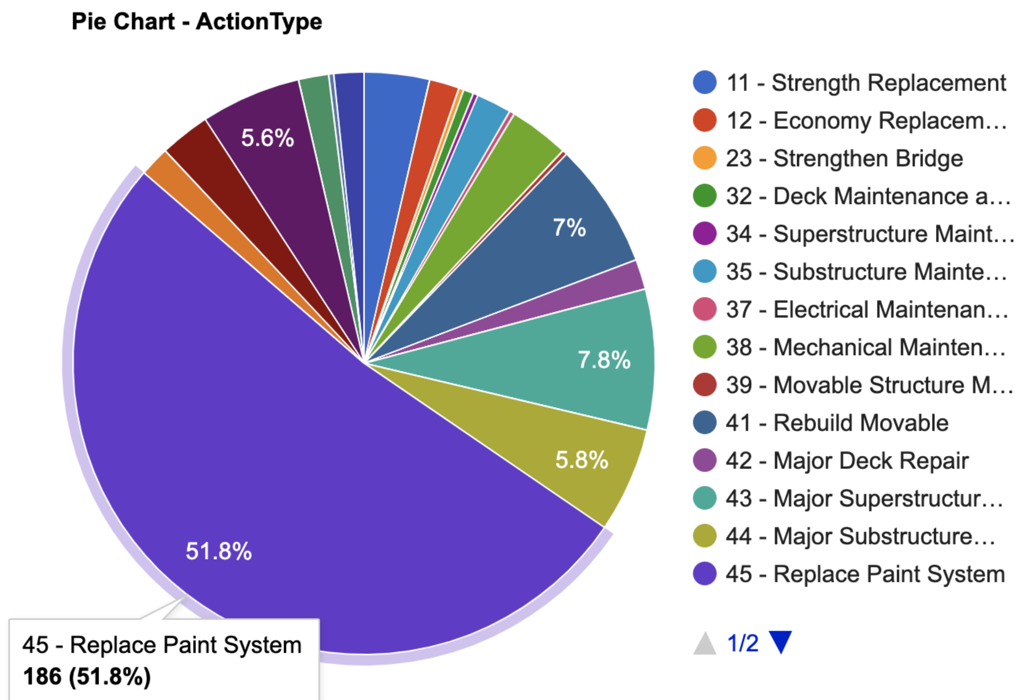


Figure 8-30. 1D Pie Chart for Number of Bridges That Requires Different Types of Actions

The system also provides the data that are used to generate the charts. Users can view the data by clicking the "Data" tab, which is located next to the "Chart" tab. Figure 8-31 shows the list of data that represent the number of bridges in different action types. Users can then either save the data in csv or excel format, or print out the data.

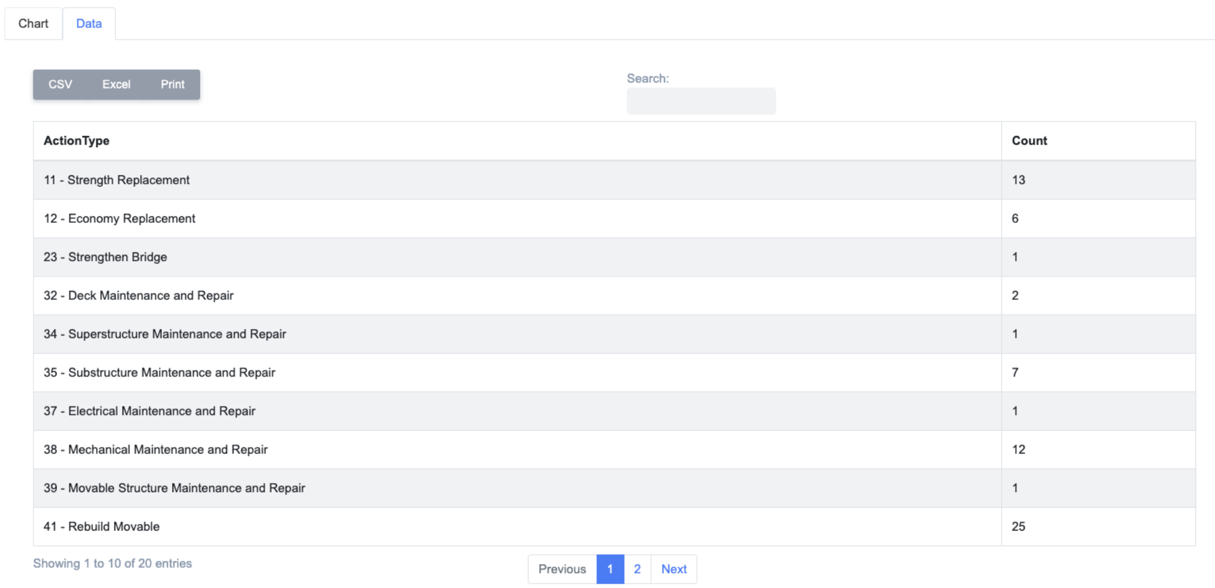


Chart | Data

CSV Excel Print

Search:

