The US Bridge Portal -Visualization Analytics Applications for the National Bridge Inventory (NBI) Database

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Abstract - *For decades, the National Bridge Inventory (NBI) has served as an extensive resource used by bridge engineers and managers to study bridge deterioration patterns and plan funding allocations for repairs and rehabilitation. Data visualization in the form of static graphs and charts are used often to summarize findings. This approach may be limited considering the fact that the NBI database is multidimensional. In order to gain valuable information and insight from the NBI database, there is the need for interactive and dynamic visual data exploration tools. This paper discusses the US Bridge Portal (USBP), a visualization data mining web application used to explore the NBI data. The USBP is a data exploration tool which generates interactive maps from the NBI database to provide an overview of bridge conditions, attributes and needs in US states. Using a combination of cross-filters and spatial outputs, the dynamic maps generated have the potential to provide a greater level of insight into the NBI data which will lead to improved bridge management.*

Keywords — Data mining, Visualization, Bridges, Infrastructure management, US Bridge Portal

I. Introduction

Bridges in the US are an essential part of the country's economic growth and well-being. Without bridges linking various commercial hubs, world economies will grind to a halt. To help state and federal agencies maintain and manage such a vast infrastructure resource, the National Bridge Inventory (NBI) database was created. The NBI database is the largest collection of bridge data worldwide. It has information on the location, attributes and conditions of over 600,000 bridges in the United States Given the fact that such a large database of bridge information exists, data mining tools have been used to address many issues related to bridge infrastructure systems management [1]. Data mining is an extension of statistical data analysis which integrates machine learning, statistical analysis, modelling techniques and database technologies to identify hidden patterns in data [2]. Data mining is essential to knowledge discovery in large multidimensional datasets. It is known that visualization of data extend human perceptual capabilities [3]. Additionally, visual representation of multidimensional data sets provides better insight into complex databases allowing more efficient management decision making. The focus of this paper is to introduce spatial visualization tools into data mining of infrastructure databases. Specifically, the study utilizes a custom made web application created by the authors to mine data from the National Bridge Inventory (NBI). This visualization data mining application can be used by bridge engineers and asset managers to improve maintenance and management activities which could lead to prolonged useful lives of the nation's bridge infrastructure. Visualization plays an important role in bridge management because it gives a general qualitative overview of data which can be used to identify areas or patterns for more focused analyses. To the best knowledge of the authors, this approach has not been applied to the NBI database prior to this work.

II. Background

The tragic collapse of the Silver Bridge between Ohio and West Virginia in 1967 which resulted in 46 deaths led to the government establishing a law which marked the genesis of uniform bridge inspection standards [4]. The National Bridge Inspection Standards (NBIS) was then developed by the Secretary of Transportation based on requirements stipulated in the Federal-Aid Highway Act of 1968 [5]. The National Bridge Inventory (NBI) is therefore the aggregate database of bridge information collected by bridge inspectors at least once every 2 years as part of the requirements of the law. This database has records of over 600,000 bridges. Each bridge record has 116 categories (items) that contain specific information about the bridge, such as information about bridge design, age, bridge evaluation, maintenance, usage and rehabilitation or replacement costs. This database has been used extensively in past applications to study the behaviour of bridges and as a basis for forecasting and decision making [4,6,7,8,9]. Summaries and inferences drawn from most of the analyses are usually represented graphically using static charts and graphs. These charts and graphs provide useful information to analysts, but may be limited when dealing with more complex data sets. In its raw form, making sense of data from this large database can be very challenging. A snapshot of data from the NBI database is presented in Fig.1, which clearly shows that it would be very difficult to visualize and analyze data in this form.

