Integrated 3D Bridge-Condition Visualization (BCV) to Facilitate Element-Based Bridge Condition Rating (EBCR)

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16. Abstract

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Abstract

Routine inspection and maintenance records are essential for bridges to function well throughout their intended lifespan. Although existing bridge management systems are efficient at data storage, it is difficult to conduct comprehensive data analysis and management due to the lack of data integration mechanism. Engineers have to manually put many pieces of bridge drawings and inspection data together to make maintenance or repair/rehab decisions. Building information modeling (BIM) can be applied in bridge asset management area, including bridge inspection/rating to help to integrate the many data pieces. In this project we developed a 3D bridge inspection data management system, using I-680 Mormon Bridge as a case, to integrate 3D visualization with bridge inspection and maintenance records for visualized data analysis and active data management. This system can be used in managing inspection data in other bridges, and other infrastructures with only minor modifications.

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Chapter 1 **Introduction**

1.1 Background

Regular maintenance and inspection are mandatory for bridges to function well throughout their intended lifespan. Inspections and condition rating of bridges are critical for establishing proper maintenance and repair schedules. Bridges have to be inspected regularly for defects which might have been caused by several natural as well as human factors. The National Bridge Inspection Standards (NBIS) were established in 1971 after the U.S. Congress added a section to the "Federal Highway Act of 1968" which required the Secretary of Transportation to establish a national bridge inspection standard. The National Bridge Inspection Standards set the requirements regarding which structures to inspect, bridge inspection frequency, inspector qualifications, report formats, and inspection & rating procedures (Hearn, 2007; Federal Highway Administration, 2012). The National Bridge Inventory (NBI) is a compilation of bridge data supplied by the States to the Federal Highway Administration (FHWA) for bridges located on public roads. According to the NBI, there are more than 600,000 bridges in the US.

Despite the inspection standards and inventory database, catastrophes due to deterioration of some critical bridge components still occurred. One such catastrophe was the I-35 Mississippi river bridge collapse on August 1, 2007. The steel truss arch bridge, which was a part of a busy highway, suddenly failed and collapsed killing 13 people and injuring 145. The investigation which ensued revealed that the probable cause of the failure was the inadequate loading capacity resulting from deterioration of the gusset plates at certain nodes. The gusset plates failed due to a combination of substantial increases in the weight of the bridge resulting from previous bridge

modifications and the traffic and concentrated construction loads on the bridge on the day of the collapse (National Transportation Safety Board 2008). During the last twenty years, there have been nearly 600 bridges that are known to have failed (LePatner 2010).

There are 2,654 bridges (2014) in Nebraska determined as structurally deficient. Most of them are in service every day. Understanding the deficiency details of each bridge is important for making quantified decisions regarding how to maintain, repair, or replace them. In order to understand the deficiency details, element-based bridge inspection (EBBI) is needed. Many states are shifting or plan to shift to an EBBI system. A big challenge in adopting EBBI system is not only the data volume increase, but also the complexity of data integration, e.g. how can we utilize the data to help to make more informed decision instead of being over-whelmed by the sudden increase in the amount of inspection data. There is an urgent need to develop an effective tool to acquire, manage inspection data and integrate inspection data with the decision support system.

Contributing to the Mississippi River bridge accident was the generally accepted practice among Federal and State transportation officials of giving inadequate attention to gusset plates during inspections with regard to conditions of distortion and bowing and exclusion of gusset plates from load rating analyses (National Transportation Safety Board 2008). Following the investigation, the National Transportation Safety Board (NTSB) made several recommendations to the Federal Highway Administration (FHWA) and the American Association of State and Highway and Transportation Officials (AASHTO). These recommendations included modifying bridge inspector training to emphasize inspection

techniques related to gusset plates and to include gusset plates as a commonly recognized (CoRe) structural element. The need for a radical change in the bridge inspection practices and the bridge management system had become inevitable.

1.2 Bridge Rating

According to the NBI, there are more than 600,000 bridges in the US. Many of these bridges are owned and operated by the federal government, states, counties and cities. Some are owned by private operators. Bridge inspections need to be performed to ensure the safety of these bridges, to discover maintenance and repair needs and to prepare for rehabilitation (Hearn 2007). The National Bridge Inspection Standards (NBIS), established in 1971, were the result of the collapse of the Silver Bridge in West Virginia, on December 15, 1967. Forty six people were killed in this accident, which had a significant impact on the American bridge builders (Lichtenstein 1993).

Subsequently, three manuals were developed to aid bridge inspections. The first manual was the Federal Highway Administration (FHWA) *Bridge Inspector's Training Manual 70* (*Manual 70)*. This manual set the standard for inspector training. The second manual was the American Association of State Highway Officials (AASHO) Manual for *Maintenance Inspection of Bridges*, released in 1970. This manual was used to determine the condition, maintenance needs and load capacity of bridges. The third manual was the FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (*Coding Guide*), released in July 1972. This manual was used to evaluate and code bridge data. All three manuals have been expanded and revised several times since.

Federal regulations currently require that every bridge be inspected once every two years. However, some bridges may require to be inspected at shorter intervals depending on factors such as age, traffic and the conditions of its components. Likewise, certain newer bridges may be inspected at intervals greater than 24 months, but not exceeding 48 months, with prior approval from FHWA (Federal Highway Administration 2012). A general condition rating is used to describe the overall condition of the bridge. This condition rating takes into account the physical conditions of the deck, the superstructure and substructure components. This information is used to determine the general condition rating on a numerical scale that ranges from 0 to 9. Here, '0' represents a failed condition, whereas '9' represents an excellent condition (Federal Highway Administration 1995). Table 1.1 shows all the numerical values and their descriptions.

TABLE: 1.1 – General condition rating (from FHWA 1995)

Condition Rating	Condition State	Description
9	Excellent	
8	Very good	No problems noted.
7	Good	Some minor problems.
6	Satisfactory	Structural elements show some minor deterioration.
5	Fair	All primary structural elements are sound but may have some minor section loss, cracking, spalling or scour.
4	Poor	Advanced section loss, deterioration, spalling or scour.
3	Serious	Loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.

2	Critical	Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored the bridge may have to be closed until corrective action is taken.
1	Imminent failure	Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	Failed	Out of service - beyond corrective action.