ActionType	Count
11 - Strength Replacement	13
12 - Economy Replacement	6
23 - Strengthen Bridge	1
32 - Deck Maintenance and Repair	2
34 - Superstructure Maintenance and Repair	1
35 - Substructure Maintenance and Repair	7
37 - Electrical Maintenance and Repair	1
38 - Mechanical Maintenance and Repair	12
39 - Movable Structure Maintenance and Repair	1
41 - Rebuild Movable	25

Showing 1 to 10 of 20 entries

Previous 1 2 Next

Figure 8-31. Data for Number of Bridges in Different Action Types

For 2D data analytics/visualization, users can select a combination of (1) a criterion A, including District, Design, Custodian, Bridge Age, and (2) a criterion B, Action Type. The system can then generate 2D charts.

For example, when users select “Design” and “Action Type”, and click “Run 2D Chart”, the system can generate a column stacked chart (Figure 8-32), a bar stacked chart (Figure 8-33), an area chart (Figure 8-34), a combo chart (Figure 8-35), and a line chart (Figure 8-36) that represent the number of bridges with different design in each action type.

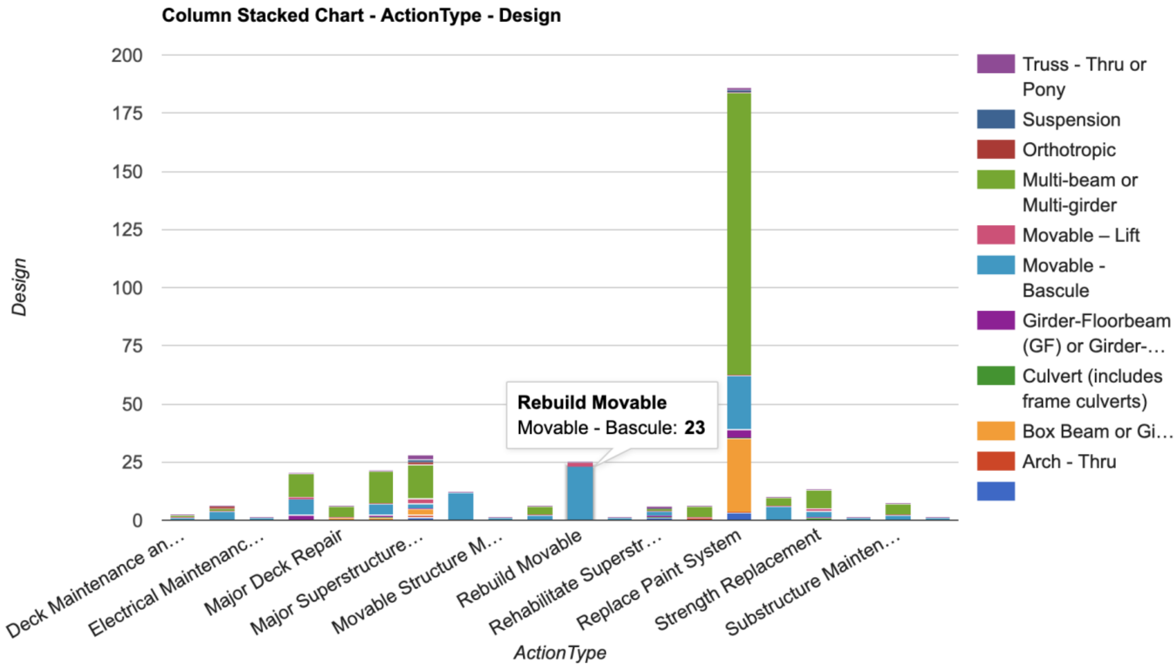


Figure 8-32. 2D Column Stacked Chart for Number of Bridges with Different Design That Require Different Types of Actions

