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INTEGRATED REMOTE SENSING AND VISUALIZATION (IRSV) SYSTEM FOR TRANSPORTATION INFRASTRUCTURE OPERATIONS AND MANAGEMENT

-PHASE TWO-

VOLUME 4

WEB-BASED BRIDGE INFORMATION DATABASE --- VISUALIZATION ANALYTICS AND DISTRIBUTED SENSING

By

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The guiding objective of this analytical tool is to enhance the capability of the National Bridge Inspection System (NBIS) through:
1) providing a better interpretation of bridge condition information;
2) providing a decision support module for bridge maintenance;
3) providing data entry and visualization functionalities for various information (text, image, and documents); and
4) providing a report generating tool for easier to interpret bridge information.

Bridge-WGI captures all the conventional functionalities of a Web 2.0 application. With Bridge-WGI, there is a capability for Bridge Management Systems (BMS) to migrate into an open architecture, secured access, and robust interactivity. Benefitting from Internet interactivity, Bridge-WGI is another step toward “anytime anywhere” global connectivity objectives. Interactive visualization provide various data interpretations including general bridge information, visual analytics, bridge condition distribution mapping, statistical graphs, conditional bridge search, pre-caution alarm, and maintenance decision support. A bridge data tablet application helps bridge inspectors input bridge data easily via the Internet.</td></tr>
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EXECUTIVE SUMMARY

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Partners in this Phase Two technology enhancement project has included the state agencies mentioned above. The multi-disciplinary research team includes the UNC Charlotte Center for Transportation Policy Studies (lead), Department of Civil and Environmental Engineering, and Boyle Consulting Inc.

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4.1 INTRODUCTION

4.1.1 Bridge Management and Maintenance

Bridge safety is a very important issue worldwide. A report from the America Society of Civil Engineers (ASCE) shows that more than 26%, or one in every four of the nation's bridges are either structurally deficient or functionally obsolete. Both the structurally deficient bridges and the functionally obsolete bridges are not safe for current traffic demand because of limited structural capacity and the older design features and geometrics (ASCE, 2009). The increasing concern about bridge safety has been understood by all level of highway agencies including federal, state and local governments, as well as other bridge owner/operators.

To provide efficient and effective maintenance programs for the national bridge system, bridge inspection and bridge maintenance decision making play a very important role in bridge management. For bridge management systems (BMS), their ability to provide a clear interpretation and concise information of a bridge's conditions is critical for bridge managers in understanding bridge conditions. A strategic maintenance decision making support system can help the bridge managers to make effective maintenance planning for structurally deficient bridges and/or the functionally obsolete bridges, which include whether the bridge need to be repaired or rebuilt, how and when to do the maintenance.

With recent development in computer technologies, including the Internet, geographic information systems (GIS), data communication and visualization, BMSs are more likely to employ those technologies for bridge safety applications. The current national bridge inventory (NBI) database does not include any image data such as remote sensing data (FHWA 1995). Since current bridge inspections are based on a two-year plan, during special situations, such as a sudden incident, a regularly scheduled inspection may not be able to identify a problem at some critical time (witness the I-35 bridge collapse in Minnesota). In this research, by using a "citizen sensor" concept, public data can be added into the bridge database as additional information for bridge maintenance.

The volunteer sensor is suggested as a tool for constructed bridge monitoring, which is useful for the management of systems where several discrete structures within the system may be miles away from each other, covering large spatial area and render networked sensing systems challenging. Examples of such systems include bridge structures on the national highway, railway and waterway systems and power transmission and distribution structures. Bridges, in particular, can benefit directly from volunteer sensors, since cars and pedestrians pass over them frequently.

This report presents the development and implementation of Web-GIS based information visualization framework with volunteering sensing data for national bridge management by applying the advanced technologies. . The overall system is described as Bridge-WGI.

4.1.2 Objectives of this research

This research was planned to develop and implement the Web-GIS based information visualization system for bridges by integrating advanced technologies including GIS, remote sensing and visualization. The Web-GIS based platform allows advanced data visualization and potential future cloud centric applications. This application will enhance the National Bridge Inspection System (NBIS) and provide an extraordinary performance which can be accessed via Internet. The bridge information can be shared via Internet widely and benefit from Internet-centric technologies.

The guiding objective of this analytical tool is to enhance the capability of the National Bridge Inspection System (NBIS) through:
1) providing a better interpretation of bridge condition information;
2) providing a decision support module for bridge maintenance;
3) providing data entry and visualization functionalities for various information (text, image, and documents);
4) providing a report generating tool for easier to interpret bridge information.
5) providing data entry functionalities for information including text, image, and documents to expand NBI database; and

6) automatically providing reports on bridge information.

4.1.3 Report Outline

Section 1 provides an introduction for this project. Section 2 provides the background and literature reviews of bridge management and bridge maintenance, including the related technologies such as Internet, GIS, visualization and citizen sensor and remote sensing. The application for bridge management system is also discussed. Section 3 introduces the system concept and the system architecture. Both applications of the client side and the server side are presented in this section. The system configuration is introduced at the end of this section. Section 4 describes the application of Web-GIS based NBI bridge information analytical visualization system (Bridge-WGI). The general information of the NBI database can be visualized by this application. The analytical information visualization technology helps bridge managers to have a better understanding of the conditions of the interested bridge or a cluster of bridges. Section 5 presents a decision making support module for bridge maintenance application by using Web-GIS technology. By using this module, the bridges which need maintenance will display on the map. Bridge managers can make the final decision of whether and how to maintain the bridge. Section 6 introduces the application of citizen sensing application for bridge health monitoring, and the citizen sensor (or volunteer sensor) can increase the bridge condition data dramatically by public anticipation. Volunteer sensing data can help the bridge managers to obtain the first-hand bridge information and to make a quick and correct reaction should sudden damage occur. Section 7 discusses the Web-GIS based application for remote sensing data such as LiDAR scan and aerial photography. By integrating those two kinds of remote sensing data, the current bridge manage system will be enhanced for bridge design, management and maintenance. The discussion is presented in section 8, including the contribution and the limitations of this research. Section 9 describes the conclusion and section 10 discusses the possible further research direction.

4.2 BACKGROUND AND LITERATURE REVIEW

4.2.1 Introduction

The importance of bridge safety is an increasingly concerned issue worldwide. The collapse of the I35 Bridge in Minnesota in 2007 brought every scientists and engineers alike to focus their attentions on the bridge safety issues. A report from America Society of Civil Engineering (ASCE) shows that more than 26%, or one in every four of the nation's bridges are either structurally deficient or functionally obsolete. Both the structurally deficient bridges and the functionally obsolete bridges are not safe for current traffic demand because of limited structural capacity and the older design features and geometrics (ASCE, 2009). The increasing concern about the bridge safety has been understood by all level highway agencies including federal, state and local governments.

4.2.2 National Bridge Inventory Standard (NBIS)

In 1971, the National Bridge Inspection Standards (NBIS) came into being and established national policy for bridge inspection and bridge inventory information maintenance. The standard updated several time. The Federal Highway Administration (FHWA) has made a considerable effort to establish NBIS, and helps bridge inspectors to inspect and evaluate bridges accurately (Rossow, 2011). The National Bridge Inventory Database (NBI) is the most extensive repository of data on highway bridges in the United States. In the database, there are more than 600,000 bridges documented in the Interstate highway system (Chase et.al, 1999). The NBI contains more than 100 information fields or items for each bridge, including basic information such as type, material, built year and construction characteristics, and geospatial information such as latitude and longitude, bridge condition information such as deck, superstructure and substructure, maintenance information such reconstruction year, traffic information and some other information. Each item has a specific coding structure, which is described in the FHWA Coding Guide (1995).

While many sensing technologies have been developed for bridge monitoring, for example ground penetrating radar, infrared thermography, fiber optics embedded sensing, ultrasound, stress wave based methods, LiDAR, etc. (Chase, 1995, Sack and Olson, 1995, Aktan et al. 1997, Washer, 1998, Peeters and Ventura, 2003, Gucunski et al. 2006), most of the techniques are focused on either in-situ placement of sensors or sensors on mobile platforms. All of these techniques can be characterized as target-intended (TI) techniques, which is designed as sensing system on a specific bridge. Sensors such as this are typically designed with an intended target with specific monitoring area and usually consist of supervised monitoring scheme (i.e. with established periodic sampling, passive sampling or continuous monitoring designs). Although some wireless sensing units have been promoted that can cover a wide area of bridges, these sensors are still very much target-centric systems.

4.2.3 Bridge Management Systems (BMS)

In the United States, several BMSs are developed for bridge management, such as PONTIS and BRIDGIT. PONTIS is a BMS developed by the FHWA in conjunction with six state departments of transportation (DOTs) and the joint venture consulting firms including Cambridge Systematics, Inc., and Optima, Inc. BRIDGIT is an initiative carried out by the American National Research Council as a research project jointly sponsored by AASHTO and the FHWA under the National Cooperative Highway Research Program (NCHRP). PONTIS supports the complete bridge management cycle, including bridge inspection and inventory data collection and analysis, recommending an optimal preservation policy, predicting needs and performance measures for bridges. Due to the widespread use of PONTIS applications, among the 34 agencies that use PONTIS, most customized the system or developed additional applications, such as providing additional data entry forms, reports or other functionality (Robert et al. 2003). Hawk (1999) introduced another bridge management system, BRIDGIT. BRIDGIT uses a project-level-based optimization strategy to provide network-level recommendations and guidance on how to allocate funds on your bridge network and optimizing network performance strategy.

Saito (1988) developed a network level bridge management system for the Indiana Department of Highways to manage state-owned bridges. The application included an effective use of available data, development of criteria to determine present and future needs, analysis of costs and impacts of bridge related activities, and development of methods to set priority for bridge maintenance, rehabilitation, and replacement alternatives.

Chase et al. (1999) developed several different relational database management approaches and data warehousing techniques to efficiently utilize the NBI bridge information and GIS databases. Three different regression methods were applied to model the relationship between condition state and plausible factors causing deterioration. Finally, She et al. (1999) developed a model to support the development of a GIS-based bridge management system by using a hybrid business and information modeling approach in Malaysia. Grivas et al. (1995) shows that bridge data can be differentiated by bridge types and suggested completeness and complexity can be determined by users. Their model is programmed on an Oracle platform.

4.2.4 Internet technology and GIS

The development of Internet technology makes it possible for data communication among the web servers and user ends. Internet technology has popularized the whole world as well as has changed our lifestyle. Through Internet, information can be shared and transferred from one place to another around the planet in a very short time. Internet users have choices for *anytime anywhere* access to the geography related information.

Geographic information systems (GIS) have been recognized as an important tool for various applications on geospatial data decision support and planning analysis. GIS technology has been widely implemented in many public and private organizations for decades, because GIS technology has special features for the storage, retrieval, manipulation, analysis, and display of geographically referenced data. (Batty and Xie, 1994). Because maps can make better understanding than written or verbal descriptions, so GIS provides great capacity for applications about geospatial data.

4.2.5 Web-GIS application

In recent years, GIS has begun to appear on the World Wide Web, ranging from simple demonstrations and references to GIS use, to more complex on-line GIS and spatial decision support systems. The availability of combining GIS and Internet technologies is becoming a reality in many fields (Kingston et al. 2000).

The application of integration of GIS and Internet technologies is getting more popular for GIS users. Users have flexible accessibility to access information any-time and any-where. Kingston et al. (2000) discuss the advantages of Web-based applications: With the Web-based system, the response database is continually being updated as the public use of the system and input their comments. The system also offers a high degree of flexibility to upload relevant information throughout the public participation process.

Most current research on Web-GIS is in environmental topics; a few applications are about integrating Internet and GIS technologies for national bridge management. Sugumaran and Meyer (2003) proposed a Web-Based Spatial Decision Support System for Environmental Planning and Management. Because of accessibility and interactivity for public user, the Internet was ideal as a research platform.

Burdziej (2011) introduced a concept of spatial decision support system (SDSS) which combines network analysis and spatial analysis of accessibility with an interactive Web-based application. Chen et al. (2010) developed an Integrated Remote Sensing and Visualization (IRSV) bridge management system which is proposed to help bridge managers to comprehend voluminous and heterogeneous bridge data from four essential perspectives: geospatial, temporal, relational and per-bridge attributes. An interactive data exploration environment is implemented to help bridge managers evaluate the bridge based on internal factors and/or external factors.

4.2.6 Visualization

Visualization is a concept which is associated with the amplification of mental processes. Since human eyes can process visual cues rapidly, so a proper information analysis technique can transform the computer into a powerful means of managing digitized information. Visualization offers a link between human eye and computer to help people identify patterns and to extract insights from large amounts of information. Visualization has been used to communicate ideas, to monitor trends implicit in data, and to explore large volumes of data for hypothesis generation (Zhu and Chen, 2005). Visualization technologies were being applied in many nonscientific contexts, including business, digital libraries, human behavior, and the Internet. As the application domains expand and computer hardware and software become more powerful and affordable, visualization techniques continue to improve. The information visualization can not only help people making a discovery, see the big picture, and see with many eyes, but also help researchers to do visual analytics (Chen, 2010). The IRSV System proposed by Chen et al. (2010) applies visualization techniques with large-scale analytical and interactive visualization to enhance the national bridge inspection systems. Esch et al. (2009) introduced a graphical 3D visualization for highway bridge ratings, the system for load rating highway bridges so that engineers can determine which structural components are in need of repair and display the information on a graphic user interface.