The condition rating provides a method for evaluating the bridge data. A bridge sufficiency rating is calculated by using three separate factors to obtain a value that indicates the sufficiency of the bridge. The rating is based on structural adequacy which accounts for 55%, functional obsolescence which accounts for 30%, and importance to the public, which accounts for 15%. The rating is a percentage where 100 percent represents an entirely sufficient bridge and zero percent represents an entirely deficient bridge (Federal Highway Administration 2011).

The American Association of State Highway and Transportation Officials (AASHTO) released the first edition of the AASHTO Guide Manual for Bridge Element Inspection in 2011 which superseded the AASHTO Guide for Commonly Recognized Structural Elements. It serves as a resource for element level bridge inspections and provides definitions of condition states. It builds on the AASHTO Guide for Commonly Recognized Structural Elements and tries to capture the condition of bridges in a standardized way. The manual incorporates several major changes which include the following:

1. Four condition states for all elements – Good, Fair, Poor, Severe.

2. The Deck and Slab units are changed from square meters to square feet.

3. Wearing surfaces are separated from the deck element.

4. Steel protective coatings are separated from steel.

The manual lists three element types:

1. National Bridge Elements (NBE's) - These represent the primary structural elements of the bridge which determine its overall safety and condition. These elements include decks, slabs, girders, columns, abutments etc.

2. Bridge Management Elements (BME's) - These represent the secondary bridge components and include joints, wearing surfaces, protective coatings, etc.

3. Agency Developed Elements - These are elements which can be created by the inspecting agency and can include non-bridge items.

The goal of AASHTO Guide Manual for Bridge Element Inspection is to fully capture the condition of the elements in a detailed manner. It is aimed at improving the Bridge Management System (BMS) and standardizing inspection data for improved quality and consistency.

1.3 Literature Review & Problem Statement

Most of the previous research related to bridge inspection deals with the inspection techniques and not the documentation of inspection data. Documentation of bridge inspection data is important, as it forms the basis for decision making. Subsequent inspections are also based on the documented data. Many people come into contact with the inspection data and it is necessary

that this data be easily understood and interpreted by all people involved in the decision-making process.

A study by Cesare et al. sought to determine the transition probabilities of bridge elements from one condition state to another. They used these probabilities to model the aging of a bridge, based on which repair policies can be determined. Similarly Hong et al. have tried to estimate the service life of concrete bridge decks based on the deterioration rate and the condition rating for decommissioning. Kallen & Noortwijk (2006) tried to create statistical models for the condition transitions of bridges in the Netherlands.

Three-dimensional visualization has been used in other areas, particularly in the Architecture, Engineering and Construction (AEC) industry, to aid in solving complex problems. Ku & Mahabaleshwarkar (2011) tried to build Virtual worlds in their research to address the communication issues and effectively complement traditional teaching approaches. They furthermore tried to integrate it with BIM to enhance construction education. Isaacs et al. used three-dimensional visualization to aid in the decision making of sustainable urban development projects. They tried to overlay multivariate sustainability information onto physical models using visualization techniques. Li & Zhu (2009) used solid modeling techniques to propose a modeling method for dynamic underground structure simulation. They used various techniques such as object organization by layer, thematic viewing, and spatial cueing to improve visualization results.

Some researchers have also tried to incorporate 3D visualization into bridge inspections. Jáurequi et al. (2005) provided an approach for documenting bridge inspection projects using QuickTime Virtual Reality, in which panoramic images are used to examine a bridge's condition with the use of a computer. Esch et al.(2009) demonstrated a 3D visualization system for load rating of Reinforced Concrete Deck Girder (RCDG) highway bridges which allows engineers to determine if any structural components are in need of repair and to convey this information effectively to interested stakeholders. However their study does not take the inspection data into consideration and the proposed rating system is not compatible with the AASHTO Guide Manual for Bridge Element Inspection.

Despite the publication of AASHTO's element based bridge inspection guidance, challenges exist in implementing element based bridge inspection and condition rating. One of the most significant barriers is the documentation and management of the inspection and rating data for the elements of interest. Considering that the size of the data set will be exponentially increased when compared to the traditional inspection and rating system, the new element based system will pose major challenges in terms of data complexity and management. For example, a typical steel bridge may have thousands of steel elements that need to be documented. Their 3D (three-dimensional) positions are also critical information in the documentation. A more robust data management system, which contains 3D element information, needs to be developed to assist with the implementation of the element based bridge inspection and rating system.

Another major challenge for bridge inspectors is the fact that the nation's bridges continue to age and deteriorate. An accurate and thorough assessment of each bridge's current and past

conditions is critical in maintaining a safe, functional and reliable highway system. To ensure accurate bridge records, proper record keeping needs to be maintained. Accuracy and consistency of the data is important since the bridge inspection process is the foundation of the entire bridge management operation and bridge management systems. Information obtained during the inspection is used for determining needed maintenance and repairs, for prioritizing rehabilitations and replacements, for allocating resources, and for evaluating and improving design for new bridges.

Most bridges designed in the 1960s and 1970s were fracture critical (Farrar et al. 1994). A fracture-critical member is a particular member of the bridge that has no redundancy, meaning that the failure of this component would cause the collapse of the entire structure (Frangopol and Curley 1987). As per the National Bridge Inventory's (NBI) records, there are around 18,000 bridges in the US that are fracture-critical. Nearly 70,000 of the nation's bridges are classified as "structurally deficient". Bridges are considered structurally deficient if significant load-carrying elements are found to be in poor or worse condition due to deterioration and/or damage, or the adequacy of the waterway opening provided by the bridge is determined to be extremely insufficient to the point of causing intolerable roadway traffic interruptions (Federal Highway Authority 2012). Nearly 8,000 of these structurally deficient bridges are also fracture critical and are the bridges that require utmost attention.

The I-35 Bridge had been classified structurally deficient since 1991. Its superstructure had a condition rating of 4 (poor condition) from then to the time of its collapse. The sufficiency rating also dropped from 75.5 in 1990 to 46.5 in 1991 and remained below 50 (National Transportation

Safety Board, 2008). The inability of inspectors to make effective decision due to the lack of tools to aid in decision making might have been one of the reasons for the collapse of the I-35 Bridge. Bridge stewards need to become more strategic in their approach towards the overall management of bridge assets in order to prevent such disasters in the future (Federal Highway Authority 2011).

Innovative solutions are required to develop a systematic approach for bridge management, which would address the nation's challenges to increase the life of its existing bridges in a cost effective manner (Federal Highway Authority 2011). This project aims to provide one such solution by developing a visual approach to bridge inspection and bridge management.