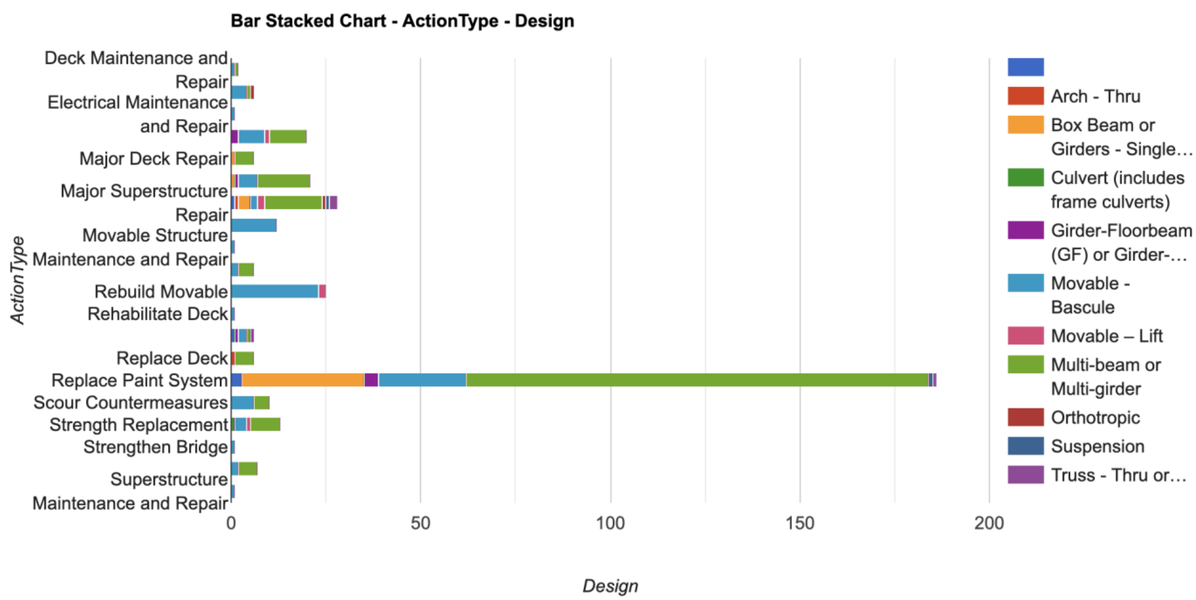


Figure 8-33. 2D Bar Stacked Chart for Number of Bridges with Different Design That Require Different Types of Actions

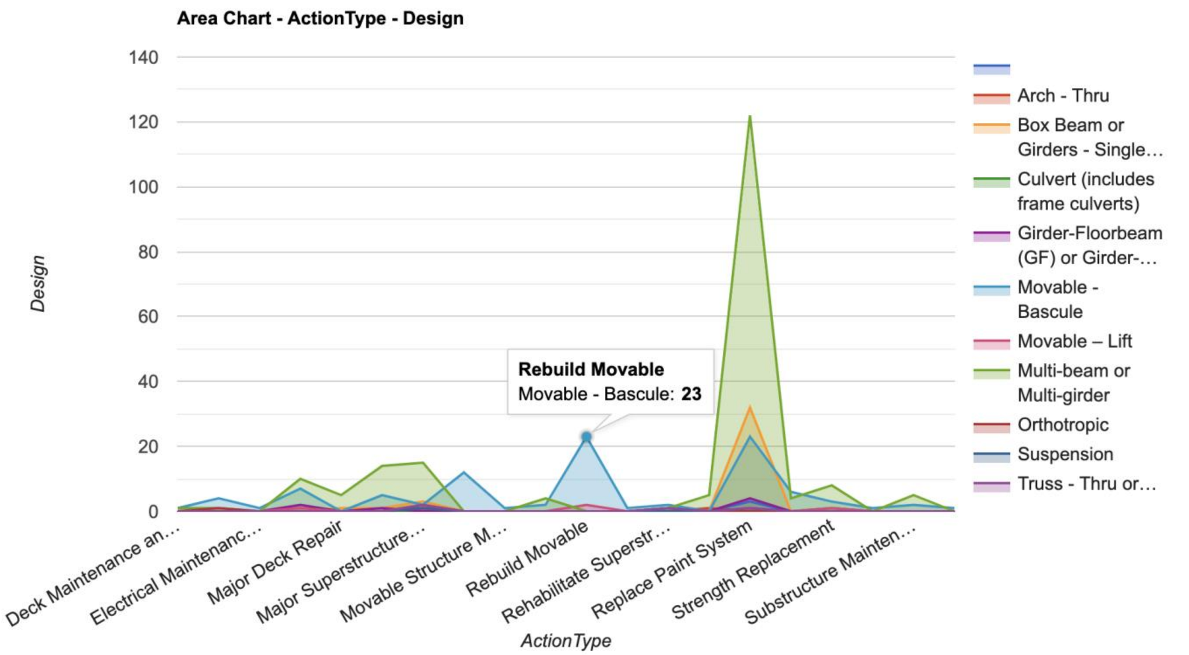


Figure 8-34. 2D Area Chart for Number of Bridges Number of Bridges with Different Design That Require Different Types of Actions