4.2.7 Citizen sensor

The free access to the Internet, the integration of GPS (geographical position systems) into everyday life and recent advances in smart phone technologies, enabled the conception of "*citizen sensors*" in the context of "*volunteered geographic information*" (Goodchild, 2007). Citizen sensor has greater implications from social media analytics prospective which studies potential social intelligence implications in Internet social network traffic flows. Nagarajan et al. (2009) described the development of Twitris for extracting and visualizing high-level metadata and analytics for social event correlations and observations from Tweeter feeds.

Citizen sensor can be considered as one type of NTI sensor and represents a critical emerging paradigm to social interactivity and operations due to the empowerment of individuals to capture and share information, typically via the use of digital gadgets, such as built-in camera or video in smart phones, and the availability of online uploads to Internet (Nagarajan et al. 2009). The shared data can be personally or socially-relevant. Social-relevant data sharing is typified by the availability of sensing tools and the geospatial-temporal positioning of individuals who possesses the awareness of events/conditions with social concerns. The citizen sensor (individual with social awareness and the capability to capture and share data) usually has the willingness and the desire to share the data. The desire may be motivated by several causes that may be calibrated by education and training.

As Goodchild (2007) noted, the power of human sensing system is a tremendous geographical resource since it is equipped with some working subset of the five senses and with the intelligence to compile and interpret what they sense. Key to the effective use of humans as sensors in specialized contexts, however, is establishing acceptable standards or metrics of credibility. By applying the public participation for bridge data input, the bridge information will get great improvement for further analysis. Internet technology makes the public participation possible from anywhere which has Internet connection available in the world. GIS technique makes the geospatial location of the people who upload the information and the location of interests.

Citizen sensor in the context of constructed facilities management utilizes the populace of social media and ubiquitous availability of camera phone and smart phone technologies to document, report and identify issues or problems associated with certain structural nodes. Citizen sensor system requires potential distributed sensors (willing citizen participants), data reporting portals and the data retrieval unit that allow engineers or managers to make informed decisions based on data input. Citizen participation in infrastructure management can be very powerful with envisioned advantages including educating citizens about the well-being of the aging infrastructure and providing the sense of engaging the public in societal management. Both advantages can help improve public relations between the bridge managers and the users of bridges.

4.2.8 Remote sensing applications for bridge management

Remote sensing technology is defined as the measurement of object properties on the earth's surface by using data acquired from terrestrial aircraft and satellites. As remote sensing platforms, satellites provide a significant amount of remote sensing imagery. Remote-sensing systems provide a repetitive and consistent view of the surface of the objects. Remote sensing of the Earth has many applications such as environmental assessment and monitoring and agriculture (Schowengerdt, 2010). Many remote-sensing systems have been developed to offer a wide range of spatial, spectral, and temporal parameters. For the past fifty years, several Commercial remote sensing (CRS) and Spatial Information (SI) technologies for wide-bandwidth spectral information sensing and imaging have been developed integrally with satellite/airborne/ground-based surveillance platforms.

Compared to satellite imagery, airborne sensors have the potential of providing images with higher resolutions. InSiteful imagery (2011) provides aerial photography with a resolution of as low as one inch, which can be made faster than most ortho-photography. Stone et al. (2004) discussed that several terminologies have been applied to similar technologies including LiDAR (Light Detection and Ranging) and Ladar (Laser Radar). LiDAR technology is also applied for highway bridge health monitoring and has further advantages, including 1) The 3D viewer model allows the engineer to review the structure directly without needing to return to the site or sorting through pages of bridge pictures, 2) a series of LiDAR scans can be connected into one global coordinate system, and 3) LiDAR is the preferred tool of analysis because of further applications (Tong et al., 2010). LiBE (LiDAR based Bridge Evaluation) methods is developed for highway bridges health monitoring to detect damage, road clearance, and deflection (Liu, 2010). Image process technology can be applied for bridge surface damage detection so that improve the capability of bridge management.

4.2.9 Summary

Bridge safety is an important issue for the public; bridge management and bridge maintenance play very important roles for bridge safety. So both the quantitative and the qualitative of bridge condition data are critical for bridge management. This research integrates the citizen sensor as an extra bridge condition data source to improve the capability of the national bridge database.

Citizen sensor can drastically increase the bridge data for bridge condition inspection; further more citizen sensor data provides instant information of the damage so that the proper maintenance can be conducted in the first time. Citizen sensor or the volunteers can act as a bridge information collector and upload the data to bridge database so that the NBI database increase dramatically. Comparing to the traditional data collection method, citizen sensing can provide bridge information in various formats (such as text, image, audio and video) and various categories (such as bridge damage, traffic jam, scene view and others). All the citizen sensor data will help further study for the bridge and the traffic by using some technologies such as data mining. Because of the instant features of citizen sensor data, the bridge managers can obtain almost instant damage information so that the bridge can be maintained in the earliest possible time.

Remote sensing technologies can be applied in highway bridge health monitoring. The 3D surface data cloud generated from LiDAR scan can be used to quantify visible damage volumes. Proper defect detection can help identify potential stability problems (Liu, 2010). The fly-over photo of deck surface of the bridge can help bridge managers to identify the critical damage on the deck surface.

Visualization technologies enhance the understanding of the bridge condition: By using visualization technology, more insightful information can be display and analyzed in front of the bridge manager, additional observation and solutions can be generated for bridge maintenance, so that bridge safety can be increased and the cost of bridge maintenance can be decreased. By integrating the remote sensing data, more analysis factors can be considered for bridge safety analysis.

Internet and GIS technologies make it possible to view the bridge data anywhere-anytime; this flexibility in accessing bridge data helps the bridge managers to maintain the bridge with new method and produce new solution with increased efficiency. By applying technologies in engineering such as infrastructure systems, it is possible to make the benefits from the technologies for the society. By applying the technologies discussed above, the NBI bridge information can be enhanced for bridge management. A powerful information visualization framework for national bridge management system is designed and implemented in this research. This framework will enhance capabilities of the existing bridge management system.

4.3 BRIDGE-WGI SYSTEM CONCEPT AND ARCHITECHTURE

4.3.1 System concept

By integrating Internet, GIS and visualization technologies, this research is focus on the development and implementation of Web-GIS based interactive information visualization system for national bridges to provide a better and more systematic bridge data interpretation. This application will enhance the National Bridge Inspection System (NBIS) and provide an extraordinary performance which can be accessed via internet. Various new features and capabilities for the bridge management system are discussed and implemented in this framework. Those features include estimation of bridge conditions, decision making support for both structural and functional improvements for bridges and public sensing data implementation. Therefore, this Web-GIS based bridge visualization framework can assist bridge managers to conduct efficient and effective maintenance on highway bridges and enable the bridge managers to make more precise damage assessments and effective solution for bridge maintenance with higher efficiency and lower cost.

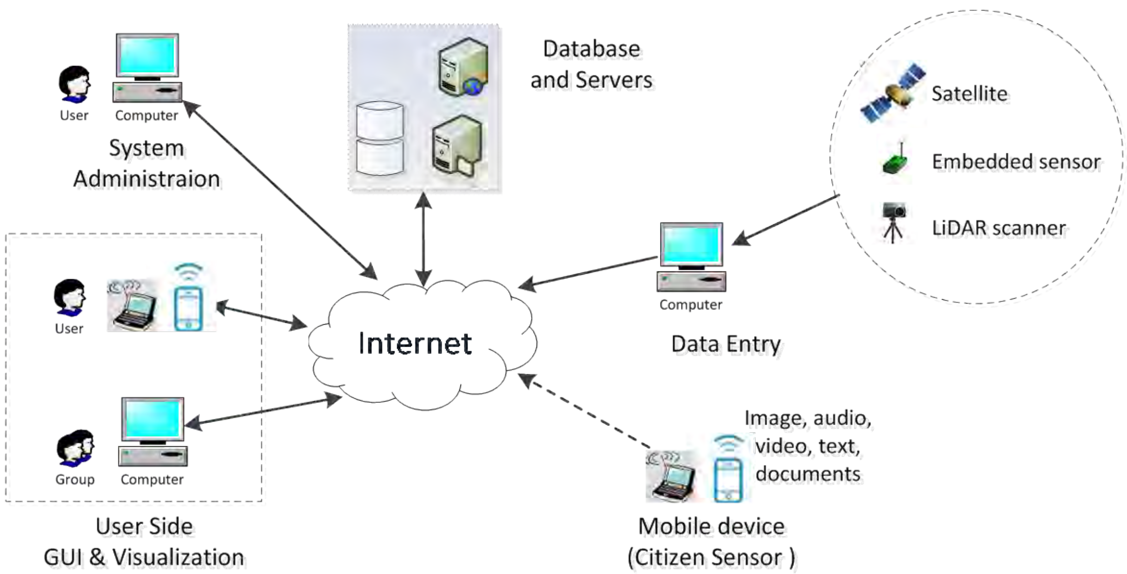


Figure 1. The concept of WebGIS-based bridge inspection system.

The architecture and features of the Web-GIS interactive visualization for bridge management system are shown in Figure 1. The framework uses MySQL database technology to support the NBI data management. Google Map serves as a map server to support the geospatial information mapping. The web applications are coded by PHP, JavaScript and HTML. The framework includes the following capabilities:

a) Display the basic information of the bridge condition rating;
b) User collaborative interactions;
c) Interactive data visualization for NBI information;
d) Data entry and document uploading;

e) Bridge condition report generation;
f) Decision-making support for bridge maintenance.

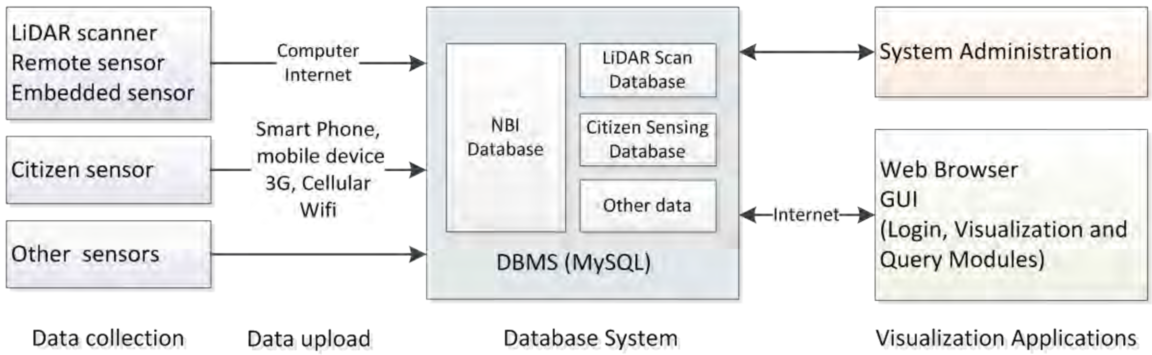


Figure 2. Architecture of Web-GIS based interactive visualization for bridge management system

The client-server model is used for this system. The main structure includes two parts: client/user side applications and server side applications. The server provides the resources for applications such as database and correlation calculations, while the client submit request to the server and send the result to client side.

4.3.2 The architecture of this system

The architecture of Bridge-WGI consists of four parts, including data collection, database management system, visualization applications and system administration (Figure 2).

4.3.2.1 Data collection and data upload

On data collection side, raw bridge condition data captured from different types of sensors are stored and uploaded to database via Internet. Various technologies are developed for bridge monitoring and bridge data collection, for example ground penetrating radar, infrared thermography, fiber optics embedded sensing, ultrasound, stress wave based methods, LiDAR, etc. (Chase, 1995, Sack and Olson, 1995, Aktan et al. 1997, Washer, 1998, Peeters and Ventura, 2003, and Gucunski et al. 2006). All of these techniques can be characterized as target-intended (TI) techniques, which is designed as sensing system on a specific bridge. Non-target-intended (NTI) sensors that can cover a wide monitoring area include remote sensors such as airborne or satellite imaging techniques (Chen et al, 2010 and Liu et al. 2010).

Citizen sensor can be considered as one type of NTI sensor and represents a critical emerging paradigm to social interactivity and operations due to the empowerment of individuals to capture and share information, typically via the use of digital gadgets, such as built-in camera or video in smart phones, and the availability of online uploads to Internet (Nagarajan et al. 2009). In this platform, based on the NBI database, LiDAR scan, aerial fly-over image and citizen sensor data are integrated for bridge management and maintenance.

4.3.2.2 Database System

The database system stores and maintains the bridge data which are captured by various sensors. NBI data is uploaded by system administrator. The LiDAR scan and aerial fly-over image are uploaded by designate system user via the computer. The citizen sensor data are uploaded by volunteer from the public. Before uploading to database, the raw data should be processed and converted to standard formats which the database has. The database system consists of NBI data, LiDAR scan, aerial fly-over image and citizen sensor data.