1.4 Three-Dimensional Modeling

Three-dimensional (3D) modeling has been used as a visualization and documentation tool in all stages of building lifecycle in the architecture, engineering and construction (AEC) industry (Esch et al. 2009). The recent technological advancements as well as innovation in this field have aided building professionals and all other building industry stakeholders alike. 3D modeling has evolved from a presentation tool to an integrated building systems solution in recent times. The building industry is adopting new technologies like Building Information Modeling (BIM), 4D simulation and Virtual Reality (VR) for information sharing (Ku & Mahabaleshwarkar 2011). Though BIM is not a recent phenomenon, it has seen a surge in the past few years (Eastman et al. 2008). Implementation of BIM has enabled a tighter control over the project outcomes, right from planning and designing to construction and maintenance of buildings.

Many owners view construction costs as only a minor component of capital expenditure when compared to the lifecycle costs of a building (Eastman et al. 2008). Building information models thus serve as great tools to facility managers in not only optimizing the maintenance costs, but also in servicing buildings better. The benefits of BIM have been proven and there is a sizable shift towards this technology in the construction industry.

Bridge inspectors can take a lot out of the building industry's shift towards BIM. The new bridge element inspection procedures by AASHTO provide an exciting opportunity to combine 3D modeling technology and the rating system to create a visualization tool for bridge inspectors. In a study done by Phares et al. (2004), it was shown that bridge inspections are not always completely accurate. The results showed that the same bridge elements were rated quite differently by different inspectors. These discrepancies might have been a result of the difference in conditions at the time of inspection, different perception of element conditions, errors in reading previous inspection records or errors in documentation. The new bridge element inspection procedures mitigate these problems to a great extent by reducing the number of condition states of elements and separating wearing surfaces from deck elements. By introducing a 3D model of the bridge and combining it with the new rating system, an integrated visualization tool can be created which would make the documentation and retrieval of information easier and also make inspections more accurate. Three-dimensional visualization has the ability to engage user's perceptual and spatial faculties and aid processing of complex information (Isaacs et al. 2011). This thesis describes about a three-dimensional visualization tool that integrates the data from an inspection with a 3D representation of the inspected bridge

and creates a database which is easier to retrieve and read. The following chapters discuss how three-dimensional modeling can be used as a tool to convey useful bridge related information in an effective manner.

1.5 Goal and Objectives

3D modeling has been used in a lot of industries for solutions that were not possible with traditional two-dimensional drawings and other means. 3D models have many apparent advantages over two-dimensional drawings. The depth in these models facilitates better understanding, which is closer to the real world than other means. 3D models can be easily understood by anyone and hence communicate to a large audience. Though 3D modeling is quite common in the building industry and other industries like aerospace, automobile and manufacturing, it has not been used as frequently for bridges. The goal of this study is to develop an integrated 3D visualization tool to fill the gap of data management in element based bridge condition rating approach. It will enable the creation a real-time virtual model of a bridge to assess its condition as described by the bridge inspector. The model would serve as a tool for the bridge inspector to communicate with other inspectors, higher authorities, government and the general public and to store information in a way that can be easily understood and retrieved.

The objectives of this project include:

1. Understanding the present data management system for bridge inspection and bridge rating, and understanding the limitations of the current systems.

2. Developing a prototype and adding functionality to the model to better visualize the bridge condition rating.

3. Giving recommendations on the usage of 3D visualization to enable element-based bridge inspection and rating.

Chapter 2 **Methodology**

2.1 Selection of Software Platform

There are several three-dimensional modeling tools available in the market; each one having its strengths. For the purpose of this particular study, a tool was required that would have an intuitive user interface and a relatively gentle learning curve. The study also required that the tool to be used be customizable to incorporate additional functionality that would be specific to the project. While many of the tools preferred by designers and artists had strong rendering capabilities, these were not useful for this study, as they had sophisticated user-interfaces and steep learning curves. The tool to be used had to be easy to learn and required to have plenty of resources, as it would be passed on to users who might not have prior artistic skills. Trimble SketchUp was selected as the tool for this project because:

1. It has an intuitive interface that makes depths easier to understand even to users who have no prior experience in three-dimensional modeling.

2. It has a gentle learning curve and can be mastered very quickly.

3. It has a strong online resource base including repositories of 3d models which are shared by users.

4. Additional functionality can be easily incorporated within SketchUp through its Ruby (programming language) Application Programming Interface (API).

SketchUp has been used in different industries such as architectural, civil and mechanical for various purposes. The simplicity of its use and customization can be demonstrated by the large number of model assemblies and plugins that are available online. In SketchUp, plugins are collections of scripts written in a programming language (like Ruby), to extend its functionality.

The use of plugins makes it possible to attain a high level of sophistication, while retaining the robustness of SketchUp's interface. The following section describes how the workflow was designed.
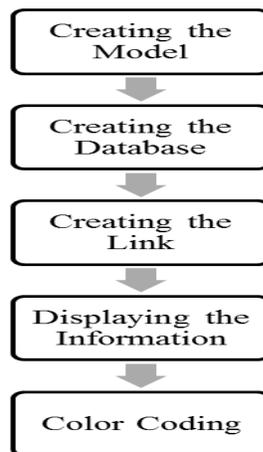
2.2 Workflow

Figure 2. 1 – The workflow

Figure 2.1 shows the workflow for the project. The first step in creating an integrated model to visualize component based bridge condition rating is to create a model of the bridge itself. The detail to which the bridge has to be modeled depends on the level of detail of the available drawings and the level of details of inspection records. For example a more detailed model can be created for a bridge that requires more attention due to its age or condition. Components can also be nested such that the detail level can be adjusted at any stage. An example of a nested component is shown in figure 2.2.
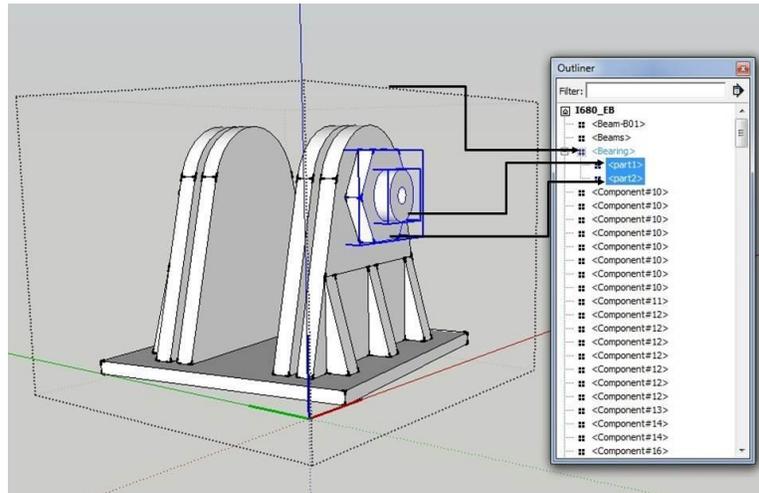
Figure 2. 2 – Nested components