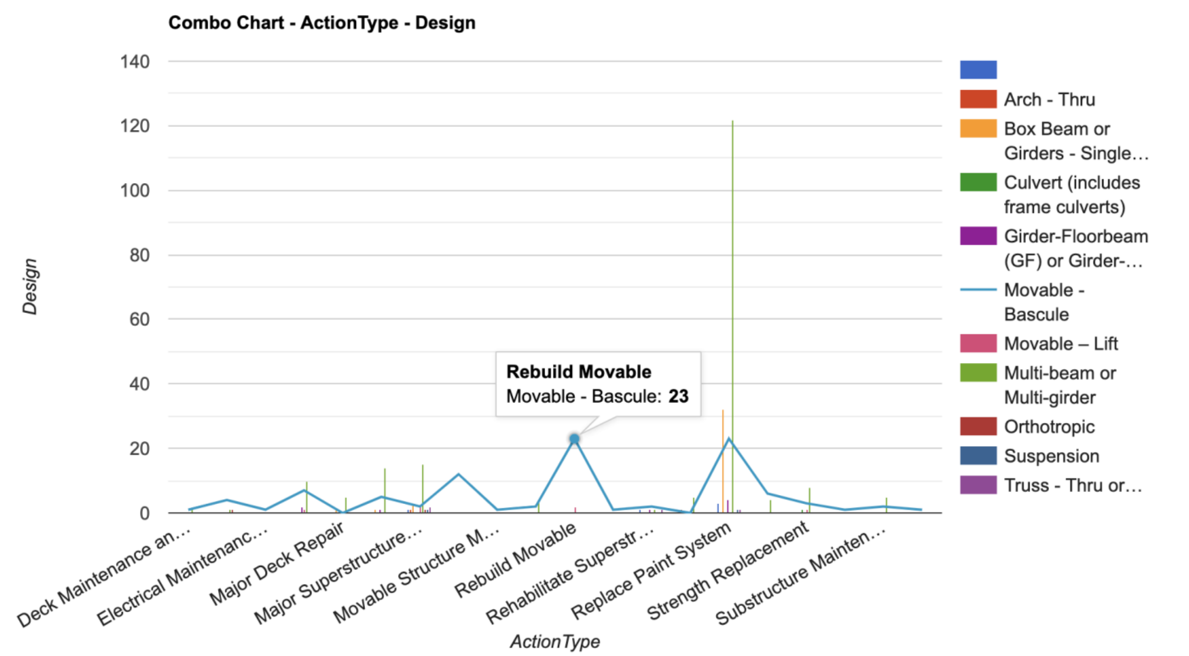


Figure 8-35. 2D Combo Chart for Number of Bridges with Different Design That Require Different Types of Actions

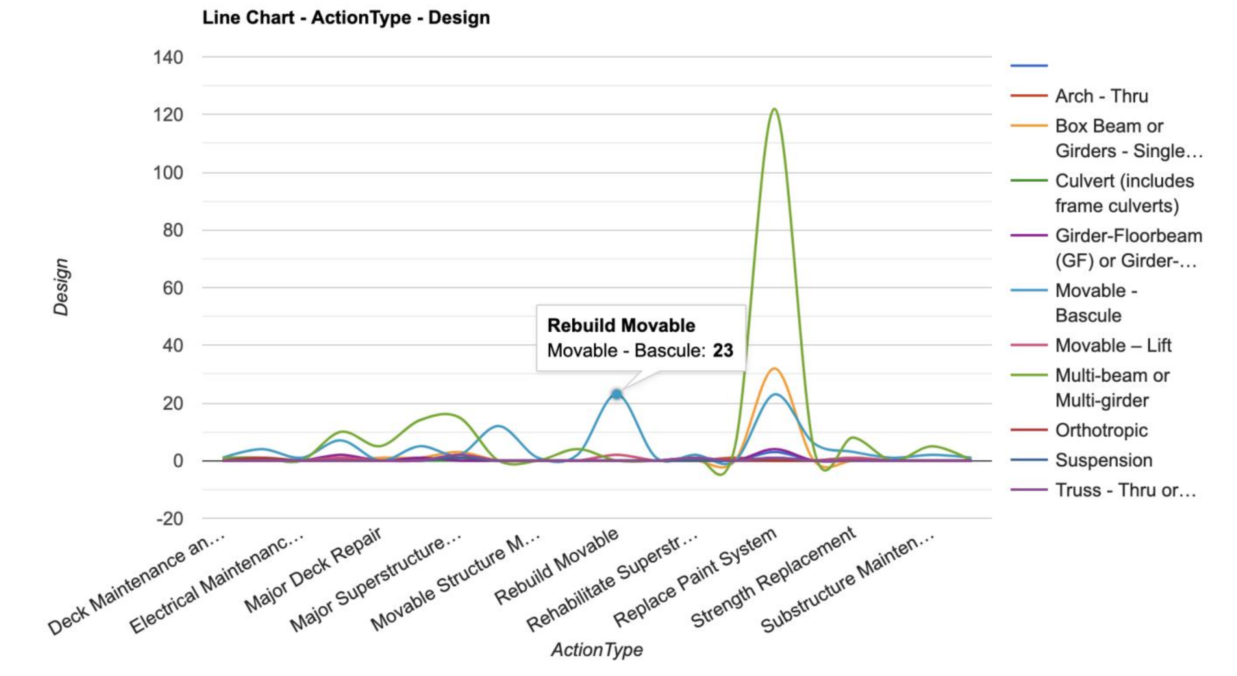


Figure 8-36. 2D Line Chart for Number of Bridges with Different Design That Require Different Types of Actions