4.3.2.3 Visualization application

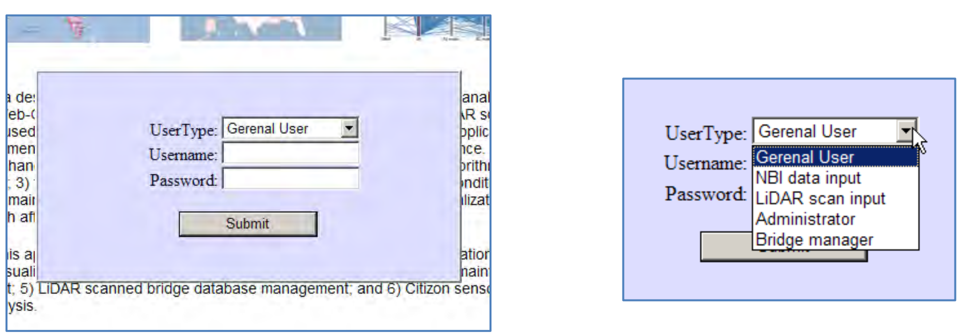
Bridge-WGI platform includes Visualization applications include all the functionalities of Bridge-WGI. On the client side, users can use computer to do applications on the national highway bridge visualization system. Both computer-based and mobile-device based web applications are implemented in this system. The structure of main applications is shown in Figure 4. All those applications can be accessed via Internet.

4.3.2.4 System Administration

System administration includes the maintenance of system such as the database maintenance and the application maintenance. The role of system administrators is supporting and maintaining the servers and database. Administrator also has responsibility to maintain scripting and supervise the condition of the system. Another functionality of administration is to make sure the entire system works well without any problems.

4.3.3 Client side applications

The clients can be desktops, mobile PCs or mobile electronics products which have access to the Internet. There are two parts, password login module and graphic user interface (GUI). Figure 3 shows the login interface.



Login interface　　　　For different user

Figure 3. Login Interface

4.3.3.1 Login

For the security issues, five-level privileges are designed for the application, including 1) general user who has privilege to view the information of national bridge system and input public data; 2) the user has privilege to input NBI data for bridge inspector; 3) the user has privilege to upload the LiDAR scanned data; 4) the administrator can maintain the data which input by other users; and 5) special privilege for bridge managers to view the maintenance decision making support. Only for the general user who do not need login, all the other privileged users must enter the username and password to access the application (Figure 3).

4.3.3.2 Graphic user interface (GUI)

The GUI is a very important part for computer application. Current design is constrained by Web2.0, and current Windows version is Window XP, hence, its presentation style and interactivities are less fluidic but can be easily improved. This bridge visualization system should be considered for user's different perspectives and for clarity for users. The main functionalities of this application include 1) Homepage of basic introduction; 2) NBI bridge information display; 3) NBI bridge condition inspection data input; 4) LiDAR scan images input; 5) LiDAR scanned bridge information display; 6) Public sensing data display for bridges; 7) Public sensing data input; 8) NBI bridge data analytical visualization; and 9) Bridge maintenance decision making support. The main interface and the functionalities of this system is illustrated in Figure 4. The GUI in client side is the interface between computer and the user. Figure 5 shows the Introduction Hompage for the Web-GIS application.

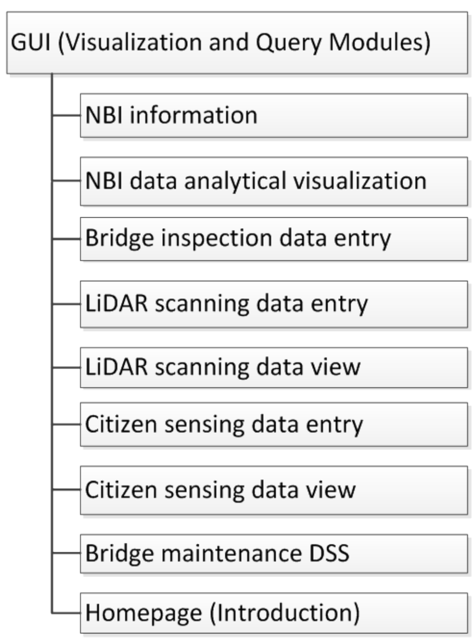


Figure 4. The main functionalities of this system

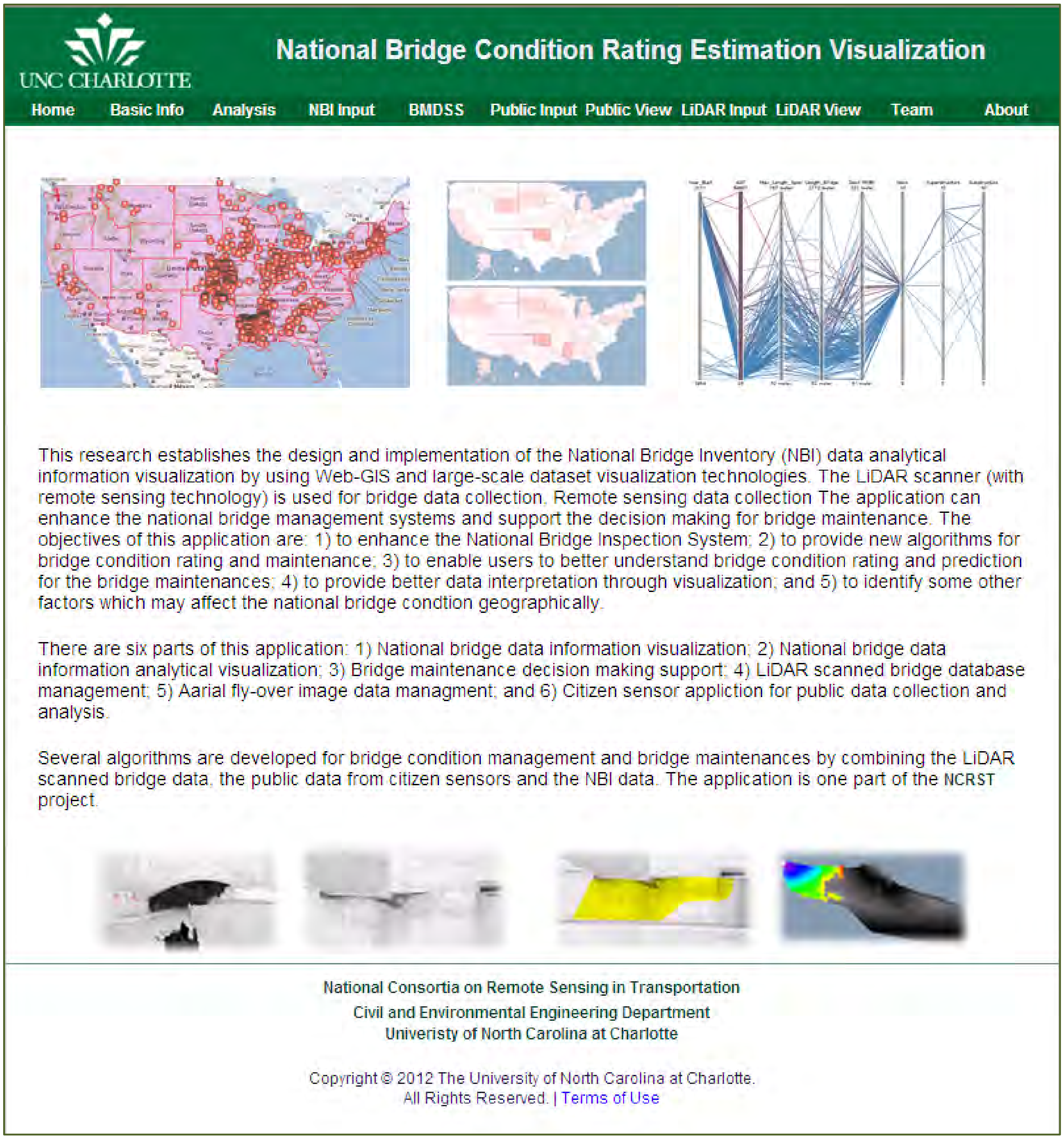


Figure 5. The graphic user interface and the homepage of this application
(testing website: http://irsv-test.uncc.edu/~ytong1/testnew/)

4.3.4 Server side applications

The server side program provides the resource for the applications. In this system, the server side includes database management system (DBMS), Internet map provider, web server and application servers, and bridge maintenance decision-making support module.

4.3.4.1 Database Management System (DBMS)

This database management system is implemented on the server side using relational database management system. The relational DBMSs are associated by related tables, which store the bridge data. The database management system consists of NBI bridge database (test and numeric data); LiDAR scanned bridge database (text, numeric and imagery data), aerial fly-over image bridge data (numeric, text and imagery data), and public sensing database (text and imagery data).

The NBI database consists of bridge inventory data of year 2008, 2009, 2010 and 2011. In the database, for each bridge, there are more than 100 information fields or items, including basic information such as type, material, built year and construction characteristics, and geospatial information such as latitude and longitude, bridge condition information such as deck, superstructure and substructure, maintenance information such reconstruction year, traffic information and some other information. Each item has a specific coding structure, which is described by the FHWA (1995). The FHWA data structure is based on ASCII, the detail structural information is showed in Appendix B.

LiDAR scanned bridge database stores the LiDAR scan data includes bridge spatial locations (Latitude and longitude), city or county of the bridge located, test date, number of uploaded image, numbers of upload documents, and some other information of the LiDAR scan test. The public sensing database stores the information uploaded by citizen sensor, including upload date, reported information, damage rank and some other related information.

The MySQL database includes eight tables in this database which are nbi2008, nbi2009, nbi2010, nbi2011, nbi, uncctest, login, and nbiinput. Among these tables, nbi2008, nbi2009, nbi2010 and nbi2011, store the NBI bridge database for the year 2008, 2009, 2010 and 2011, respectively. Table nbi and uncctest are used for remote sensing bridge data and citizen sensor data. Table login store the username and password for security issues. The nbiinput table stores the bridge inspection data of bridge conditions. The detailed structure of the database is shown in Table 1a through Table 1d.

Table 1a. Data structure for tables nbi, nbi2008, nbi2009, nbi2010, and nbi2011.

Field	Type	Null	Key	Default	Extra
row_id	int(11)	NO		0	
stfips	char(2)	YES		NULL	
region	char(1)	YES		NULL	
item8	char(15)	YES		NULL	
item5a	char(1)	YES		NULL	
item5b	char(1)	YES		NULL	
item5c	char(1)	YES		NULL	
item5d	char(5)	YES		NULL	
item5e	char(1)	YES		NULL	

Field	Type	Null	Key	Default	Extra
item2	char(2)	YES		NULL	
item3	char(3)	YES		NULL	
item4	char(5)	YES		NULL	
item6a	char(24)	YES		NULL	
item6b	char(1)	YES		NULL	
item7	char(18)	YES		NULL	
item9	char(25)	YES		NULL	
item10	char(4)	YES		NULL	
item11	char(7)	YES		NULL	
item12	char(1)	YES		NULL	
item13a	char(10)	YES		NULL	
item13b	char(2)	YES		NULL	
item16	char(8)	YES		NULL	
item17	char(9)	YES		NULL	
item19	char(3)	YES		NULL	
item20	char(1)	YES		NULL	
item21	char(2)	YES		NULL	
item22	char(2)	YES		NULL	
item26	char(2)	YES		NULL	
item27	char(4)	YES		NULL	
item28a	char(2)	YES		NULL	
item28b	char(2)	YES		NULL	
item29	char(6)	YES		NULL	
item30	char(4)	YES		NULL	
item31	char(1)	YES		NULL	
item32	char(4)	YES		NULL	
item33	char(1)	YES		NULL	
item34	char(2)	YES		NULL	
item35	char(1)	YES		NULL	
item36a	char(1)	YES		NULL	
item36b	char(1)	YES		NULL	
item36c	char(1)	YES		NULL	
item36d	char(1)	YES		NULL	
item37	char(1)	YES		NULL	
item38	char(1)	YES		NULL	
item39	char(4)	YES		NULL	
item40	char(5)	YES		NULL	
item41	char(1)	YES		NULL	
item42a	char(1)	YES		NULL	
item42b	char(1)	YES		NULL	

Field	Type	Null	Key	Default	Extra
item43a	char(1)	YES		NULL	
item43b	char(2)	YES		NULL	
item44a	char(1)	YES		NULL	
item44b	char(2)	YES		NULL	
item45	char(3)	YES		NULL	
item46	char(4)	YES		NULL	
item47	char(3)	YES		NULL	
item48	char(5)	YES		NULL	
item49	char(6)	YES		NULL	
item50a	char(3)	YES		NULL	
item50b	char(3)	YES		NULL	
item51	char(4)	YES		NULL	
item52	char(4)	YES		NULL	
item53	char(4)	YES		NULL	
item54a	char(1)	YES		NULL	
item54b	char(4)	YES		NULL	
item55a	char(1)	YES		NULL	
item55b	char(3)	YES		NULL	
item56	char(3)	YES		NULL	
item58	char(1)	YES		NULL	
item59	char(1)	YES		NULL	
item60	char(1)	YES		NULL	
item61	char(1)	YES		NULL	
item62	char(1)	YES		NULL	
item63	char(1)	YES		NULL	
item64	char(3)	YES		NULL	
item65	char(1)	YES		NULL	
item66	char(3)	YES		NULL	
item67	char(1)	YES		NULL	
item68	char(1)	YES		NULL	
item69	char(1)	YES		NULL	
item70	char(1)	YES		NULL	
item71	char(1)	YES		NULL	
item72	char(1)	YES		NULL	
item75a	char(2)	YES		NULL	
item75b	char(1)	YES		NULL	
item76	char(6)	YES		NULL	
item90	char(4)	YES		NULL	
item91	char(2)	YES		NULL	
item92a	char(3)	YES		NULL	