The second step is to create a database of inspection records for each component. These records are obtained from the inspection reports of the bridge. For instance, each component can have a description, image and notes related to it. The database may be created initially and updated with each subsequent inspection. This database may be hosted either on a server or locally. Hosting on a server is more advantageous as it can be accessed from anywhere. Once the database is created it is possible to update it from the inspection site. This approach can be beneficial because valuable information is not lost or distorted through multiple conversions. It may sometimes be hard to interpret field notes when there is a delay between inspection and report creation.
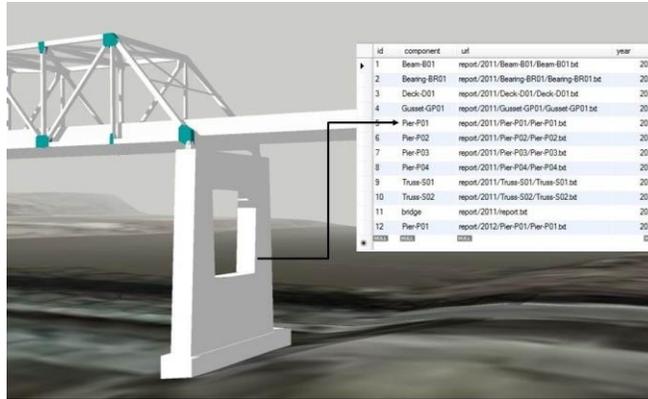
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Figure 2. 3 – Assigning the name attribute

The third step is to create a link between each component in the database and its manifestation in the model. It requires that there is a common attribute between a component and its manifestation in the model that uniquely identifies it. This attribute can be the name, or a unique ID. Figure 2.3 shows an example in which a name attribute is used to relate a component in the database to its corresponding manifestation in the model. Creating this link makes it possible for SketchUp to access all information pertaining to a component available in the database.

Once a link is created between the database and the model, the next step is to display pertinent information in the model to extract information useful for the assessment of the component. This information can be displayed in a separate window as shown in figure 2.4. This makes it easier to locate components and access pertinent information than when only field notes and reports available.
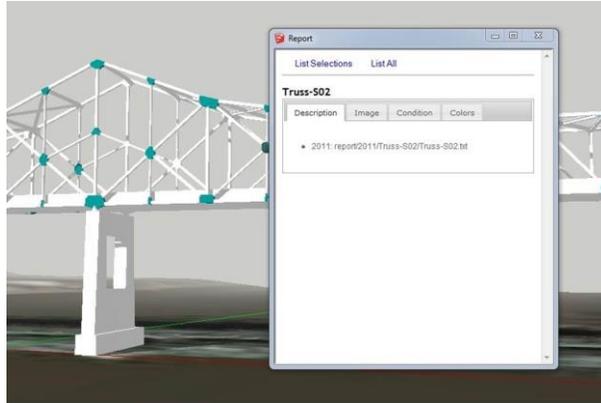
Figure 2. 4 - Window showing component information

Displaying information pertaining to a component in the model is useful, but it still does not create the desired visualization that would make the condition rating easily assessable. To achieve this, a visual link may be created between the component's model and its corresponding rating with the use of colors. Figure 3.5 shows how this can be achieved.
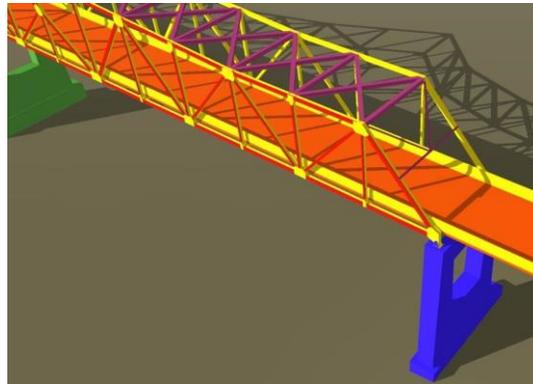

Figure 2. 5 - Color coding

These steps would not only the make retrieval of information easier, but also assist in assessing the condition and formulating an action plan for the bridge at an element level. Once this workflow has been created, it is necessary to write the code that achieves this functionality. When the code has been written, it is possible to enable component-based bridge condition rating

for any bridge by following the first two steps. The major part in this process is to create the model and database for the first time. Once this is done, these can be reused over and over again, on subsequent inspections. One advantage that this approach has is that the conditions of the bridge and its components at different stages of its life cycle can be easily compared. This enables the inspectors to formulate rapid action plans to correct progressively worsening defects. This would mean that potential accidents that are a result of delayed actions or improper assessment of the situation might be avoided. Bridges are a symbol of economic development and technological advancement. With aging infrastructure it is of utmost importance that every measure be taken so that these bridges do not hinder progress, or worse, be a cause of danger to the public.

The Chapter 3 shows how this workflow is created in detail and how a prototype is built to study the condition of a bridge certain bridge.

As discussed in the earlier, there are five major steps in creating an integrated 3d model that would enable component based bridge condition rating. These steps are discussed in more detail in this chapter. But first, it is important to understand the system architecture.