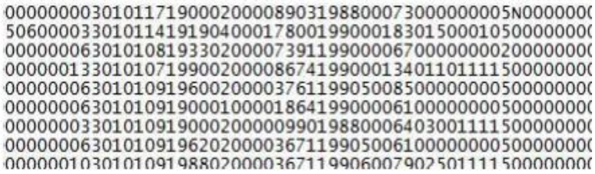


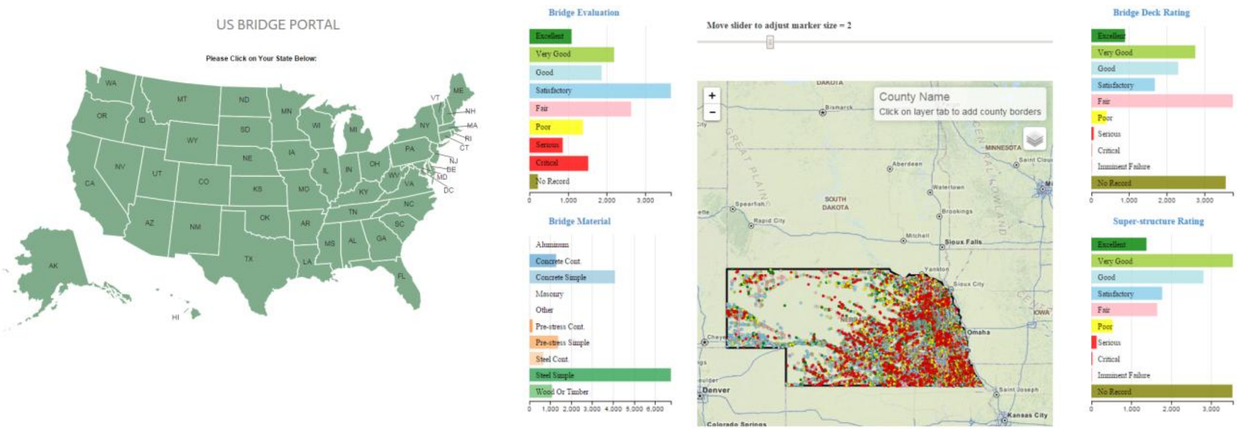
Fig. 1. Snapshot of NBI data in ASCII format

To address these shortcomings, the authors created an interactive web mining application called US Bridge Portal. The USBP uses information from the NBI database as a basis for knowledge discovery in bridge asset management throughout the US. The USBP can be used for decision and policy making, research, business and educational purposes by generating highly interactive maps of the US showing the locations and conditions of bridges nationwide. It provides bridge asset managers or any other interested parties, the ability to make sense of the NBI data. Using efficient dimension reduction algorithms, this application is able to handle very large datasets and provide a graphical and spatial interface for exploring the NBI data. Additionally, this application renders bridge data analysis accessible to bridge managers and civil engineers who may not be very familiar with arcane programming languages generally used for data analysis. The USBP serves as an intermediary platform which transforms this data into interactive maps and charts that can be exported and further analysed using some other data analytics tools.

III. Using the US Bridge Portal (USBP)

The data visualization procedure using the USBP starts with opening a web page with the interactive map of the US [10]. The next step is to select the US state of interest after which the Bridge Portal application is initiated. The Bridge Portal application plots the geographical location of all bridges in the selected state (Fig.2), where each bridge is represented by a colored circle. The color of the circle corresponds to the bridge structural evaluation. Bridge structural evaluations contain information on how well bridges are maintained and operated. The green color represents the bridges in excellent and very good condition (bridges that are superior or equal to desirable design criteria), while the red color represent bridges in bad conditions (bridges needing rehabilitation or replacement).

Currently, the application displays a total of 9 unique charts that correspond to 9 items in the National Bridge Inventory. Depending on the data structure, charts in the applications are organized as row charts of bar charts. Bar charts have interval data entries, while row charts have categorical data entries. All charts are interactive and selecting any of the categories in the row charts and any range within the bar charts will update the map by filtering the data. The filtering process is based on an efficient crossfilter.js library (<0.3ms) and can easily process up to several million data entries simultaneously. Records from all charts are summarized in the table at the bottom of the page. The table is also interactive and updates itself based on the filters selected. Utilizing the crossfilter.js library, bridges in a specified condition can be filtered based on material type, design, condition, traffic and maintenance costs. This becomes very useful for bridge asset managers, especially ones investigating trends in bridge deteriorations (conditions) across states. The USBP allows engineers to find bridges of interest using very complex and specific queries. Furthermore, if used by bridge managers the application's satellite view



(i) (ii)

Fig. 2. (i) US Bridge Portal Interactive Map. (ii) User interface of the US Bridge Portal application at state level

layer can be turned on in order to better visualize the location of the bridge. This feature could be very beneficial depending on the application task For the development of this application, five

JavaScript libraries were used (jQuery.js, d3.js, dc.js, crossfilter.js and leaflet.js). The jQuery.js is a simple and efficient document object model (DOM) manipulation library with ability to incorporate event handling from other applications (such as cascade styling sheet (CSS) and PHPs). Dc.js is also a highly efficient charting library that utilizes CSS friendly scalable vector graphic (SVG) format to create interactive plots and visualizations. D3.js is the powerful and fast visualization library that allows manipulations and data driven transformations on HTML pages. Crossfilter.js is map reduced based library, used for processing multivariate data sets in the browser. Crossfilter.js is an extremely efficient and fast library that supports very large data sets in the order of millions of records and can be used for multidimensional data mining. Lastly, leaflet. js, is a simple, high performing interactive map library. This highly adaptive library works efficiently on both desktop and mobile browsers. All java script libraries are integrated by custom made HTML code.