Field	Type	Null	Key	Default	Extra
item92b	char(3)	YES		NULL	
item92c	char(3)	YES		NULL	
item93a	char(4)	YES		NULL	
item93b	char(4)	YES		NULL	
item93c	char(4)	YES		NULL	
item94	char(6)	YES		NULL	
item95	char(6)	YES		NULL	
item96	char(6)	YES		NULL	
item97	char(4)	YES		NULL	
item98a	char(3)	YES		NULL	
item98b	char(2)	YES		NULL	
item99	char(15)	YES		NULL	
item100	char(1)	YES		NULL	
item101	char(1)	YES		NULL	
item102	char(1)	YES		NULL	
item103	char(1)	YES		NULL	
item104	char(1)	YES		NULL	
item105	char(1)	YES		NULL	
item106	char(4)	YES		NULL	
item107	char(1)	YES		NULL	
tem108a	char(1)	YES		NULL	
item108b	char(1)	YES		NULL	
item108c	char(1)	YES		NULL	
item109	char(2)	YES		NULL	
item110	char(1)	YES		NULL	
item111	char(1)	YES		NULL	
item112	char(1)	YES		NULL	
item113	char(1)	YES		NULL	
item114	char(6)	YES		NULL	
item115	char(4)	YES		NULL	
item116	char(4)	YES		NULL	
funded	char(1)	YES		NULL	
federal	char(1)	YES		NULL	
wo	char(17)	YES		NULL	
dt	char(2)	YES		NULL	
wo_2	char(16)	YES		NULL	
stat	char(1)	YES		NULL	
sr1	char(1)	YES		NULL	
sr2	char(4)	YES		NULL	
status	char(2)	YES		NULL	

Field	Type	Null	Key	Default	Extra
date	char(4)	YES		NULL	
longdd	double	YES		NULL	
latdd	double	YES		NULL	
stpostal	char(2)	YES		NULL	
version	char(2)	YES		NULL	
done	tinyint(4)	YES		0	

Table 1b. Data structure for table uncctest.

Field	Type	Null	Key	Default	Extra
id	char(18)	YES	PRI	NULL	
jpgnum	tinyint(4)	YES		NULL	
zipnum	tinyint(4)	YES		NULL	
docnum	tinyint(4)	YES		NULL	
xlsnum	tinyint(4)	YES		NULL	
pdfnum	tinyint(4)	YES		NULL	
flsnum	tinyint(4)	YES		NULL	
testyear	year(4)	YES		NULL	
city	varchar(20)	YES		NULL	
fwsnum	tinyint(4)	YES		NULL	

Table 1c. Data structure for table nbiinput.

Field	Type	Null	Key	Default	Extra
id	char(18)	YES	PRI	NULL	
stfips	char(2)	YES		NULL	
region	char(1)	YES		NULL	
item8	char(15)	YES		NULL	
item58	char(1)	YES		NULL	
item59	char(1)	YES		NULL	
item60	char(1)	YES		NULL	
item90	char(4)	YES		NULL	
latdd	double	YES		NULL	
longdd	double	YES		NULL	
done	int(11)	YES		NULL	

Table 1d. Data structure for table login.

Field	Type	Null	Key	Default	Extra
username	varchar(10)	NO	PRI		
password	varchar(10)	YES		NULL	

4.3.4.2 Map server, Web server and application server

A map server offers web map service (WMS). A WMS is a standard protocol for serving geo-referenced map images over the Internet that are generated by a map server using data from a GIS database (OGC,2012). The specification was developed and first published by the Open Geospatial Consortium in 1999 (Scharl and Klaus 2007). Map server is a development environment for building spatial information over Internet. Some open source software including GeoServer, MapServer, and Geozilla.

Google Maps is a web mapping service application and technology which is provided by Google, that powers many map-based services, including the Google Maps website and maps embedded on third-party websites via the Google Maps API (GoogleMap,2012) This system mainly uses Google Map API that supports the web map service for geospatial mapping information. By using JavaScript programming and Google Map API, the geospatial mapping can be implemented.

Web server and application server provide very important functions in a network. A web server can provides a primary function to deliver web pages on the request to clients. A server can deliver HTML documents and other additional contents such as images, style sheets (CSS), and scripts. Web servers provide two types of data: static data and dynamic data. The static data normally is stored at a server, while the dynamic data are constructed by programs that execute at the time a request is made. A high-performance web server can typically deliver several hundred static files per second (Iyengar and Challenger, 1997).

4.3.4.3 File system

File system maintains all the files used for this system, such as the webpages (.html, .php, and .css file), geospatial document such as .kml file and some other uploaded data for bridges such as the image file, report document (Microsoft Word, Excel document, pdf file), LiDAR scanned image data (.fls and .fws file), and other document such as compressed file (zip). These files reside in specific folders in the server. Since the MySQL database has weakness of storing multimedia data such as image, documents and audio files, file system is used to store the bridgeb multimedia data.

4.3.4.4 Bridge maintenance decision-making support system (BMDSS)

This module provides functionalities of bridge maintenance decision-making support and assists bridge managers to identify and rank bridges that need to be repaired, re-built, and/or expanded to meet growing traffic demand. With this support, bridge managers can be assisted to make decision for bridge maintenance, such as which bridge need to be maintained, what kind of maintenance needed, and when the bridge should be maintained. The decision-making support module can enhance the capability of the bridge management system by providing an instant solution for maintenance.

4.3.5 System configuration

This application is developed by HTML, PHP, JavaScript and MySQL Database. Server system: Linux coe-web3 2.6.18. PHP Version 5.3.6 (Appendix A). The base system architecture is built with scripting languages for both server side and client side. Google MapAPI supports the map service on the client side. On the server side, MySQL database is used to manage the database, an Apache server with HTML, PHP and JavaScript used for system communication, developing additional system functionality through internal scripting, and establishing dynamic links with external software and data sources. This arrangement allows a participant with access to an Internet connection and a graphic Web browser to interactively and remotely explore Web-GIS system.

4.3.5.1 Server Hardware:

The server hardware is a Dell PowerEdge R210 with 16GB of RAM and 2 x 1TB hard drives. The physical server is running VMware ESXi 4.0. The server hosts two virtual machines named irsv.uncc.edu (production) and irsv-test.uncc.edu (testing). Both virtual machines are configured with 7GB of RAM and 900GB of local storage, which is split into a system drive and a data drive. Each guest runs on a separate physical hard drive.

4.3.5.2 Server configuration:

The virtual machines are operating through the RedHat Enterprise Linux 5.6 which runs the following software:

Tomcat application server. Tomcat Apache web server v2.2.3;
BlazeDS application server with the turnkey configuration was upgraded in place;
MySQL database server v5.0.77;

A nightly backup is operated to back up important files and databases to a folder on an OpenAFS server. The OpenAFS folder is backed up to tape each night. Nightly tape backups are kept for six weeks and semi-yearly backups are kept for 2 years. Some of the tapes are kept in a fire-resistant safe.

The Linux operating system files and configuration is managed by scripting and an automated installation. The manual steps to configure VMware and bootstrap Linux are documented by the IT group. Because of these procedures, there is no need to back up the OS.

4.3.6 Summary

The Web-GIS based bridge visualization framework consists of several functionalities, including 1) the client side applications on which platform user can input data, visualize the information for the general application of national highway bridge network; 2) the client side administration for the system including the data modification and database management; 3) the server side applications of system administration; 4) the volunteer sensor data collection and data entry; 5) the remote sensing bridge monitoring data application; and 6) the bridge maintenance decision making support module embedded in the system.

The configuration of the system is structured by servers (map server, file server, MySQL database and application server) and clients which provides the applications to the user. Three database are implemented in this design, including the database for NBI data, the database for remote sensing bridge data (LiDAR scan and aerial image), and the database for citizen sensing (image, text, audio and video). Users can use the system with an appropriate privilege to input data or/and view bridge health information. The system administrators can input, modify and delete all the bridge data generated by citizen sensors.

The most current bridge health monitoring system only uses the NBI data which is obtained by the inspection with a 2-year inspection circle. The citizen sensor increase the amount of bridge condition data and the citizen sensor can provide instant data which may improve the capability of bridge management dramatically especially for sudden damage on the structure. The integration of NBI bridge data, remote sensing data and the citizen sensor data can be analyzed to make new solutions for bridge management and maintenance by comparing to the most current bridge management systems which only use the NBI data. Furthermore, the Internet helps bridge managers access the application anywhere and anytime.

4.4 WEB-GIS NBI BRIDGE INFORMATION ANALYTICAL VISUALIZATION

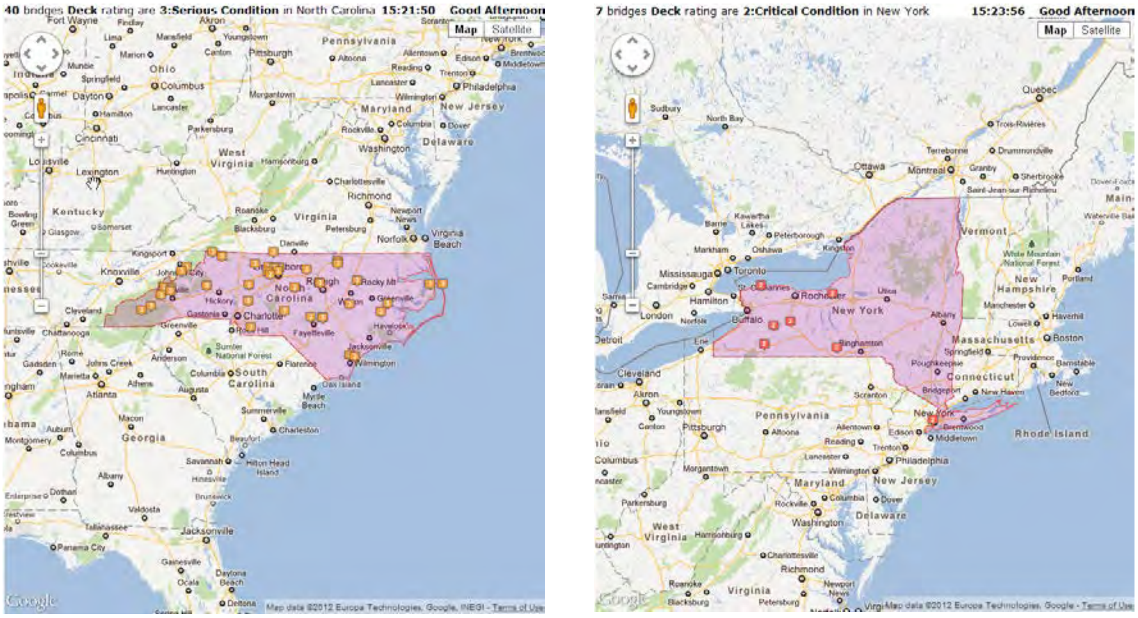
4.4.1 Introduction

In this section, the applications of information visualization and analytical visualization technologies for NBI bridge database are discussed. The information visualization is designed for visualizing the general information of NBI database, such as the general information of an individual bridge and the bridge condition in a selected State. Wang et al. (2010) described in detail several visualization techniques integrable for bridge data viewing. This research further enhances the functionality via Web-based GIS platform.

4.4.2 Information Visualization for NBI bridge information

Main interface of this module is shown in Figure 6. The main functionality is display the bridge condition rating for deck, superstructure and substructure for all the states, the database include the NBI data from year 2008 to 2011. Users can choose deck, superstructure or substructure for bridge part, state and year to display the bridge under the same condition rating, such as all the bridges those deck rating are 3 in North Carolina and in the NBI 2010 report (Figure 7a). The selected bridges are shown as icon with geospatial coordinates on the map with a scaled color (Figure 6). The distribution of the bridges with same condition rating can provide brief information of bridge conditions in the selected State. For example in Figure 7b, all bridges with deck condition rating is 2 or in critical condition in New York State are shown in the map. There are 7 bridges which deck condition rating is in critical condition; 6 bridges are located in the west, and one bridge is located in southern part. If any bridge is selected in the map, the detail information window will be opened (Figure 9a). Bridge can be searched by bridge ID and geospatial coordinates (latitude and longitude) with bridge selection tools (Figure 8).

Figure 6. This color scale stands for the bridge condition rating from 0 through 9.



a). Deck condition rating is 3 (Serious condition) in North Carolina state in 2010.

b). Deck condition rating is 2 (Critical condition) in New York state in 2009

Figure 7. The bridge information display in North Carolina and New York State

Bridge selection tool (Figure 8) is designed for searching a bridge by using geospatial coordinates since the geospatial coordinates of the bridge (latitude and longitude) is the key parameter for GIS application. Before displaying the information of an individual bridge, the bridge must be located. To search a specific bridge, this system offers four solutions, 1) choose from the map, click a bridge icon to open a new page for the information; 2) locate a bridge by bridge ID, in this case, only the identical bridge will be selected; 3) locate a bridge by using latitude and longitude in decimal degree format; 4) locate bridge by using latitude and longitude in degree, minute and second format. Considering a possible difference between the geospatial coordinates which user types for locating the bridge and the geospatial coordinates which stored in the database, in such case, a variable of distance is used for locating a bridge.