3.1 System Architecture

Figure 3.1 shows the architecture of the system. The first part consists of the digitization of the available data to create the database and the model required for the system. Next, automation is brought into the system with the use of the Application Programming Interface (API). This results in the evolution of the integrated three-dimensional model, which is the output of this system.
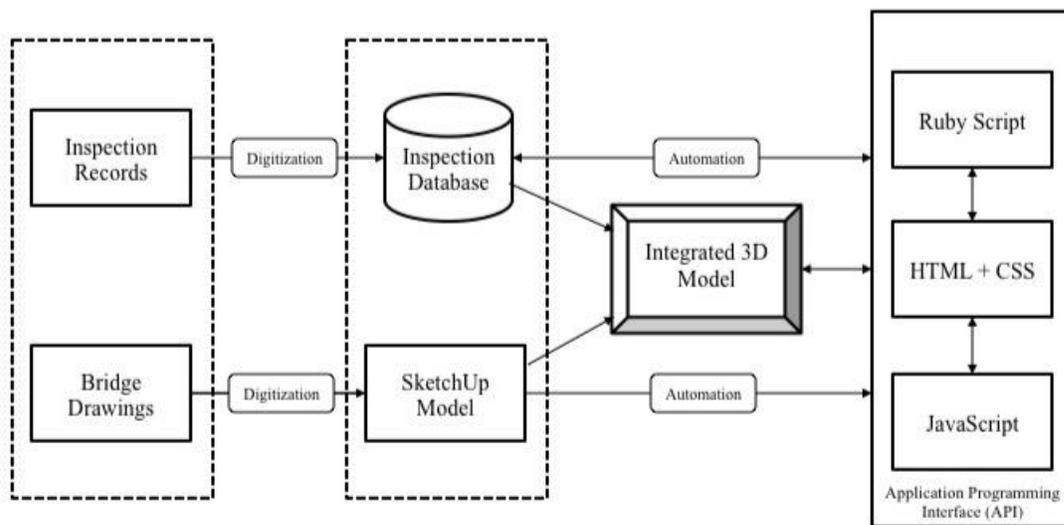

Figure 3. 1 - System architecture

3.2 Creating the Model

The first step in the workflow is to create the model of the bridge. For this study, the I-680 EB Mormon Bridge, which is located in Omaha, Nebraska, was chosen. The location of the bridge is shown in figure 3.2. Figure 3.3 shows an overview of the bridge. This bridge was finished in 1952. While the entire bridge was modeled, the level of detail was varied between various components to show the flexibility of this approach.

Figure 3. 2 - Location of the Mormon Bridge

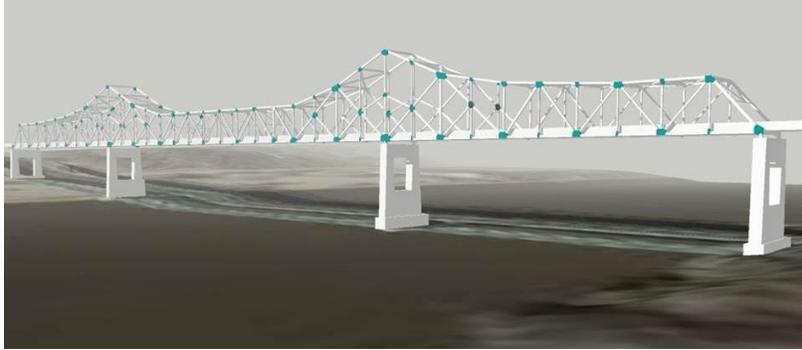**Figure 3. 3 - Picture showing the Mormon Bridge**

Figure 3. 4 - Model of the bridge created in SketchUp

The drawings that were a part of the inspection report were utilized to model this bridge in SketchUp. The total length of the structure is 1602'-9" from center-to-center of abutment bearings with a 26'-0" roadway width. Spans 3, 4, and 5 are the main thru-truss superstructure spans crossing the Missouri River and consist of two continuous cantilever thru-truss spans and one suspended span. The truss floor system is comprised of rolled steel sections. The superstructure is supported on two concrete abutment substructures units and eight concrete piers, two of which are in water. The two lanes of traffic travel eastward on a 26-foot clear roadway. The completed model is shown in figure 3.4.

3.3 Creating the Database

The database was created from the inspection report of the inspection that was performed from August 24, 2009 to September 4, 2009. The data of each identifiable component was entered into three separate tables in the database. These three tables consisted of the description, images and condition of each component. The tables are shown in figure 3.5.

id	component	url	year		id	component	rating	year	comment
1	Beam-B01	report/2011/Beam-B01/Beam-B01.txt	2011		1	Beam-B01	1	2011	Excellent
2	Bearing-BR01	report/2011/Bearing-BR01/Bearing-BR01.txt	2011		2	Bearing-BR01	2	2011	Good
3	Deck-D01	report/2011/Deck-D01/Deck-D01.txt	2011		3	Deck-D01	3	2011	Fair
4	Gusset-GP01	report/2011/Gusset-GP01/Gusset-GP01.txt	2011		4	Gusset-GP01	4	2011	Poor
5	Pier-P01	report/2011/Pier-P01/Pier-P01.txt	2011		5	Pier-P01	2	2011	Bad
6	Pier-P02	report/2011/Pier-P02/Pier-P02.txt	2011		6	Pier-P02	1	2011	Excellent
7	Pier-P03	report/2011/Pier-P03/Pier-P03.txt	2011		7	Pier-P03	2	2011	Good
8	Pier-P04	report/2011/Pier-P04/Pier-P04.txt	2011		8	Pier-P04	3	2011	Fair
9	Truss-S01	report/2011/Truss-S01/Truss-S01.txt	2011		9	Truss-S01	4	2011	Poor
10	Truss-S02	report/2011/Truss-S02/Truss-S02.txt	2011		10	Truss-S02	5	2011	Bad
11	bridge	report/2011/report.txt	2011		11	bridge	3	2011	Fair
12	Pier-P01	report/2012/Pier-P01/Pier-P01.txt	2012		12	Pier-P01	3	2012	Good

id	component	url	year	comment
1	Beam-B01	report/2011/Beam-B01/Beam-B01.jpg	2011	
2	Bearing-BR01	report/2011/Bearing-BR01/Bearing-BR01.j...	2011	
3	Deck-D01	report/2011/Deck-D01/Deck-D01.jpg	2011	
4	Gusset-GP01	report/2011/Gusset-GP01/Gusset-GP01.jpg	2011	
5	Pier-P01	report/2011/Pier-P01/Pier-P01.jpg	2011	
6	Pier-P02	report/2011/Pier-P02/Pier-P02.jpg	2011	
7	Pier-P03	report/2011/Pier-P03/Pier-P03.jpg	2011	
8	Pier-P04	report/2011/Pier-P04/Pier-P04.jpg	2011	
9	Truss-S01	report/2011/Truss-S01/Truss-S01.jpg	2011	
10	Truss-S02	report/2011/Truss-S02/Truss-S02.jpg	2011	
11	bridge	report/2011/bridge.jpg	2011	
12	Pier-P01	report/2012/Pier-P01/Pier-P01.jpg	2012	

Figure 4. 5 - Tables showing information related to the components

The database also contains the data from previous inspection report. This can be used to compare the condition of components between the two reports. Later inspection reports can also be added to this database.