IV. Case Studies

The USBP application can be used in diverse ways to ameliorate bridge maintenance programs. Integration of the application into current asset management programs will lead to greater value-for-money in terms of bridge condition monitoring. To demonstrate the USBP's versatility as an asset management tool, case-studies were conducted using bridge data from two states, Nebraska and California. The most recent NBI data set (2014) was used for this demonstration and only bridges with available longitude and latitude data were taken into consideration.

A. *Nebraska Bridge Portal*

According to the 2014 NBI database, the state of Nebraska had a total of 15, 371 bridge records. The average age of the bridges in the state was 44.01 years and the Average Daily Truck Traffic (ADTT) for all bridges is 141 trucks. There were a total of 6.7% bridges that were superior to present desirable criteria (bridges in excellent condition), and there were 15.4% of the bridges needed replacement or extensive repairs (bridges in serious and critical conditions). The most prevalent bridge type design in Nebraska was the stringer/multi girder bridge (53.6%) and the most frequently used bridge material was steel (48.2%). While steel bridges account for almost half of the all bridges in the Nebraska, they account for 64.4% of bridges in need of extensive corrective action or replacement. Accordingly, wood and timber bridges account for only 7% of all bridges in the state but also account for 33.2% of all bridges that needs to be repaired or replaced. To investigate relationship between bridge structural evaluation, bridge super-structure condition rating and bridge material, the following analysis was performed. Bridges with superstructure ratings of serious, critical and imminent failure were cross-referenced (by selecting the corresponding bars on the interactive charts) with steel and wooden bridges in need of immediate rehabilitation or replacement. The results show (Fig.3) that the bridges with above mentioned characteristics are clustered in the north and south-eastern corners of the state.

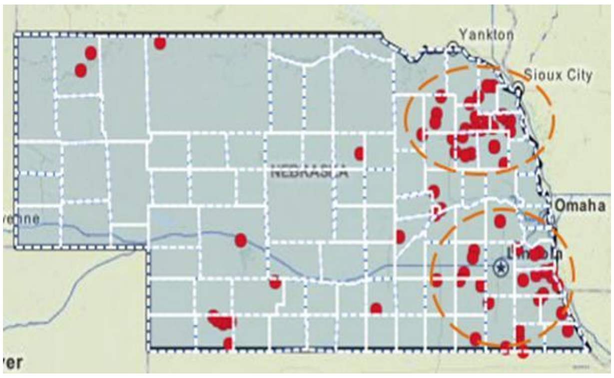


Fig. 3. Clusters of wooden and steel bridges in serious or critical conditions in Nebraska (orange dashed circles). The county borders are shown with white dashed lines.

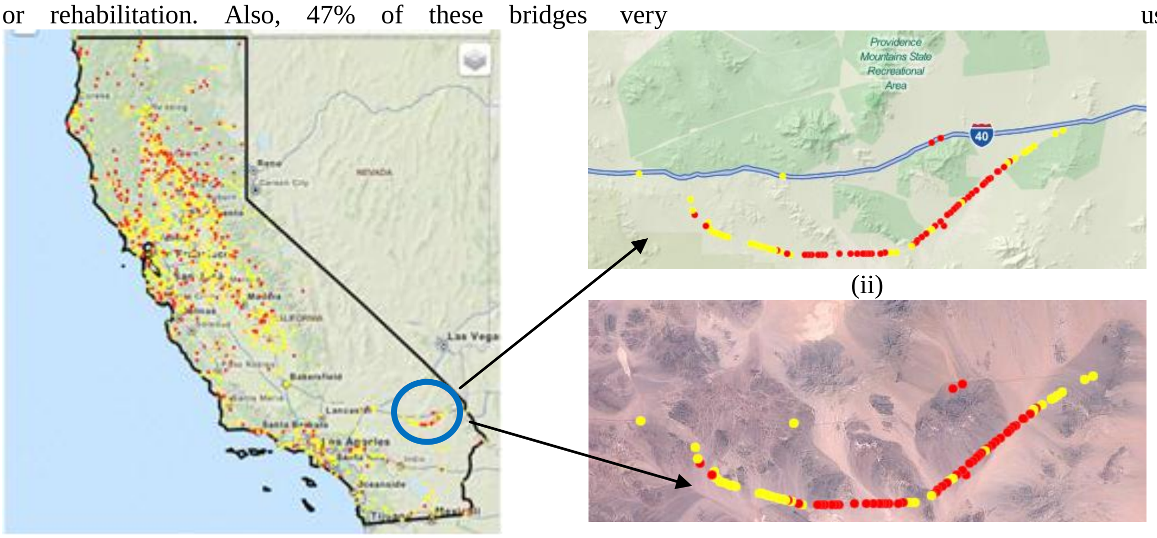
Further investigation showed that the average age of these bridges is 80.42 years, with Average Daily Traffic (ADT) of 222.9 and ADTT of only 20.9 trucks. Additionally, an average replacement or rehabilitation of cost of 96% of the bridges was only $142,611. Results also indicate that 82% of these bridges were built in 1935 (or earlier) and majority of them are spanning irrigation canals in the rural parts of the state.