CHAPTER 9. COATING CONDITION MODELLING USING MACHINE LEARNING ALGORITHMS

To provide a better understanding of coating deterioration, the project team proposes a machine learning (ML)-based steel bridge coating deterioration modelling approach to predict coating conditions using selected data from the developed SBC database. To develop the deterioration model, several ML models were implemented and tested based on the collected bridge data. The best working model is selected to evaluate the impact of environmental factors on the performance of coating deterioration prediction. The proposed methodology included four main steps: (1) data collection, (2) data preprocessing, (3) deterioration model development, and (4) performance evaluation.

9.1 Data Collection

Three main types of data were collected for this study: data on bridge characteristics, data on bridge coating performance, and data on environmental factors that affect bridge coating performance. The bridge characteristic data were collected from the National Bridge Inventory (FHWA 2021). These data include bridge specifications (e.g., design type and custodian), operational conditions (e.g., built year and reconstruction year), inspection data (e.g., superstructure, substructure, and deck condition rating), and traffic volume (e.g., average daily traffic and percent of truck traffic). Coating performance data were obtained from Florida DOT's bridge management system. These data include the steel element type, and percentages of coating in condition state 1, 2, 3, and 4. Table 9-1 shows a brief description of the main bridge characteristic data.

Table 9-1. A Brief Description of Main Bridge Characteristic Data

Data name	Brief description	Data type
Maintenance	The agency responsible for the maintenance of the bridge	Categorical
Year built	The year in which the bridge was built	Numeric
Year reconstructed	The year in which the bridge was reconstructed	Numeric
Service_on	The type of service on the bridge	Categorical
Service_und	The type of service under the bridge	Categorical
Deck condition	Structural evaluation rating of the bridge's deck condition assigned by the inspectors	Categorical
Superstructure condition	Structural evaluation rating of the bridge's superstructure condition assigned by the inspectors	Categorical
Substructure condition	Structural evaluation rating of the bridge's substructure condition assigned by the inspectors	Categorical
ADT	Average daily traffic	Numerical
Percent_ADT_truck	Percentage of truck traffic in average daily traffic	Numerical

The environmental factor data include two major types of data: weather data and airborne pollutant data. The weather data were collected from the website of Florida Automated Weather Network (FAWN 2020). These data include dew point temperature, temperature of the soil, temperature of the air, and relative humidity. The airborne pollutant data were collected from the website of National Atmospheric Deposition Program (NADP 2020). These data include deposition of several airborne pollutants. The deposition measures the amount of chemical that is transferred to a square meter of ground via precipitation. Table 9-2 shows a brief description of the main environmental factor data. This study focused on the highway steel bridges in the state of Florida. As a result, the bridge characteristic and coating performance data for 1,409 bridges were collected. As a bridge can have multiple coating components, a total of 2,265 data instances were included in this study.

Table 9-2. A Brief Description of Main Environmental Factors

Environmental factor	Brief description	Data type
temp_dp_2m	The annual average dew point temperature at 2 meters above the ground	Weather data
temp_air_2m	The annual average temperature of the air at 2 meters above the ground	
rh_2m	The annual average relative humidity at 2 meters above the ground	
rain_2m	The annual average depth of rainfall measured by a tipping bucket gauge at 2 meters above the ground	
CI	The annual average chloride deposition level in precipitation	Airborne pollutant data
H	The annual average acidity level in precipitation	
SO4	The annual average sulfate deposition level in precipitation	
NO3	The annual average nitrate deposition level in precipitation	

9.2 Data Preprocessing

Four steps were conducted to process the collected data for developing the ML-based prediction model. First, data instances that contain missing values in any of the features were removed. Second, the data values of the numerical features were normalized using min-max normalization method, which rescales the values into a range between 0 and 1. Third, the data values of categorical features were converted into numerical values using one-hot encoding. Fourth, the environmental factor data were mapped to each bridge using Inverse Distance Weighted (IDW) interpolation, which is a deterministic interpolation method that estimates unmeasured values from values surrounding the prediction location (ERSI, 2021). IDW method was selected as it is a popular method for determining the unknown value from known environmental and climatic parameters in research studies (Masoudi 2021).