3.4 Creating the Link

To create a link between the components in the model and the database, a common attribute is required. The name of the component was used to link the components by entering it as an attribute in the model. This attribute is then compared to each of the record in the database by sending a query. If the name matches, the information inside the database is retrieved by the

component. It is important to note that the name given to a component should be exactly the same as the name in the database. Code is written to first prompt for the name of a component and the input value is then stored as an attribute. This process is shown in figure 3.6.
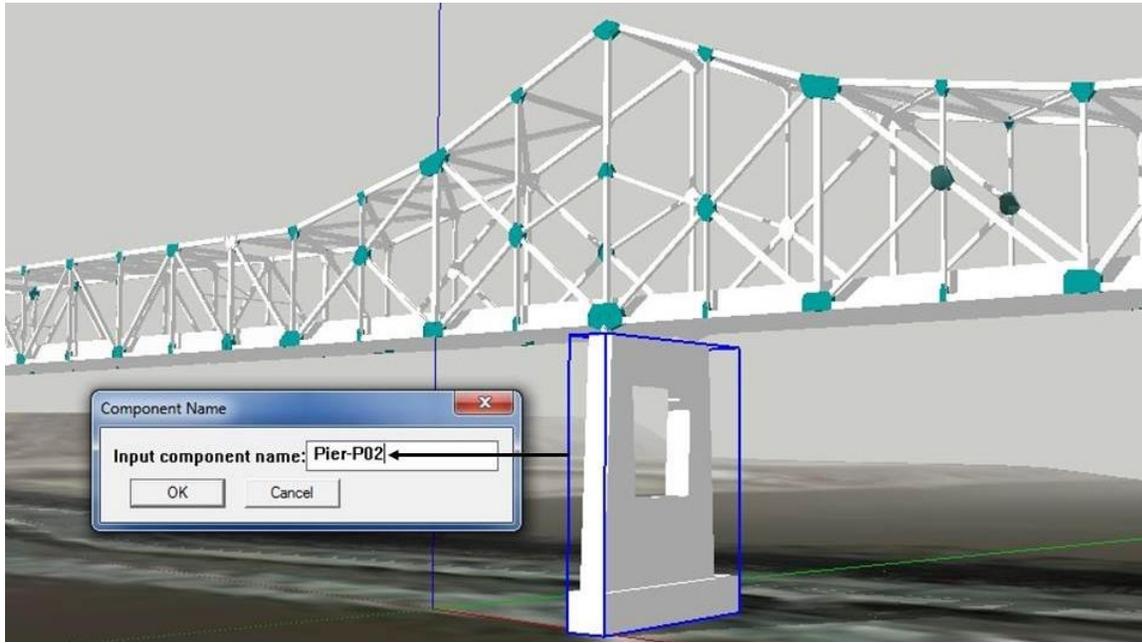

Figure 3. 6 - Attaching a name to a component

3.5 Displaying Information

Once the link is created between the model and the database, this can be shown using a WebDialog within SketchUp. A WebDialog is an instance of the web browser. In other words, it is a dialog box, which can be used to access information about the current model in SketchUp. A WebDialog can display pages formatted with the Hypertext Markup Language (HTML). JavaScript can be used to access ruby scripts from a WebDialog (Scarpino, 2010). A WebDialog showing the information about a component is shown in figure 3.7.
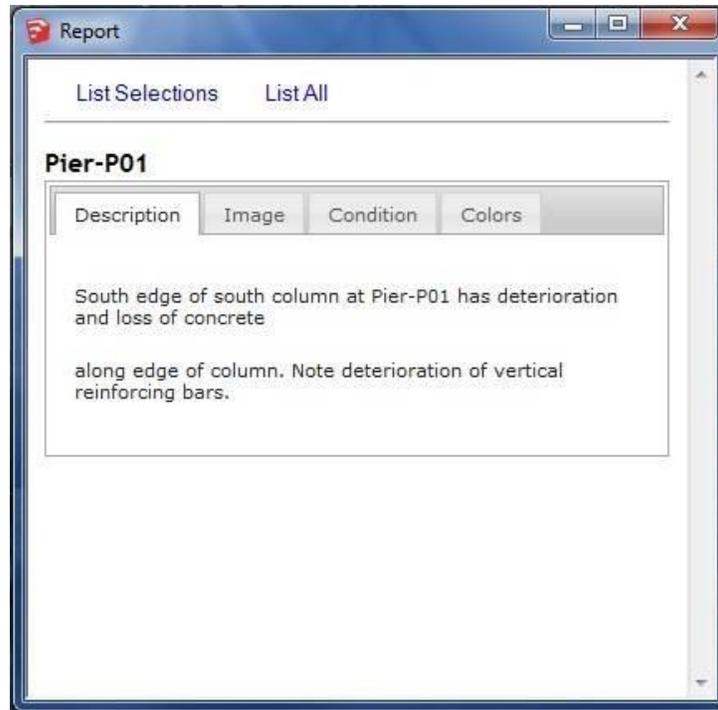
Figure 3. 7 - A WebDialog inside SketchUp

3.6 Color Coding

The next step is to color code each component according to its rating. When creating the link between the database and the model, the rating has already been accessed by the model. The color of each component must be upon its rating. One way to change a components color is to directly change the component's material property. By using this method, the color will be changed permanently and there is no way of reverting back to the original color. This causes a problem due to the following reasons:

1. If the condition rating changes over time, there is no way of showing this difference.

2. There is no way of showing the original texture of the component. This is more of a presentation issue.

3. There is no way grouping objects with same rating to control their visibility.

To avoid these problems, the concept of layers has been used. A layer is used in SketchUp to control the visibility and behavior of objects. Moreover, objects in the same layer can be made visible or invisible at the same time. In the code, new layers are created to represent the condition ratings of components. Each component's rating is then evaluated and its layer value is then set to the corresponding layer. It is then possible to give a color to each layer and not modify the color of individual components. The components can then be controlled by either coloring them by layer or otherwise. The components with a similar condition rating can either be isolated or hidden. All these actions can be achieved by clicking buttons in the WebDialog. Figure 3.8 shows how the components are colored according to their rating.