Additionally, the information on geographical location of these deficient bridges can be used in resource allocation by the bridge stakeholders. By providing county borders, the information of this map can be used by the policymakers to focus on specific counties within the state which may require increased maintenance funding and oversight. Finally, by analyzing bridges based on the geographical location using the USBP, the effects of the environment in addition to ADTT, structure type, structure material and bridge age can be understood better by bridge engineers, which will help improve future designs (in terms of state specific bridge designs and specifications).

B. California Bridge Portal

NBI database from 2014. showed that there are a total of 24,888 bridge records in the state of California. The average age of all bridges in the state in the state was 47.31 years and average ADTT for the state is 1871 trucks. A total of 6.3% bridges were in excellent and good conditions while 2.4% of the bridges required replacement or extensive repairs (bridges being in serious and critical condition). The most prevalent bridge type design was stringer/multi girder bridge (31.2%) and the most frequent bridge material is concrete (63.2%). Steel bridges accounted for only 10.7 % of the bridges in California and they made up 44.4% of bridges requiring high priority of corrective action of replacement. Accordingly, wood and timber bridges account for only 2.36% of all bridges in the state, but account for 16.4% of all bridges that needs to be repaired or replaced. Spatial analysis of the bridges that need to be repaired or replaced (red circles) showed no obvious clustering pattern (Fig. 4 (i)). However, there was an unusual stretch of the bridges in the south east corner of the state indicated by the yellow dashed circle in Fig. 4 (i). Further investigations revealed that all the bridges of interest are on the National Trails Highway in the Mojave Desert. There were a total of 49 bridges on this segment of the road that needed immediate repair or rehabilitation. Also, 47% of these bridges superstructure is evaluated as being in poor condition. Interestingly, the data showed that these are all wooden bridges built in 1935. ADTT of these bridges is 128.1 and an average bridge replacement cost of $334,116.

In essence, the Bridge Portal application is intended to be used for information (data) mining by both, professionals and general public. Considering information that these bridges are being located on "Historic Route 66" highway, it is debatable should these bridges be replaced with more efficient and better performing bridges, or restored and preserved as part of historic heritage. In this case USBP can be used to inform/educate general public about the state of infrastructure in the state of California. Also given the size of the state of California, the USBP provides a very useful



(ii)

(i) (iii)

Fig.4. (i) California Bridge Portal with location of all bridges in CA (2014). Blue circle represents the region of interest with the cluster of bridges in bad condition. (ii) Street view of bridge cluster in bad condition in Mojave Desert. (iii) Satellite view of the same bridge cluster in Mojave Desert.

approach to visualize and monitor conditions of the bridges at the network level with relative ease.

V. CONCLUSION & RECOMMENDATIONS

The US Bridge Portal provides a visualization data mining tool which can be used in different ways by the general public, civil engineers, researchers, and especially bridge asset managers. Data visualization using maps gives information on the locations of bridges which is essential to bridge management. The filters available in the application also help managers in directing the focus on bridges with specific attributes exhibiting similar behaviour. In the future, the US Bridge Portal could be used to enhance bridge inspection and monitoring procedures. Also, visualization helps in providing an easy way to view structural deficiency trends among bridges across states. Individual counties within states can also be visualized to provide county-specific information. This is possible based on the dynamic maps that are generated as a result of the filtering process and becomes very important information for rehabilitation planning and repair works. Finally, policy makers on the federal, state and local level can use US Bridge portal to gather information about specific aspects of the bridges in their jurisdiction. Information such as network-level
of performance which will be difficult to obtain using the NBI data in its original format can be easily derived from the USBP.