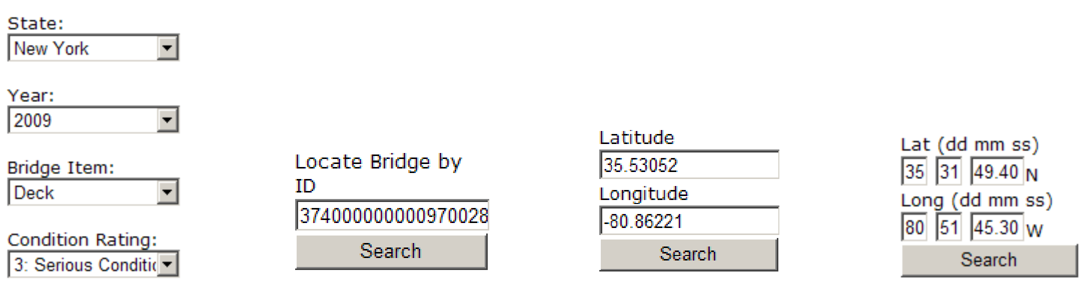
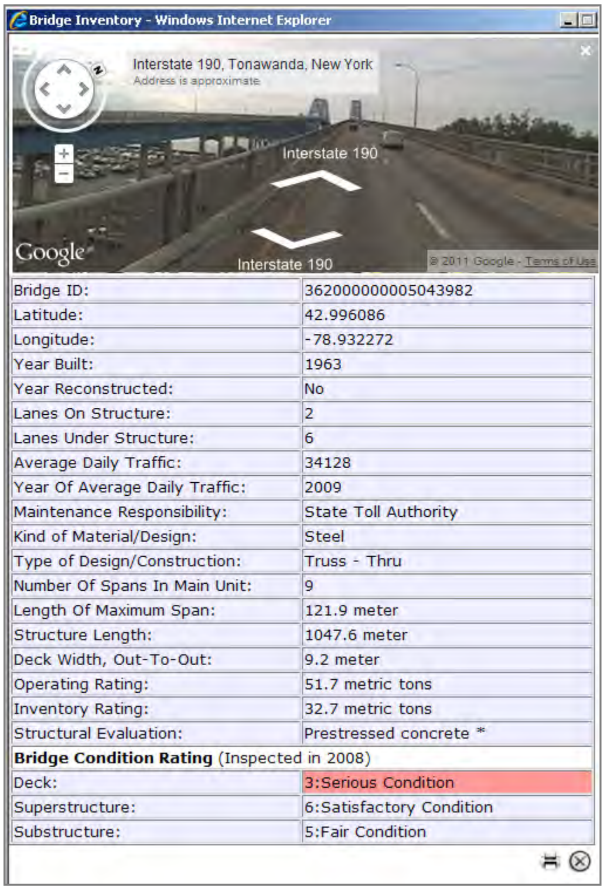


Figure 8. Bridge selection tools

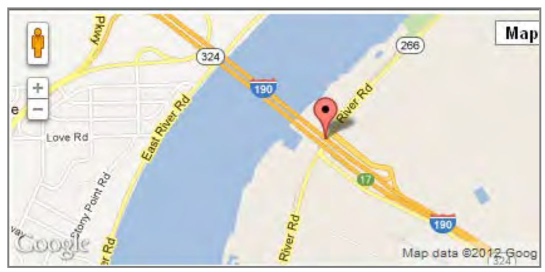
The other application is about the basic information visualization of an individual bridge. The information includes the map of the bridge, general information of the bridge and the bridge condition rating information. Based on the Google Map API, the map can be zoomed in or out, and different map views can be shown (map view, satellite image and street view). The basic information of the bridge includes bridge ID, latitude, longitude, year built, year reconstruction, lanes on structure, average daily traffic (ADT), etc. In the bridge condition rating part, the condition rating of deck, superstructure and substructure are shown. If the condition is less than 4 or in bad conditions, the background of the cell will change to red (Figure 9a). In the lower-right corner, there is a printer icon for printing this page.



Bridge ID:	362000000005043982
Latitude:	42.996086
Longitude:	-78.932272
Year Built:	1963
Year Reconstructed:	No
Lanes On Structure:	2
Lanes Under Structure:	6
Average Daily Traffic:	34128
Year Of Average Daily Traffic:	2009
Maintenance Responsibility:	State Toll Authority
Kind of Material/Design:	Steel
Type of Design/Construction:	Truss - Thru
Number Of Spans In Main Unit:	9
Length Of Maximum Span:	121.9 meter
Structure Length:	1047.6 meter
Deck Width, Out-To-Out:	9.2 meter
Operating Rating:	51.7 metric tons
Inventory Rating:	32.7 metric tons
Structural Evaluation:	Prestressed concrete *
Bridge Condition Rating (Inspected in 2008)	
Deck:	3:Serious Condition
Superstructure:	6:Satisfactory Condition
Substructure:	5:Fair Condition

The information of the bridges

b) Satellite image of the bridge



c) Map view of the bridge

Figure 9. The Information of the bridge

Bridge information visualization module provides general bridge information to the users. The bridge information can be viewed from different perspectives, such as allowing user interactivity including select the state, year, bridge item for bridge condition display (Figure 10). The application allows both state-level and individual bridge information visualization, hence, all bridges within the NBI can be displayed either nationwide or statewide.

A big picture of the bridge condition nationwide can provide general information for the bridge managers to generate some view of bridge conditions among the states, such as the statistic distribution among the states and the geospatial distribution. This system allows user to view the bridges of an individual state or the whole nation. The different combination of bridge condition rating can be chosen from deck, superstructure and substructure, such as the visualization of all the bridges which the deck rating is 3 (or in critical condition) of North Carolina in year 2010 (Figure 7a) and the visualization of all the bridges which superstructure condition rating is 2 (or in critical condition) within New York state in 2009 (Figure 7b). Based on the advantage of Internet and GIS, the bridge information not only is presented in plain format (tables, sentences, and numbers) but also is presented with geospatial features-the bridge can be viewed on a map.

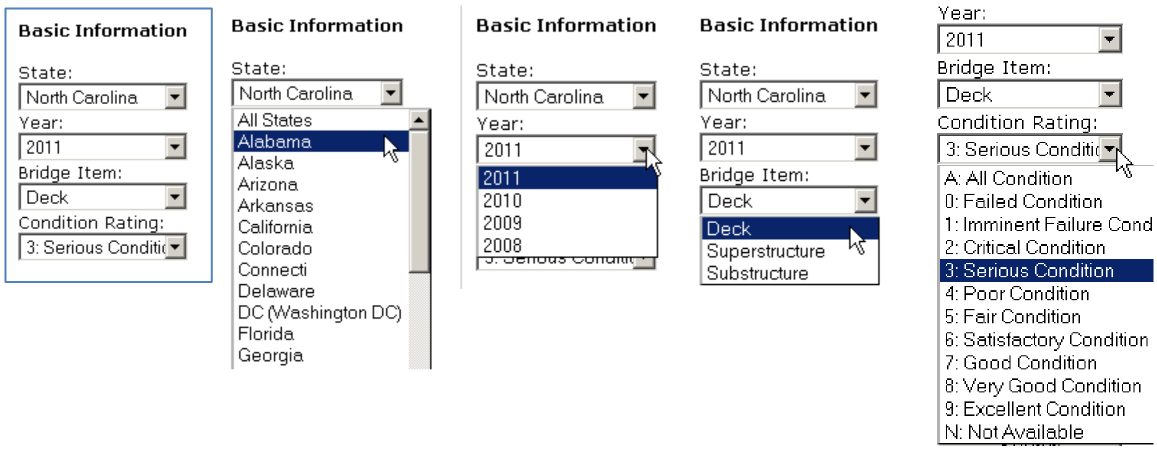


Figure 10. The option for bridge selection

The detail information of an individual bridge will provide the general information of the bridge condition (Figure 9a). The main information includes the location (latitude and longitude) on the map, the built year, the inspection year, and the bridge condition rating for deck, superstructure and substructure, and some other parameters. Among that information, the bridge condition ratings of deck, superstructure and substructure are critical for bridge management. If the condition rating is a lower value which usually means the structure may need be maintained, the background will be colored in red (Figure 9a). The map can be shown in three views including street view (Figure 9a), satellite image view (Figure 9b) and map view (Figure 9c). With the built-in capability of Google Map, the map also has other features such as zoom-in/out functions.

The bridge data is organized by data format, which may include image files for captured bridge photos, text files from inspector notes or public reports and numeric files that include bridge ratings, other numeric data and analytic results including ratings. Bridge selection can also by inputting bridge coordinates or bridge number. This design also provides a print functionality for the bridge information; the print icon help the user get a hard copy of the bridge information

4.4.3 Analytical visualization of Bridge Information

Analytical visualization can discover more aspects of the bridge condition which may not easily be figured out from the plain format such as table and document. Visualization technologies provide some techniques to assist user Visual analytics can be developed into power tools for the bridge manager's decision making process: Based on the domain knowledge characterization (bridge management), Wang et al. (2010) identified three critical analytic modes that can be useful in a bridge management application: dynamic geospatial analysis, high dimensional structural analysis and scalable temporal analysis. Following Wang et al. (2010), the adopted analytical visualization components within bridge visualization includes geospatial display, scatter plot and parallel coordinate visualization of bridge data. Comparative views of bridge condition ratings of bridges from different states are also available, which provides a high-level appreciation of state bridge performances.

Figure 9 shows the nationwide bridge distribution of all the bridges with failed deck condition in NBI data 2010. The map shows there are high density in Kansas, Oklahoma and Louisiana. Possible further study should be proposed to figure out the reason and solve the problem.

4.4.3.1 Bridge condition rating based on state distribution visualization

Visualization technology can generate some unexpected images from which the bridge managers can figure out new observations. One example is that the national bridge distribution for deck rating is 0 (failed condition) in Figure 11. From the map, we can see there are 915 bridges which deck is in failed condition in all States. Most of those bridges are located in several States including Kansas (KS), Oklahoma (OK), Louisiana (LA) and Mississippi (MS), while some other States are in better condition such as North Carolina (NC), Colorado (CO), Maine (ME), Nevada (NV) , North Dakota (ND), South Dakota (SD), and Virginia (VA). All those information may bring up potential further studies on what causes those distributions.

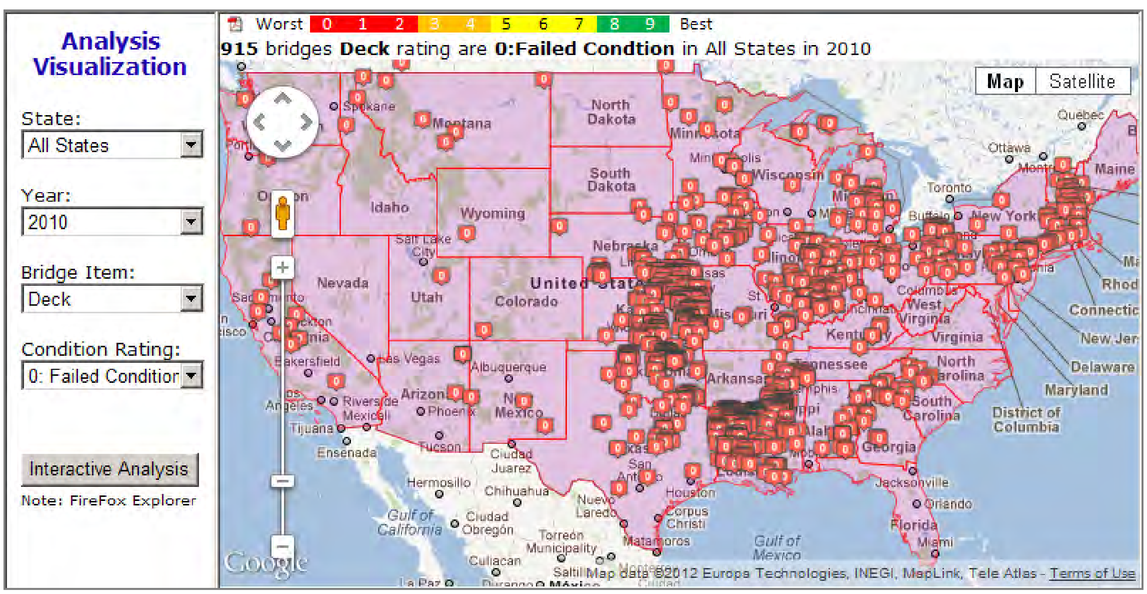


Figure 11. The distribution of bridges with deck condition rating of Zer0 (failed condition) in 2010.

4.4.3.2 Parallel Coordinates interactive visualization

Parallel coordinate visualization is a powerful tool to provide interactive multiple-parameter comparisons. A multiple axis parallel coordinate (MAPC) view provides high level viewpoints that actually reduce the abstract dimensions of bridge parameters allowing bridge managers to detect and identify causal relationships and trends in data variables (Figure 12). Bridge managers can use their domain expertise to select and simultaneously compare several bridge parameters, physically visualize possible correlations between different bridge attributes and establish mental correlations. Figure 12 shows an interactive view of several bridge parameters. Each straight line linkage between the parallel coordinates represents a single bridge.