Figure 3. 8 - Color coding of the bridge

Chapter 4 **Results and Conclusions**

4.1 Results

The results are summarized in this chapter. For the purpose of this study, 20 different components were identified and a detailed report was prepared for each component. This report contains the description, image and condition rating of each element. Three different tables were then prepared for the description, image and condition rating. This report is shown in figure 4.5. The goal was to display this information in the model. A detailed model of the Mormon bridge was created using SketchUp. In this model, the 20 elements for which the detailed report was prepared were identified. These elements were then given a name by right clicking them and selecting the "Attach Name" method in report. This procedure is shown in figure 4.1.
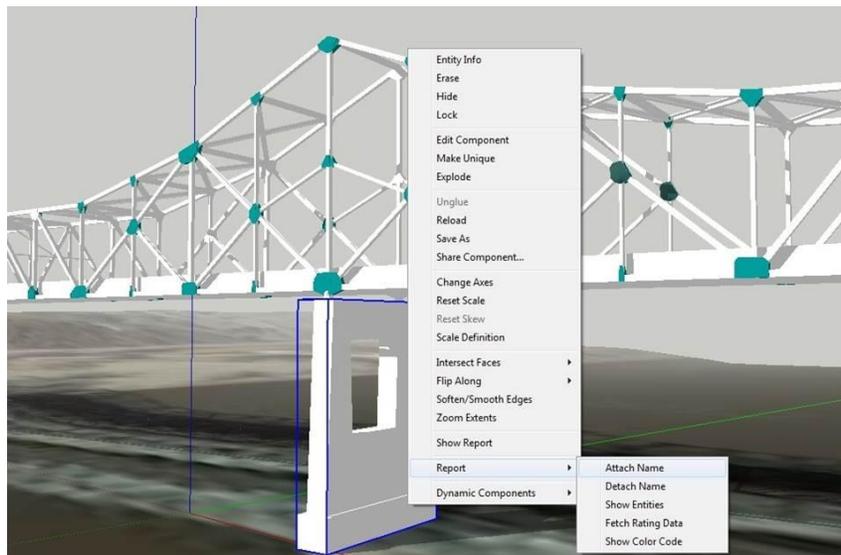

Figure 4. 1 - Attaching a name to a component

The names given to these components in the model were exactly the same as those of the corresponding components in the tables. If properly connected, each component should retrieve the information from the database and show it in a dialog box in the SketchUp window. This was

done by right clicking a component, which had an attached name and selecting the "Show Report" method. A window then opens up which shows the information about this component inside it. It is formatted in HTML in such a way that the Description, Image and Condition information were displayed in separate tabs inside the report window. This report is shown in figure 3.7 in chapter 3.

The description tab displays the URL of the text file which contains it description. When this URL is clicked, a detailed description of the component is shown. The images can be viewed by clicking on the image tab inside the report window. This tab contains the URL of the images and the thumbnail of the images which are associated with the component that is selected. When, clicked on, these images open in separate windows that can be resized. Several images can be opened side-by-side for comparison. For instance, two images of the same component from two consecutive inspections may be compared by placing them side by side. This is shown for Pier-P01 in figure 4.2.
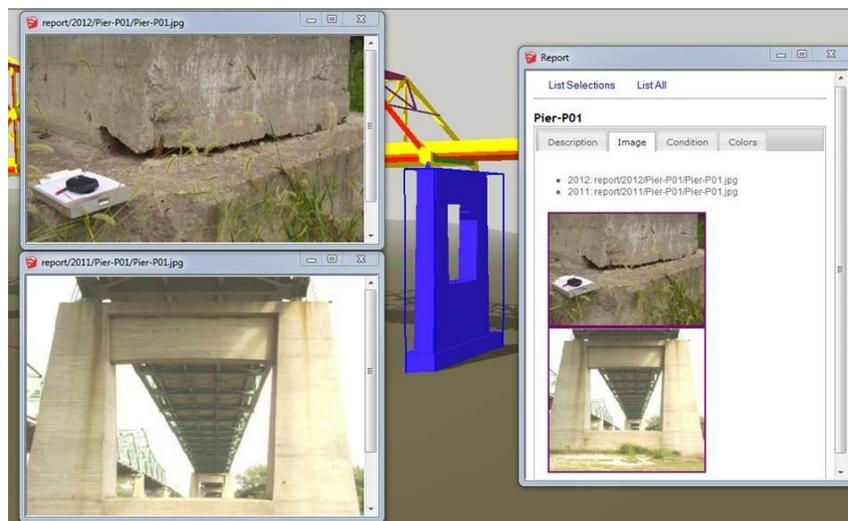

Figure 4. 2 - Image windows

The numerical condition rating and comments associated with the component can be viewed inside the condition tab of the report window. The condition rating of Pier-P01 is show in figure 4.3.
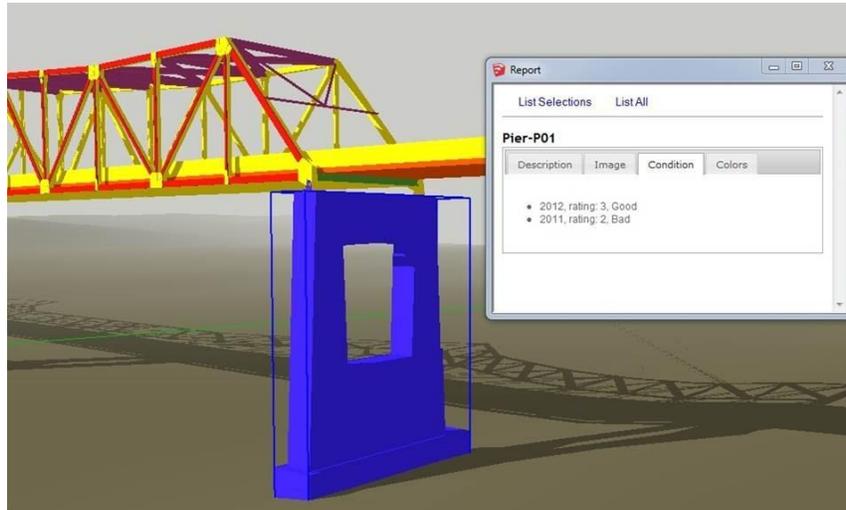