As an open source application, all the data processing and visualization for Bridge Portal are performed in the browser. This proved to be a significant processing challenge, especially for the states that have large number of bridges since browsers are not designed to handle such large files. For example, there are total of 52,907 bridges records in Texas (with file size of 13.08 Mb) that need to be loaded and processed in the browser. The network test for the Texas Bridge Portal showed that loading time of web page was 4.74 seconds, while loading time of the data file with the bridge records was 5.99 seconds.

In contrast, the states with a relatively smaller number of bridges are processed very efficiently. A typical example is Rhode Island which had only 767 bridge records (and a file size of 143 Kb) and loading web page time of 2.23 seconds and loading time of data file of only 0.059 seconds. The potential solution to this problem is to transfer data processing from the client (browser)-side to the server-side processing. Additionally, data obtained from the NBI are not error-proof. Some of the errors found in the data base are bridge location coordinates such as those shown in Fig.5.This is not unusual considering the size of the database. Since the NBI database forms the basis for funding allocation for bridge maintenance, it is imperative that at least, coordinates of bridges are without errors.

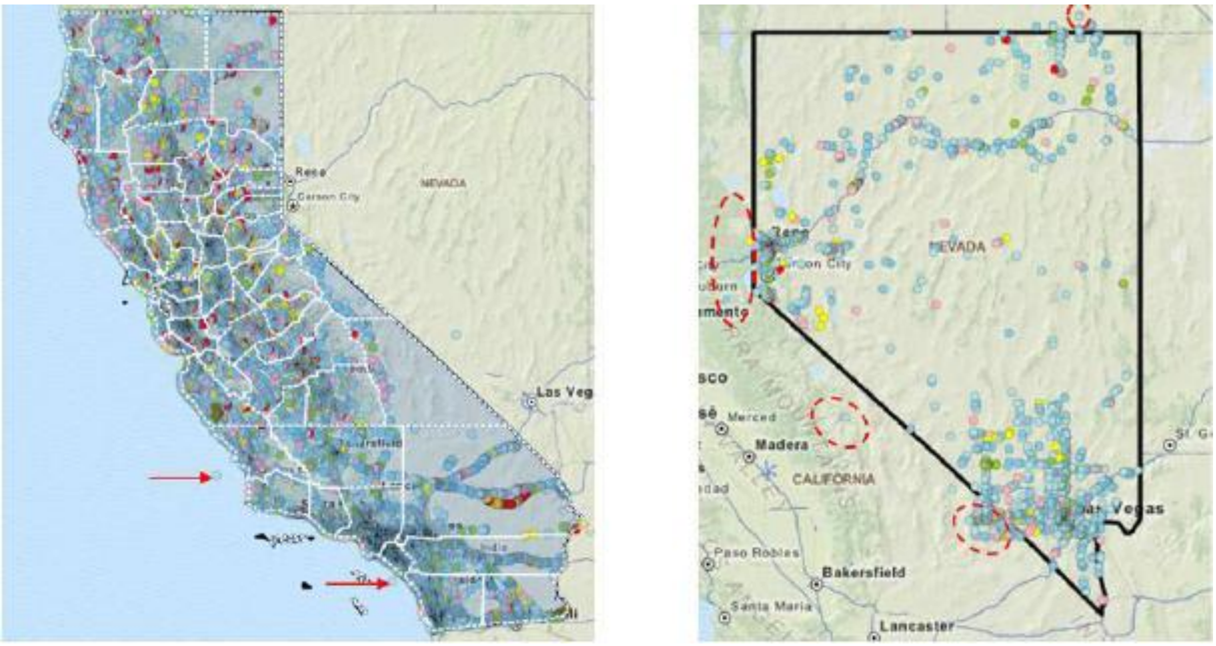


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Fig. 5. (i) Inaccurate location of bridges (indicated by red arrows) in California. (ii) Inaccurate locations of bridges in Nevada (indicated by red dashed circle).

Although, state Department of Transportation agencies can use USBP with the aim of identifying bridges having inaccurate coordinates and update bridge records accordingly. The NBI database will continue to be a major resource that is used by policy makers, bridge managers, engineers and researchers for funding allocation, maintenance planning, and understanding bridge behavior over time. The USBP application has the potential to play a major role in the advancement of bridge management. The visualization and filtering functionalities available in the USBP application will provide information that was previously difficult to obtain in a simplified manner within a short-period of time.

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