Figure 12 shows the parallel visualization of selected bridges which deck condition rating is 3 (serious condition) in North Carolina in 2010. In Figure 12, all the bridges are chosen for the parallel visualization (ADT from 10 to 26001). If we change the interest to higher ADT, such as ADT from 22362 to 26001, the result will change as shown in Figure 13. This parallel visualization presents that most bridges with higher traffic volume among the selected bridges were built in between 1950 and 1970, all these bridges are having maximum span length of in between 170 and 200 meter and all those bridge have bridge length of in between 150 meter and 700 meter, while the deck width of those bridges are different. The new-built bridges don't have the higher traffic volume. A possible reason is that all those higher traffic volume bridges built in between 1950 and 1970 are the US highway and/or Interstate highway.

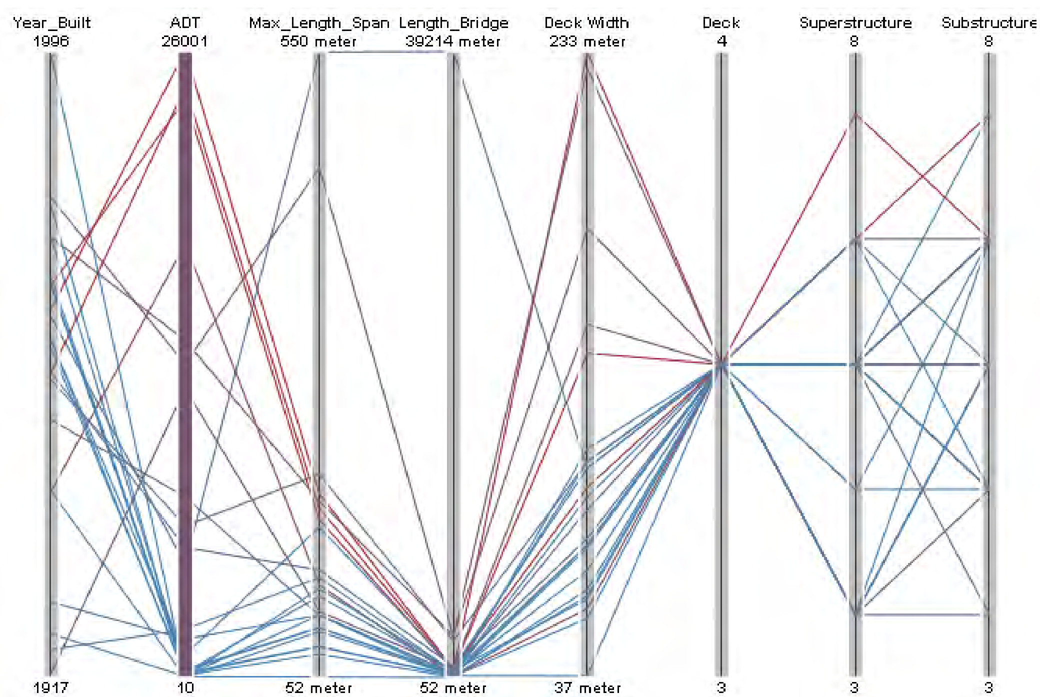


Figure 12. The parallel coordinates visualization for the selected bridges (all ADT value from 10 to 26001)

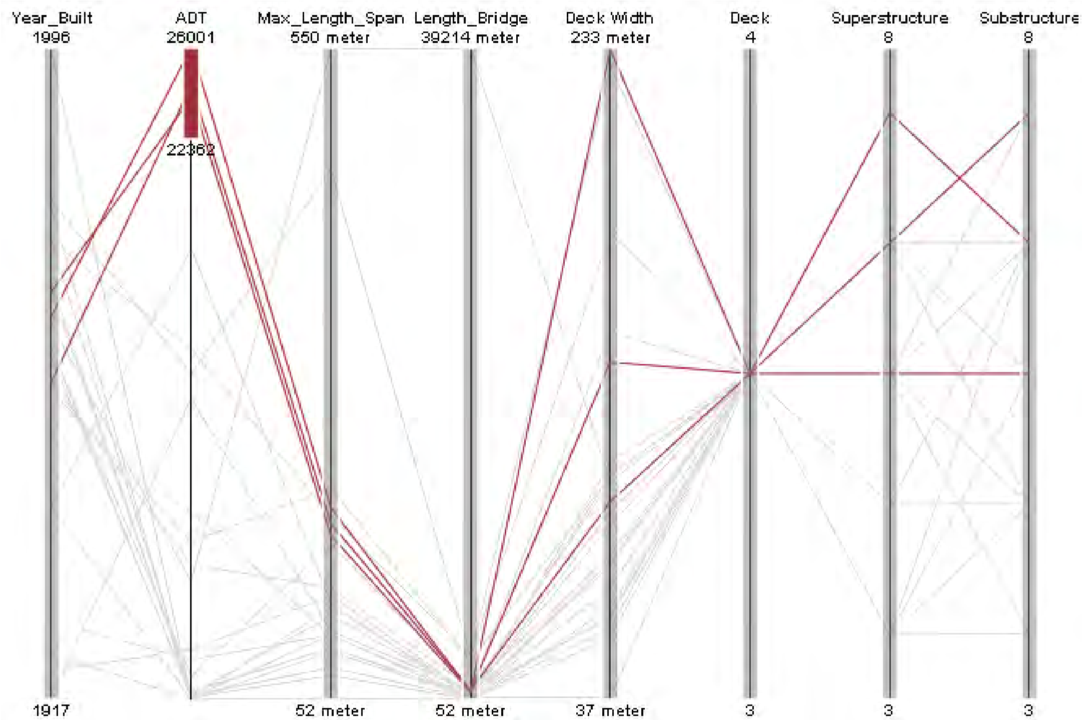
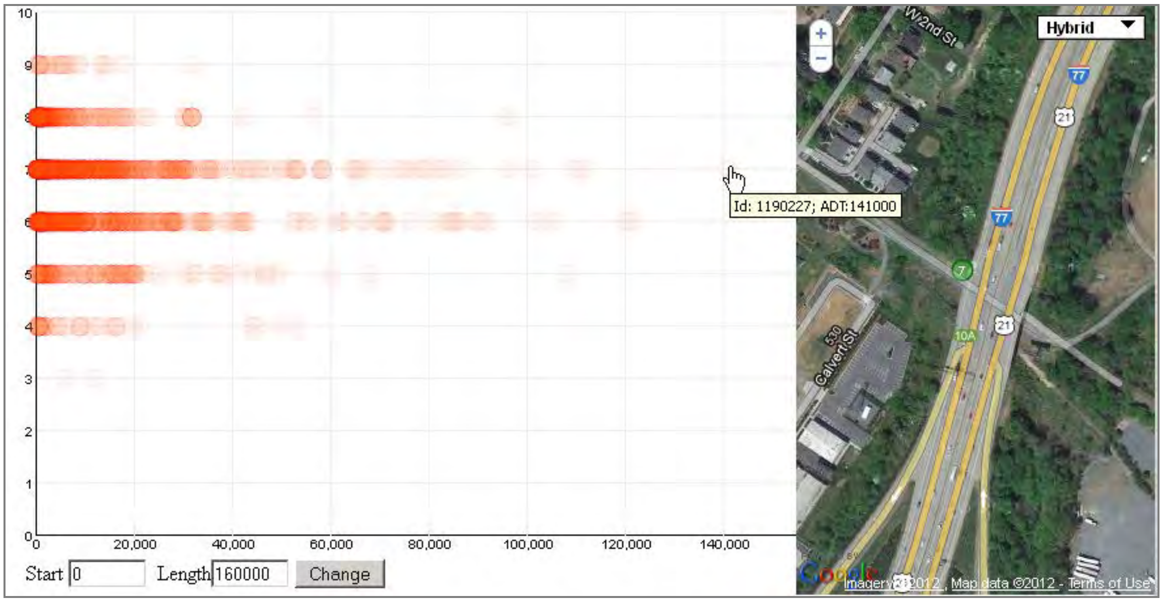


Figure 13. The parallel coordinates visualization for selected bridges, showing ADT from 22362 to 26001

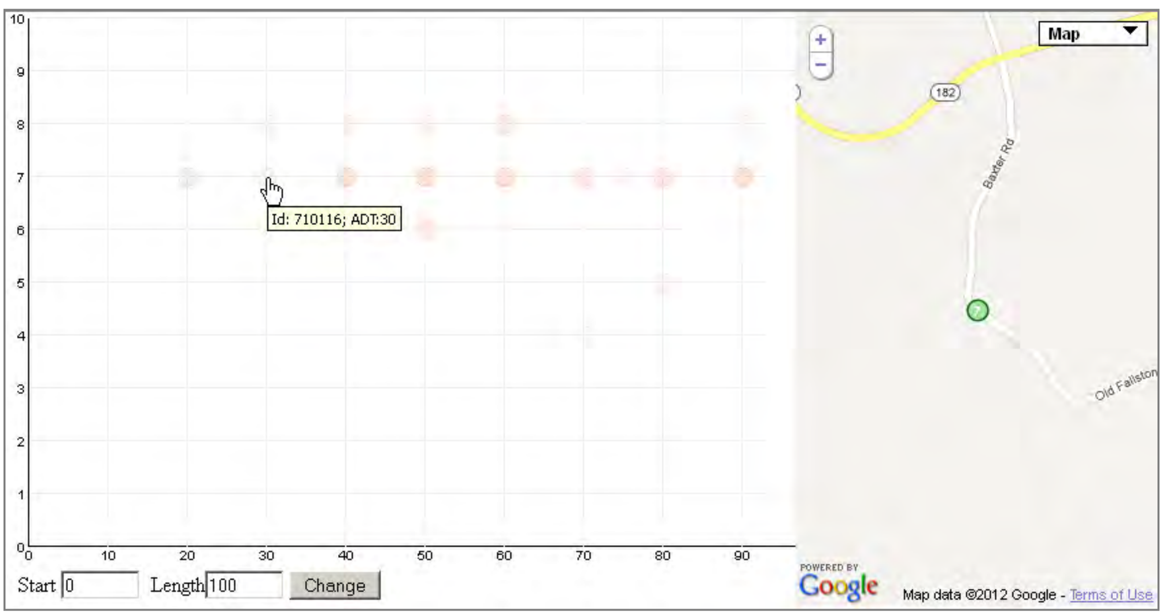
4.4.3.3 Scatter plot interactive visualization

Multiple scatter plot visualization of NBI data can be implemented including data correlations between different bridge parameters within the NBI database. Figure 14a shows the scatter plot correlation between deck rating and average daily traffic (ADT). In this tool, there are mainly two parts, the large area in the left is the plot area and the right side is the map area for display the location of a selected bridge. In the plot area, the red dot presents bridge. The dot with darker color means there are more bridges overlapped since they have the same value of ADT and deck condition rating.

A critical issue with comparative studies of different bridge parameters is that the scale used may be different; hence, scalable axial components must be used. If an interested bridge selected in the scatter plot, the bridge location will shows in the right-side map. The horizontal axis is the value of ADT which scales from 0 through 160,000. The vertical axis is the value of deck condition rating from 0 through 9. By using the multiple scatter plot, some information are very easy to get by reading the plot, such as which bridge has the largest ADT or the largest traffic volume and what value range is the dominated ADT among these bridges. In Figure 14a, the right-most red circle (bridge) has the largest ADT of 141,000 and the ID is 1190227; the dominated ADT is less than 20,000. This interactive visualization also allow user to view a selected fragment of ADT by using the bottom two input boxes. The scatter plot in Figure 14b shows that the horizontal axis scaled from 0 through 100, a new view of the scatter plot.



a). All individual bridges are visualized in this scatter plot. The map shows location of the bridge which has the maximum ADT and indicates that the ADT is 141000 and the bridge ID is 1190227.



b). All bridges with ADT less than 100 are selected and visualized in this scatter plot. The map show the bridge has ADT of 30 and the location of the bridge.

Figure 14. The scatter plot for comparison of deck condition rating of the bridge and the ADT of the bridge

Another application of scatter plot is about the correlations between the deck condition rating and the year built of the bridge (Figure 15). A linear relationship between the deck condition and the year built is descripted in the plot. It's very easy to pick any bridge and visualize the information, such as the oldest bridge among these bridges.