Figure 4. 3 - Condition rating

It would easier to assess the condition of each element if rather than showing the numerical representation of the condition; the elements have some property in the model that could depict this. This can be done with the use of colors. There are four possible condition ratings for all elements. Each condition was assigned a particular color. To color each element according to its condition rating, the fourth tab in the report window has to be accessed. This tab contains several buttons with different functionalities. The first button "Fetch Rating Data" will fetch the numerical rating data from the condition table and attach it to all corresponding components inside SketchUp. This is attached as an attribute to the component. The color can then be shown by clicking the "Show Color Code" button. When clicked, all elements inside SketchUp will be colored according to their rating. This is shown in figure 4.4. One can easily assess the condition of each component and also of the entire bridge visually.
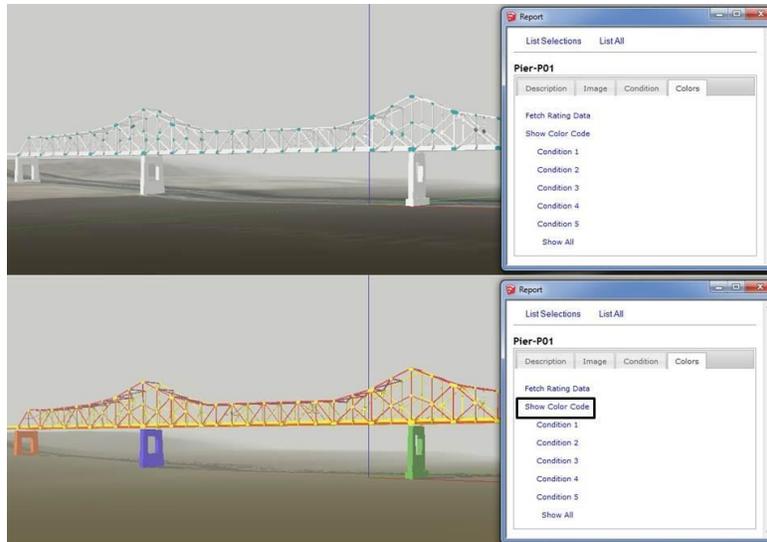
Figure 4. 4 - Bridge components before and after color coding

Another important feature is the ability to show only those elements which have a particular condition rating. This functionality is achieved with the use of the next four buttons in the colors tab. When the first button "Condition 1" is clicked, only those elements which have a condition rating of 1 are visible. The next four buttons also have the same functionality and show elements with ratings 2, 3 and 4 respectively. This functionality is shown in figure 4.5. The last button "Show All", displays all the components again, if one of the four buttons was previously clicked.

One way validate whether the model is connected to the database or not is to test it with the use of colors. Fortunately, this functionality already exists. This means that if different components have different colors upon clicking the "Show Color Code" button (assuming that they have different condition ratings), the model is automatically validated. With this, all the functionality to enable component based bridge condition rating was achieved. The results show that the model can be connected to any database by simply altering a few lines of code. This means that the code is generic and can be used to connect any bridge model to its database. The deployment

of this plugin is quite easy and can be setup on any system within minutes. Moreover, the operations are quite fast and do not require systems with high configuration.
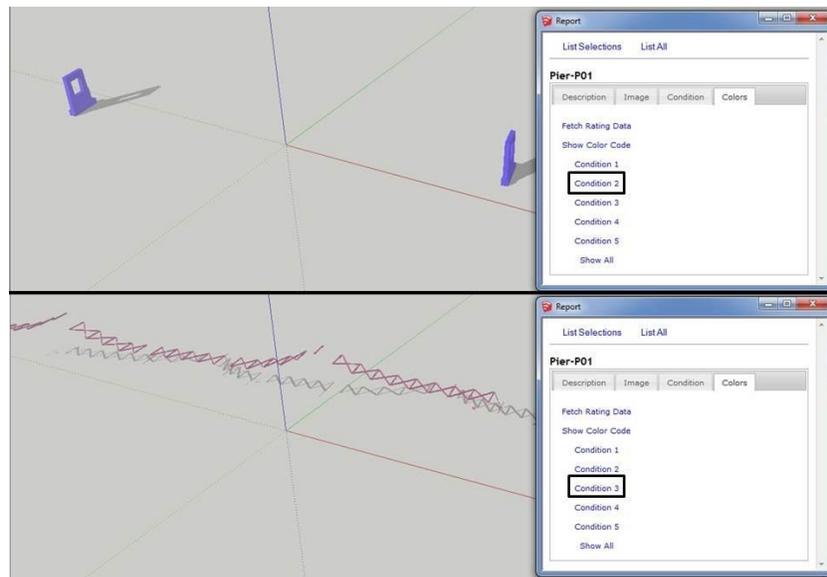

Figure 4. 5 - Filtering components with same condition rating

4.2 Conclusions

The AASHTO Guide Manual for Bridge Element Inspection is an effort to try to capture the condition of the bridge elements in a detailed and timely manner. Though it forms an excellent platform for bridge inspections, there are some limitations, such as data complexity and management. Hence, it was important that a new data management system was developed which complements the advantages of element level inspection approach. This data management system also needs to contain 3D element information to assist with the implementation of an element based bridge inspection and rating system in an effective manner. The prototype implementation of this project proved that the idea behind the thesis is valid.

The three-dimensional visualization tool developed in the process, could serve as a useful instrument for bridge inspectors and other people involved in policy making of bridges, and in their efforts to preserve the existing bridges that form the lifeline of the nation's road network. As discussed earlier, three-dimensional visualization has the ability to engage user's perceptual and spatial faculties in a way that makes the processing of complex information easier. The 3D model will function as a powerful medium through which users can understand bridge data in an effective manner. This will in turn aid in critical decision-making, which could prove to be vital for the nation's bridges. While bridge preservation is one part of the nation's bridge program, proper bridge management will ensure safety in a cost-effective manner. It will also ensure that a smooth transition is made from the old bridges to the new ones, which should be designed to overcome the limitations of their predecessors.

The new bridges will present new challenges to bridge designers, inspectors and policy makers. New bridges will also present an opportunity for technology to be integrated in a way that bridge management is completely automatic. The visualization tool discussed in this thesis would not only remain useful, but could be truly integrated with the bridge management system. One current limitation of this tool is that is only as good as the inspector's observation and field notes. To avoid this limitation, bridge condition assessment could be completely automated with the use of sensor technology. Sensors could be placed on certain critical elements or on all bridge elements to collect real-time data about the condition of these elements. This would enable accurate assessment of the bridge at the element level in real-time. The real-time data could be fed directly into the model's database to enable constant monitoring.

Many other technologies such as augmented reality present exciting avenues for future research in the area of bridge management. This would make the next generation of bridges intelligent in the sense that they would convey information about themselves. The ultimate goal is create a reliable network of infrastructure that would ensure complete safety for the public.

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