9.3 Deterioration Model Development

The aim of the proposed deterioration model is to predict the coating conditions based on selected bridge data. The coating condition is measured by the percentages of coating in condition state 1, 2, 3, and 4, which are positive real numbers adding up to 1. The coating condition prediction task can be thus formulated as a multi-output regression problem. Multi-output regression is a predictive modelling task that involves two or more dependent numerical output variables (Xu et al. 2019). There are two categories of methods that are commonly adopted: problem transformation methods and algorithm adaptation methods. Problem transformation methods convert the multi-output problem into independent single-output subproblems, while algorithm adaptation methods adapt specific single-output algorithms to directly handle multi-output datasets (Borchani et al. 2015). For this preliminary study, two problem transformation methods were implemented: direct multi-output regression and chained multi-output regression. The direct multi-output regression divides the problem into multiple single-output regression subproblems; The chained multi-output regression creates a linear sequence of models, where each model takes the prediction of previous models in the chain as inputs when making its own prediction (Spyromitros-Xioufis et al. 2012). Both the direct and chained multi-output regression methods use the support vector regression (SVR) as the base model. Three algorithm adaptation methods were implemented, including k nearest neighbors (KNN), decision tree, and deep neural networks (DNN). For the DNN model, a feed-forward architecture was adopted to benchmark similar bridge deterioration modelling efforts (Ali et al. 2019; Liu and El-Gohary 2019; Assaad and El-adaway 2020). Parameter tuning was conducted to identify the optimal parameter(s) for each ML model. For example, after the parameter tuning, the DNN model with five hidden layers and the rectified linear unit activation function was developed.

9.4 Evaluation

The aim of the performance evaluation is twofold: (1) to compare the performance of different ML models in predicting the bridge coating conditions and (2) to evaluate the impact of environmental factors on the performance of bridge coating deterioration modelling. As a commonly adopted measure for regression analysis, the mean squared error (MSE) was selected as the evaluation metric to measure the performance of the prediction. The MSE is the average squared difference between the predicted coating condition percentages and the actual percentages. For each experiment run, a 10-fold cross-validation was conducted to avoid overfitting of the ML model. In each validation iteration, the data in the training fold was used to train a ML model. The trained ML model was then tested using the data from the testing fold. The mean value and standard deviation of MSE over the ten folds were reported.

9.5 Experimental Results and Analysis

Table 9-3 shows the performance of different ML models for predicting the bridge coating conditions using the selected bridge characteristic data. Among the five models tested, the DNN model achieved the best performance, with mean MSE of 0.077 and standard deviation of 0.004 over the 10 testing folds. The DNN model was thus selected to further evaluate the impact of using environmental factor data on deterioration prediction. Experiments were conducted to compare the prediction performance of DNN models built on four datasets: bridge characteristic data only, bridge characteristic data + weather data, bridge characteristic data + airborne pollutant data, and bridge characteristic data + complete environmental data (weather and airborne pollutant data).

The evaluation results are summarized in Table 9-4. When adding weather data or airborne pollutant data, the mean MSE was improved by 11.3% and 10% respectively, but the standard deviation worsened in both cases. The increased standard deviation in the prediction performance could be largely attributed to the noisy information contained in the environmental data. The noisy information may be brought by the factors that have low relevance to coating deterioration or by the interpolation method used to estimate the factor values of individual bridges. The best mean MSE (0.066) was achieved when adding both weather and airborne pollutant data. The evaluation results indicate that using the environmental factor data could improve the performance of prediction model despite increasing its variance.

Table 9-3. Prediction Performance of Different ML Models

ML model	Mean MSE	Standard deviation
KNN	0.080	0.036
Decision tree	0.125	0.051
Direct multi-output regression with SVR	0.085	0.042
Chained multi-output regression with SVR	0.085	0.046
DNN	0.077	0.004

Table 9-4. Prediction Performance of Different Feature Datasets

Feature dataset	Mean MSE	Standard deviation
Bridge characteristic data	0.077	0.004
Bridge characteristic data + weather data	0.069	0.011
Bridge characteristic data + airborne pollutant data	0.070	0.013
Bridge characteristic data + complete environmental factor data	0.066	0.010

CHAPTER 10. DISCUSSION AND FUTURE RESEARCH

Even with the continuous development of coating technology, coating systems are still susceptible to deterioration, and thus unable to provide protection for the long-term designed bridge service life. Several factors can potentially result in coating premature failures. For example, poor surface preparation, choice of application techniques, inappropriate specification employment, and coating material formulation are the key reasons behind adhesion-related premature failures of coating systems (Tator and Lanterman 2016). The chemical reaction between coating materials and incompatible steel surfaces can induce substrate-related premature failures (e.g., chalking, alligatoring, discoloration, cissing, and grinning). Moreover, exposure to moisture, high temperatures, soluble salts (particularly chloride ion concentration), wind, acidity, and ultraviolet (UV) light further increases the deterioration rate of coatings (Al-Sodani et al. 2018; Sharp et al. 2013).