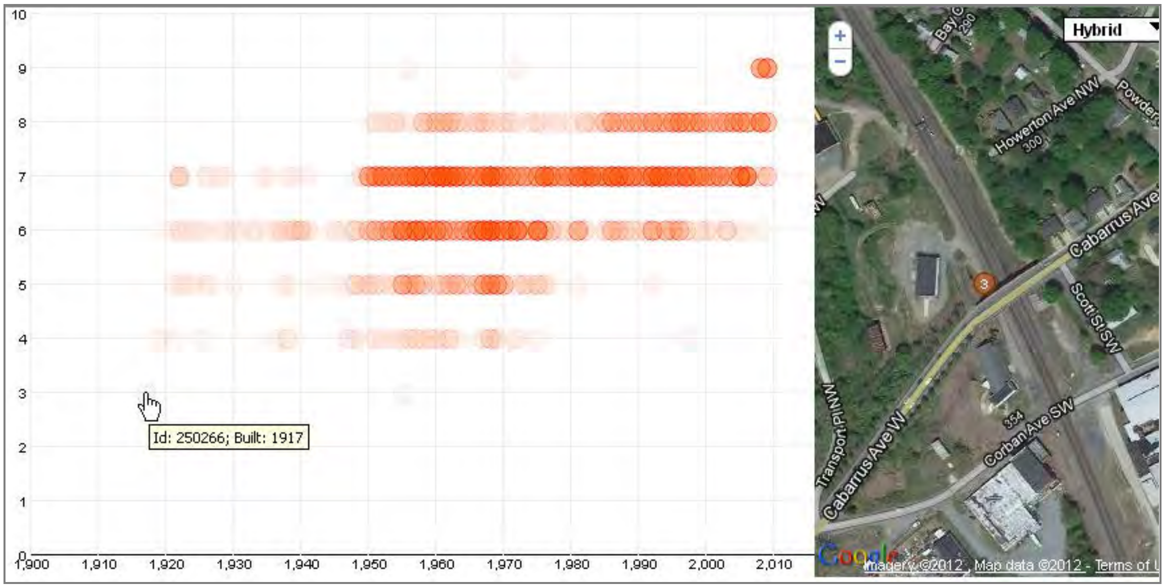
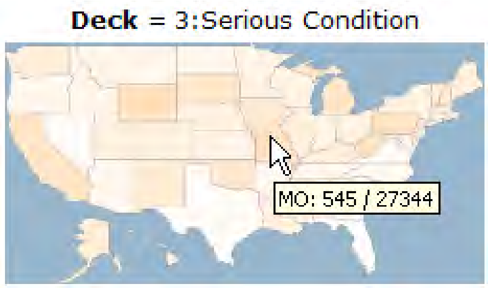


Figure 15. scatter plot for comparison of deck condition rating and the year built of the bridge

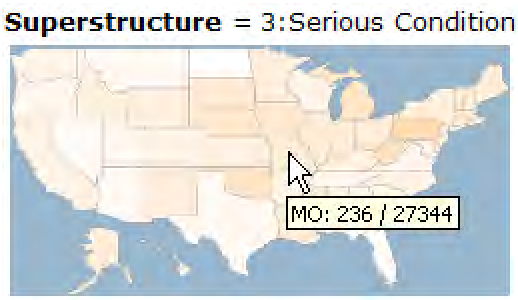
4.4.3.4 Choropleth map visualization

The choropleth map (a type of thematic map) provides an easy way to visualize how a measurement varies across a geographic area and it shows the level of variability within a region. The technique is used for visualizing the bridge condition distribution cross all States. Single hue progression is used for mapping the bridge condition data which is a ratio of the number of the bridges which in a specific condition rating value to the number of the whole bridge in the state; the State with a larger ratio will be filled a darker color in the map. As shown in Figure 16, the choropleth map shows bridge deck with critical condition. If move the mouse over a state in the map, a tip shows more information, such as OK 716/25829 (Figure 16d), which means that the State Oklahoma has 716 bridges with critical deck condition and there are totally 25829 bridges in this State. From this map, if comparing the two States between Oklahoma (darker background) and North Carolina (lighter background), the ratio of Oklahoma is larger than that of North Carolina.

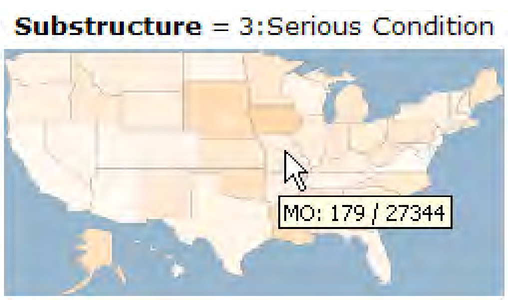
Most researches are focus on one state or one specific area. This study is focus on the national bridge information. The map-based visualization can answer the questions such as what distribution of the bridge condition in the United States and which state has more percentage of failed bridges? Figure 16 shows the bridge condition rating distribution; Figure 16a shows Missouri and Wyoming have darker color which means these two states have more bridges in serious condition with deck. In state Missouri (MO), there are 545 bridges which deck condition rating is 3 (Serious condition) while the state totally has 27344 bridges, so the ratio is around 1.99%. Similarly, in North Carolina there is zero bridge in critical condition with superstructure and the color is white (Figure 16d). .



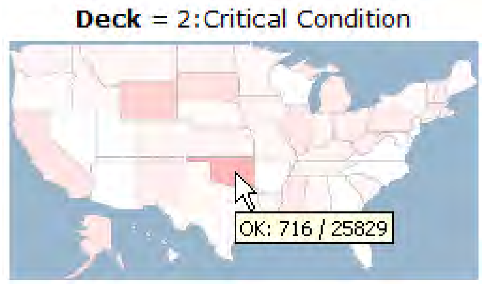
a). the number of bridges which have deck rating condition is 3 (serious condition) , the selected state is Missouri.



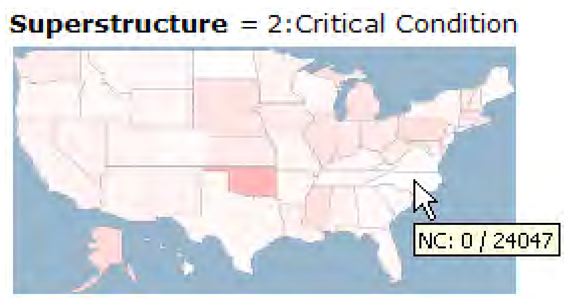
b). the number of bridges which have superstructure rating condition is 3 (serious condition) , the selected state is Missouri.



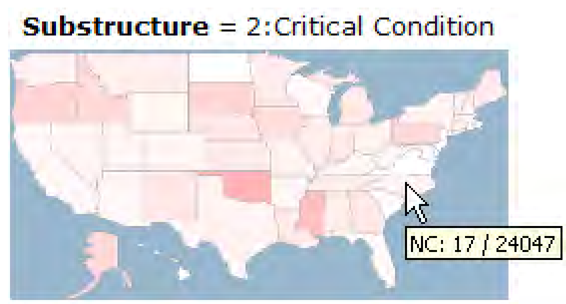
c). the number of bridges which have substructure rating condition is 3 (serious condition), the selected state is Missouri.



d). the number of bridges which have deck rating condition is 2 (critical condition), the selected state is Oklahoma.



d). the number of bridges which have superstructure rating condition is 2 (critical condition), the selected state is North Carolina.



e). the number of bridges which have substructure rating condition is 2 (critical condition), the selected state is North Carolina.

Figure 16. The choropleth map shows the distribution of the bridge rating conditions

Note: 1) The information displayed in map is the number of the bridge over the number of all the bridges in the state, For example, the notation “OK: 716/25829” d) means that there are 716 bridges which deck ration is in critical condition while there are totally 25829 bridges in state Oklahoma (OK). 2). The color indicates the value of the percentage of number of the bridge, darker color shows higher percentage.

4.4.4 Summary

Visualization techniques are used for large scale dataset, such as the NBI bridge database. User can explore the bridge information by use this application. With this visualization system, 1) bridge managers can view the general information of the any interested bridge; 2) bridge managers can generate several knowledge of the bridge damage from various views; 3) interactive analytical visualization make it possible to figure out the correlation between two variables of the bridge dataset; 4) choropleth map assist the bridge managers to get a general idea of the bridge condition distribution all the States. Therefore, the visualization techniques provide unique images and knowledge of the bridge database to bridge managers and enhance the capability of bridge management systems. Visualization may help the user to make an exploit about the damage and to do further analysis.

4.5 DECISION MAKING SUPPORT FOR BRIDGE MAINTENANCE

4.5.1 Introduction

Bridge management and maintenance are very important to highway network. Bridge owners must make decisions to maintenance and improvements. Considering the funding constraints and the overall needs of the highway system, effective and practical methods must be developed to meet the challenging needs. Both states and federal government have been working to develop and implement automated decision-support models to assist bridge managers. (Hearn et al., 2000)

Both the structurally deficient bridges and the functionally obsolete bridges are not safe for current traffic demand because of limited structural capacity and the older design features and geometrics (ASCE, 2009). To provide an efficient and effective maintenance approach for national bridge system, bridge inspection and bridge maintenance decision making play a very important role in bridge management. A strategy maintenance decision making support can help the bridge managers to make effective maintenance plans for structurally deficient bridges and/or the functionally obsolete bridges, which include whether the bridge need to be repaired or be rebuilt, how and when to do the maintenance.

There are many factors that make contributions to the bridge deterioration, such as traffic volume, age of the bridge, climate and environmental conditions, structural type and traffic pattern. For identifying and ranking bridges which need to be maintained, an efficient approach should be designed to improve both operational and structural efficiency of the bridges. Since the bridge and highway network is a Geo-spatial system and the advantage of Internet makes flexible accessibility, a Web-GIS based methodology will be implemented and tested to support the decision making for bridge maintenance.

The objective of this section is design a very simplistic tool which can estimate the maintenance needs of bridges and the level of maintenance for national highway bridges. The applied bridge data is from NBI bridge database. A bridge maintenance ranking model and a bridge lane expansion model will be discussed in this section. Those two simplistic models should be improved in further studies.

4.5.2 Decision making for bridge maintenance

Several parameters should be considered as the factors which make contribution to the bridge deterioration. In this design, five major measures should be considered for identifying and ranking bridge for management and maintenance. These measures include the year built (or year rebuilt), traffic volume, bridge condition rating (include deck, superstructure and substructure), functional classification and sudden damage.

Besides the severe environmental conditions, the high volume of traffic and heavy truck load make the major contribution to bridge deterioration since the traffic flow is the main function for highway system. Furthermore, traffic volume also influence to the traffic flow. So traffic volume is an important factor for identifying the number of lanes on the road to make a fluent traffic. Average annual daily traffic (AADT) is a measure of traffic volume on the roadway.

Bridge condition rating shows the overall condition of the deck, superstructure and substructure. Bridge condition ratings are obtained by a two-year inspection by qualified inspector. Base on the condition rating of deck, superstructure and substructure, the operating rating of the bridge can be calculated. Therefore the bridge condition rating can help to identify the maintenance for the bridges.

Functional classification of highway indicates the importance of traffic continuity. Therefore, the bridge on a more important class level should have priority to get maintenance than the bridge on less important class level.

Sudden damage should also be considered for bridge maintenance. Sudden damage may not be found by regular inspection (every two years). But the consequence is critical or deadly for the bridge safety.

4.5.3 Bridge maintenance ranking model and implementation

For identifying whether a bridge need rebuilt, urgent repair, regular maintenance, and/or expand lanes to meet the increasing traffic volume, several factors should be considered, such as AADT, condition rating (deck, superstructure and substructure), sudden damage, year built (or rebuilt). Due to a limited budget, the functional classification should be applied for identifying the priority of the maintenance. The following suggests a very simplistic model for condition ranking.

Let R_{AADT} stand for AADT of the road, R_{class} stand for road class, B_{deck} stand for bridge deck condition rating; B_{sup} stand for bridge superstructure condition rating; B_{sub} stand for bridge substructure condition rating; B_{sudden} stand for sudden damage. B_{built} stand for the year built. $B_{rebuilt}$ stand for the year rebuilt. B_{lane} stand for number of lane of the bridge. Y_{now} stand for current year.

For road class R_{class} the smaller value, more important for traffic. (Appendix A)
For bridge condition rating B_{deck} , B_{sup} and B_{sub}, the smaller value, the worse condition, (Appendix A)
For sudden damage B_{sudden} the smaller value, the worse condition, (Appendix A)

Two models can be developed to identify periodic maintenance and repair, rebuild or/and lane expansion, B_{rank} stands for the final ranking of the bridge, the result shows what kind of maintenance should be done; $B_{lanereq}$ stands for the lane expansion solution. The models for B_{rank} and $B_{lanereq}$ are stated as follow:

$B_{rank} = f(B_{deck}, B_{sup}, B_{sub}, B_{class}, B_{sudden}, B_{built}, R_{AADT})$; and

Here is a simple approach to implement the two models,

// ranking bridge maintenance (repair , rebuilt or regular maintenance)
For each bridge {

B_{rank} = Min { B_{deck} * B_{sup} * B_{sub}* (B_{class} mod 10)+0.5, B_{sudden}* (B_{class} mod 10)}
* (10 + (B_{class} mod 10) - B_{class})/5 // rural /urban
* (5- (Y_{now}-B_{built})/50) * K; // age of bridge

If (B_{rank}= 0)
Message "Rebuilt the bridge"
If (B_{rank}<=N1)
Message "Emergency situation maintenance and repair required with 30 days "
If (N1<B_{rank} <=N2)
Message "Urgent situation maintenance and repair required with 180 days"
If (N2< B_{rank} <=N3)
Message "maintenance and repair required with one year"
If (B_{rank} >N3)
Message "following the regular maintenance schedule"
}

4.5.4 Bridge lane expansion model and implementation

For identifying whether a bridge need to expand lanes to meet the increasing traffic volume, the dominate factor is AADT. Let R_{AADT} stand for AADT of the road, and B_{lane} stand for number of lane of the bridge. $B_{lanereq}$ stands for the lane expansion solution. A very simplistic model for lane expansion $B_{lanereq}$ is stated as follow:

$B_{lanereq}$ = f (R_{AADT} , B_{lane} , DDHV, MSF, PHF, f_{HV} , f_P).