To better understand coating performance in the field, there is a need to analyze the large amount of field data to offer new insights and knowledge. These data are available in the routine bridge inspection reports and other documents (e.g., construction documents, maintenance contracts, cost summary). These data may include geographic information of bridges, bridge structural conditions, types of steel surface preparation, types of coating systems, service conditions, project-specific modifications to standard requirements, and maintenance and repair methods and costs. However, existing coating-related data are inadequate and unorganized to evaluate the premature failures of coating systems (Kreislova and Geiplova 2012). First, these data are mostly unstructured data with less analytical competence. It is challenging and time-consuming to search, retrieve, and obtain relevant knowledge. Second, these data are from heterogenous sources and are often disconnected from each other. For instance, coating performance data are not connected to the coating maintenance history or costs, thus resulting in difficulties for identifying and assessing the factors contributing to premature coating failures.

Thus, the SBC database developed as part of this project is the first step toward better data and knowledge management regarding coating systems. Due to the project scope, this project only includes a limited set of data for coatings on steel bridge structures. However, this project identifies those data that should be required input for an effective database on all new construction and maintenance projects with coating related activities. The SBC database offers an effective data structure that contains all data that are recommended to be included for future construction and maintenance projects with coating related activities. It also offers effective functions that allow FDOT engineers to easily search and view the relevant data, add the new data, edit or delete the existing data, and analyze the data to offer visualized information.

In the future, it is recommended that the SBC database can be further extended to include coating related data for concrete bridges. This is because corrosion of steel in reinforced concrete bridges is also a major concern for the structural integrity, long-term durability, and maintenance of the Florida highway infrastructure. Corrosion of steel in reinforced concrete is largely associated with chloride-induced corrosion, but carbonation-induced corrosion should not be disregarded as some substructure components away from splash areas may be subjected to interactions with atmospheric carbon dioxide. Furthermore, concrete structural elements susceptible to crack development would cause more adverse conditions by allowing for a direct path of deleterious chemical compounds to facilitate corrosion initiation and thus affect the overall durability of an element.

Moreover, the database can be further enriched to include advanced data analytics functions. For example, a prediction functional module can be added to allow users to predict bridge coating performance using the data in the database. This function would be helpful for FDOT engineers to better predict when and where coating premature failures may occur, thus offering time sensitive guidance on maintenance activities.

The database system can also be further upgraded to include information and knowledge management functions. For example, information search and retrieval, knowledge classification, knowledge summarization, and knowledge recommendation functional modules can be included. These functions not only allow users to search for relevant knowledge about coating systems but also automatically recommends relevant information and knowledge based on users' contexts and preferences.

The SBC database developed as part of this project together with other new functions that can be developed in the future will eventually support more systematic data-driven analysis of coating performance and premature failures. This will lead to new knowledge on factors that impact coating performance and potentially better practices that improve coating lifespans in the field.

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APPENDIX - ASSESSMENT OF STRUCTURAL STEEL COATING APPLICATIONS DATA AVAILABILITY AND DATA COLLECTION SURVEY

Summary: Florida Department of Transportation (FDOT) recently started a project that aims to assess factors that contribute to structural steel coating applications. The project will gather, catalog, and assess historical data available at the FDOT district level with the goal of creating a database capable of identifying and correlating factors that result in premature coating failure.

Purpose: This survey aims to collect information about (1) availability of different types of data related to steel bridge coating system, and (2) methods that will be used for data collection.

Duration: The survey will take around 10 minutes to complete.

Confidentiality: The records of this study will be kept private and will be protected to the fullest extent provided by law. In any sort of report, we might publish, we will not include any information that will make it possible to identify you. Research records will be stored securely, and only the researcher team will have access to the records.

Right to decline or withdraw: Your participation in this study is voluntary. You are free to participate in the study or withdraw your consent at any time during the study.

Researcher Contact Information: If you have any questions about the purpose, procedures, or any other issues relating to this research study you may contact Lu Zhang at 10555 West Flagler Street, EC 2935, Miami, FL 33174, (305)-348-7227, luzhang@fiu.edu.

Which of the following types of coating-related data are available **within FDOT** (select all that apply)?

- ☐ Coating performance data
- ☐ Surface preparation data
- ☐ Environmental exposure data
- ☐ Coating application/repair data
- ☐ Coating cost data
- ☐ Other, please specify ______________________________

If you have selected “coating performance”, which of the following data are available for each bridge (select all that apply)?

If you have not selected “coating performance”, please skip this question.

- ☐ Type of coating material used
- ☐ Coating condition
- ☐ Level of coating degradation
- ☐ Type of coating failure
- ☐ Coating inspection record
- ☐ Coating maintenance record
- ☐ Manufacturer of coating material
- ☐ Debris accumulation information
- ☐ Other, please specify ____

If you have selected “surface preparation”, which of the following data is available for each bridge (select all that apply)?

If you have not selected “surface preparation”, please skip this question.

- ☐ Pre-cleaning measure
- ☐ Surface cleaning type
- ☐ Coating application delay
- ☐ Surface roughness
- ☐ Quality control test results
- ☐ Other, please specify____

If you have selected “environmental exposure”, which of the following data is available for each bridge (select all that apply)?

If you have not selected “environmental exposure”, please skip this question.

- ☐ Salt concentration
- ☐ Chloride exposure level
- ☐ Water PH level
- ☐ Temperature
- ☐ Relative humidity
- ☐ Distance from the shore
- ☐ Prevailing winds
- ☐ Airborne pollution
- ☐ Contaminant deposition
- ☐ Ultraviolet light (UV) exposure
- ☐ Other, please specify ____

If you have selected “coating application/repair”, which of the following data is available for each bridge (select all that apply)?

If you have not selected “coating application/repair”, please skip this question.

- ☐ Coating application/repair contractor
- ☐ Time of coating application/repair
- ☐ Quality control information
- ☐ Steel substrate condition
- ☐ Steel geometric constraint for coating (e.g. bolts, cuts, edges)
- ☐ Coating application method
- ☐ Coating touch-up and repair method
- ☐ Other, please specify ____

If you have selected “coating cost”, which of the following data is available for each bridge (select all that apply)?

If you have not selected “coating cost”, please skip this question.

- ☐ Coating material cost
- ☐ Coating application cost
- ☐ Coating repair cost
- ☐ Coating removal and replacement cost
- ☐ Other, please specify ____

If you have selected “coating performance”, could you please specify the source of these data if these data are available (e.g., from inspection report, from coating material database, from contract documents)?
If you have not selected “coating performance”, please skip this question.

Please be as specific as you can.
Please include a link to the data if the data is open to public.
Please enter NA if you don't know the source of data.

○ Type of coating material used

____

○ Coating condition

____

○ Level of coating degradation

____

○ Type of coating failure

____

○ Coating inspection record

____

○ Coating maintenance record

____

○ Manufacturer of coating material

____

○ Debris accumulation information

____

○ Other

____

If you have selected “surface preparation”, could you please specify the source of these data if the data is available (e.g, from contract documents)?
If you have not selected “surface preparation”, please skip this question.

Please be as specific as you can.
Please include a link to the data if the data is open to public.
Please enter NA if you don't know the source of data.

- ○ Pre-cleaning measure ________________
- ○ Surface cleaning type ________________
- ○ Coating application delay ________________
- ○ Surface roughness ________________
- ○ Quality control test results ________________
- ○ Other ________________

If you have selected “environmental exposure”, could you please specify the source of these data if the data is available (e.g., from United States Geological Survey)?
If you have not selected “environmental exposure”, please skip this question.

Please be as specific as you can.
Please include a link to the data if the data is open to public.
Please enter NA if you don't know the source of data.

○ Salt concentration

____

○ Chloride exposure level

____

○ Water PH level

____

○ Temperature

____

○ Relative humidity

____

○ Distance from the shore

____

○ Prevailing winds

____

○ Airborne pollution

____

○ Contaminant deposition

____

○ Ultraviolet (UV) light exposure

____

○ Other

If you have selected "coating application/repair", could you please specify the source of these data (e.g., from contract documents)?

If you have not selected "coating application/repair", please skip this question.

Please be as specific as you can.
Please include a link to the data if the data is open to public.
Please enter NA if you don't know the source of data.

- ○ Coating application/repair contractor ________________

- ○ Time of coating application/repair ________________

- ○ Quality control information ________________

- ○ Steel substrate condition ________________

- ○ Steel geometric constraint for coating (e.g. bolts, cuts, edges) ________________

- ○ Coating application method ________________

- ○ Coating touch-up and repair method ________________

- ○ Other ________________

If you have selected "coating cost", could you please specify the source of these data (e.g., from cost summary)?
If you have not selected "coating cost", please skip this question.

Please be as specific as you can.

Please include a link to the data if the data is open to public.
Please enter NA if you don't know the source of data.

- ○ Coating material cost ________________

- ○ Coating application cost ________________

- ○ Coating repair cost ________________

- ○ Coating removal and replacement cost ________________

- ○ Other ________________

Are you willing to share the above-mentioned data sources with FIU research team?

- ○ Yes (1)
- ○ No (2)
- ○ Maybe, but I need to get permission first (3)
- ○ Other, please specify (4) ____

If yes or maybe, please leave you contact information so we can reach out to you later to collect the data.

____