Here is a simple approach to implement the two models,

// ranking lane expansion
For each bridge {
temp = (R_{AADT} /24) /(MSF * PHF * f_{HV} * f_P) – B_{lane}
if (temp>0){
Blanereq = Int (temp +1);
Message "need expand lane";
}
}

where, K, N1, N2, N3, N3 are constants.
PHF: peak-hour factor, 0.95
f_{HV} : heavy-vehicle adjustment factor , 0.68
f_P : driver population factor , 1.0
MSF: maximum service flow rate, 2200

4.5.3.1 Data

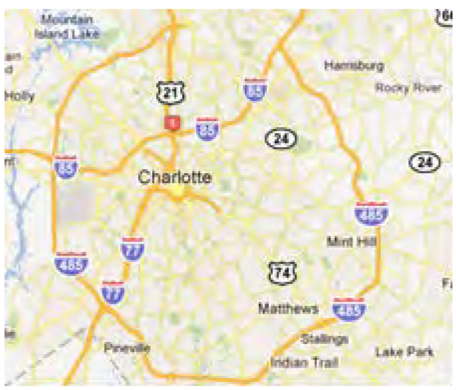
There are two different techniques to measure the AADT for a road segments. One method is continuous count data collection, the other is short-term data collection.

Normally the short-term data collection method is applied to collect AADT data by using portable sensor. Bridge condition rating data can be obtained from national bridge inventory (NBI) database; the bridges are inspected by inspectors every two years by using counting equipment. The road classifications for each bridge are also obtained from NBI database. The number of lane of the bridge is also required.

Remote sensing data (Section 4.7) and citizen sensor data (Section 4.6) are additional bridge for this application. The remote sensing data include the LiDAR scan and aerial fly-over image. Citizen sensor data is captured and uploaded by citizen or volunteers such as a vehicle driver, a vehicle rider or someone who is capable to found damages on a bridge. When the citizen sensor finds a sudden damage on a bridge, the damage data can be collected. he/she can report it via smart phone or computer. In the implementation, user can upload data through Internet or by make phone call. “Citizen Sensor” can increase the sensing capability efficiently and quickly for bridge inspection.

4.5.3.2 A Web-based GIS application

For demonstration purpose, these algorithms are applied in a Web-based GIS for city of Charlotte; the data used is from national bridge inventory (NBI) database. All the bridges need maintenance and repair, rebuilt and/ expand lane are display with priority both in colors and number.



(a)

Bridge ID:	374000000001191036
Latitude:	35.273028
Longitude:	-80.844722
Functional Class of Inventory Route:	11
Year Built:	2005
Year Reconstructed:	No
Lanes On Structure:	1
Average Daily Traffic:	56500
Operating Rating:	99.9 metric tons
Inventory Rating:	53.1 metric tons
Bridge Condition Rating (Inspected in 2009)	
Deck:	8:Very Good Condition
Superstructure:	8:Very Good Condition
Substructure:	7:Good Condition
Public Report	
Damage:	9:No report by public
Bridge lane expansion	
Number of lane need expanded:	1:One more lanes needed

(b)

Figure 17 Implementation (map and the detail information)

(a) Map shows the bridge which need expand lane, (b) The information of the bridge

Figure 17 show the demonstration result for lane expansion application. As shown in the Figure 17a, one bridge is displayed and that means the bridge need lane expansion. Figure17b shows the detail information of the bridge. This simplistic demonstration shows that the lane expansion model and Web-GIS help to identify the bridge which needs maintenance. The result shows that there is one bridge needs maintenance of lane expansion (Figure 17b).

4.5.5 Summary

In this design, several measures are considered, actually there are some other factors also make contribution to the bridge deterioration. Such as population growth trend, traffic volume grows trend, area functionality (school, business center), income, etc. Another thought is that a regression model can be developed for future estimation, such as applying historical data to predict the future data. In a specific area, there may be similar factors, such as same geographical features, same climate and same vehicle patterns, which influence the bridge condition and performance. So one study should be considered, such as how to figure out the special area which has the same environmental and social factors which influence to bridges and highway system; a shortest path algorithm can be applied to this application. By analyzing the bridges system from environmental perspective, a special area can be figure out from bridge ranking, so that engineers can get another solution to improve the environmental and infrastructural systems.

4.6 CITIZEN SENSING APPLICATION IN BRIDGE MONITORING

4.6.1 Introduction

In this section, the citizen sensor is suggested as a tool for constructed facility monitoring, which is useful for the management of systems where several discrete structures that may be miles away from each other, covering large spatial area and render networked sensing systems challenging. Examples of such systems include bridge structures on the national highway, railway and waterway systems and power transmission and distribution structures. Bridges, in particular, can benefit directly from citizen sensors, since cars and pedestrians pass over them frequently.

Contrast to Twitris (Nagarajan et al. 2009), the citizen sensor for bridge monitoring (BRIDGE-WGI) requires a domain-specific, targeted data collection system to mobilize and interact with citizen sensors. Benefit from the bursting populace of web-based GIS such as Google-Earth® or Microsoft VirtualEarth®, BRIDGE-WGI consists of multiple tools (enablers) that engages citizen sensors and automatically organizes critical data for bridge management: Similar to the 911 emergency phone call system, citizens can report imminent danger to a bridge by using smart phone technologies and wireless Internet reporting. BRIDGE-WGI can significantly enhance bridge inspection, which currently relies on a bi-annual visual inspection cycles involving bridge inspectors driving to inspect the physical structure. Due to their wide spatial locations, networked bridge monitoring is difficult to implement. For network-wide application, several different monitoring schemes may be needed to simultaneously capture different schema data to help enhance bridge health state diagnosis, which ultimately will improve overall bridge management (Wang et al. 2010).

This section discusses the Web-GIS based bridge monitoring system that integrates several sensor enabling applications that have been developed that can be distributed to citizens using social network. Bridge Locator, a smart phone based tool and implementation for bridge image capture and reporting, is discussed. System security and other social-related issues that need to be addressed to avoid abuse of the system are discussed in detail in the section.

4.6.2 Citizen sensor-Smart Phone application

In the context of operations, citizen sensor can be active or passive systems: Active systems are people who willingly help monitoring, on the other hand, passive system is embedded sensors that can continuously monitor. In the context of structure, citizen sensor can be organized or non-organized - depending on the system design. Non-organized systems would require robust data mining and advanced analytics to identify critical data. Organized systems can use preset criteria to screen collected data.

Citizen sensor can be considered as one type of NTI sensor and represents a critical emerging paradigm to social interactivity and operations due to the empowerment of individuals to capture and share information, typically via the use of digital gadgets, such as built-in camera or video in smart phones, and the availability of online uploads to

Internet (Nagarajan et al. 2009). The shared data can be personal or socially-relevant. Social-relevant data sharing is typified by the availability of sensing tools and the geospatial-temporal positioning of individuals who possesses the awareness of events/conditions with social concerns. The citizen sensor (individual with social awareness and the capability to capture and share data) usually has the willingness and the desire to share the data. The desire may be motivated by several causes that may be calibrated by education and training.

The objective of a citizen sensor system for bridge monitoring is specifically the motivation of voluntary information sharing amongst citizens to enhance bridge condition monitoring and potential disaster responses. The BRIDGE-WGI system consists of several enabling technology components for citizen use including an online Web-GIS data visualization portal, Bridge-WGI, a smart phone application for distribution, Bridge Locator, and a centralized data management system. The functional components that would constitute a BRIDGE-WGI system: 1) Data Collection – multiple types of sensor data can be collected; 2) Data Upload – portal for data collection which include physical wired or wireless Internet access points; 3) Centralized Database – where data can be organized for future analysis; 4) Data Visualization – interactive Web-GIS geo-spatial visualization of bridge physical location and affiliated bridge data in organized fashion (Figure 2).

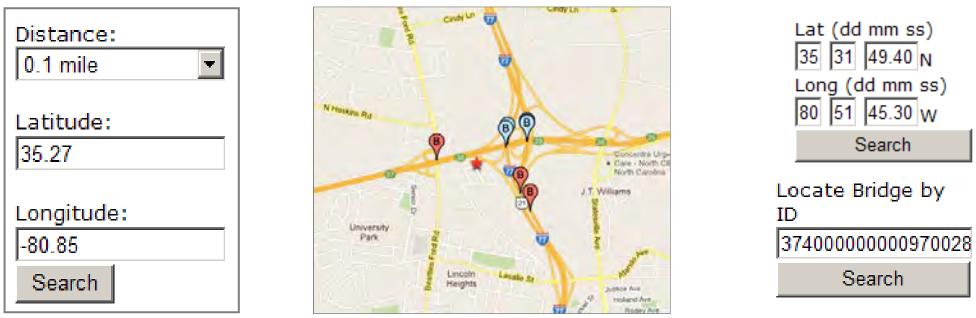
4.6.3 Design and implementation

The Internet GIS-based bridge visualization platform is called Bridge-WGI, which integrates the embedded database and Web-GIS for data visualization and reporting. The conception of Bridge-WGI embraces a larger content then just citizen sensing component - Since the specific goal is to assist national bridge monitoring and management, existing bridge management operatives are also integrated into Bridge-WGI, making it a robust and inclusive data collection system. The Bridge-WGI resides within the computer server with a website frontend access (www.ncrst.uncc.edu). Bridge-WGI enables the design/update/maintain of NBI bridge data which displays selected basic information from NBI database including bridge condition rating for deck, superstructure and substructures. Bridge-WGI also includes advanced analytical visualization for the NBI data including parallel-coordinate views. Bridge-WGI allows both system-level and individual bridge information visualization, hence, all bridges within the NBI can be displayed either nationwide or statewide. Base map from existing interactive Web GIS server systems such as Google Map, Bing Map or Microsoft Virtual Earth can be adopted within Bridge-WGI. All user interactions from the Web GIS servers such as zoom in/out, street view and satellite or map views, can be used.

4.6.3.1 Bridge select tool- computer Citizen sensor data Collection

Data entry is the important part for volunteers sensing application. When a volunteer find a event and want to upload the information to the bridge database, the most important information includes the location of the bridge (latitude and longitude) the name of the bridge, the date and time of the reporting, the detail description and some other information. For some mobile device which has geographic position system (GPS) tracker features, the geospatial location of the bridge can be figured by the mobile device. In this design, a bridge locator interface is designed for user locating the bridge for data uploading.

To locate a bridge, the system has three options. First method is using the latitude and longitude in decimal format (Figure 19-a), the map will display all the bridges in the area within a distance from the center (latitude and longitude) (Figure 19-b). The second option for locating a bridge is using the latitude and longitude in degree, minute and second format (Figure 19-c). The third method is to locate a bridge by using the bridge ID. Once the bridge located, the bridges are displayed in the map. The information of NBI Bridge ID and the location of bridges are provided. The interface for volunteer data uploading can accept the user to collect data and upload data to database.

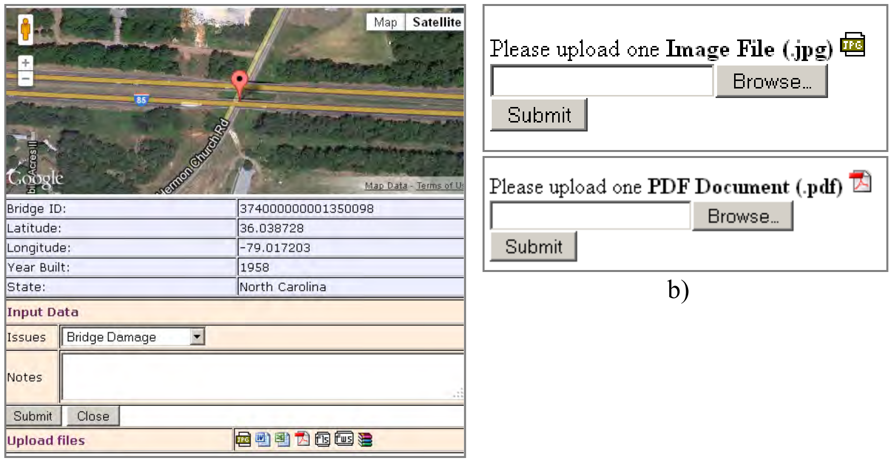


a) b) c)

Figure 18. Bridge locator

4.6.3.2 Data entry

Once the bridge is located, the related information should be uploaded to the database. There are mainly four parts for the volunteer sensing data uploading page (Figure 20a), including a map shows the bridge location, several general bridge information (Bridge ID, latitude, longitude, the year built and State), data input part (reporting issue, and description), file uploading part which provides the functionalities for upload various documents including image file (.img), Word document (.doc), Excel document (.xls), Adobe document (.pdf), ZIP file (.zip) and LiDAR scan data (.fls and .fws). In the document uploading window, user can select a document to upload (Figure 20b).



b)

a)

Figure 19. Public data entry interface(a) and the image pdf document upload interface (b).

4.6.4 Bridge Locator-Smart Phone data collection

The citizen sensor data collection function within Bridge-WGI is provided by a specific smart phone application that allows citizen sensor to capture/annotate/upload bridge data. Bridge Locator is an Android application that reads in bridge data from the master database location data and locates bridges near the user within a certain radius using the user hand held device's GPS capabilities. Bridge Locator is developed using Basic4Android and Android SDK (system development kit). The main features of Bridge Locator include user selection of a search radius (in miles), and use the smart phone's 3G/WiFi/GPS signals to locate all the bridges near the user within the search radius. The accuracy of the bridge location is dependent on the device's GPS signal and the cell tower triangulation. The best available location source selection is then in the order of GPS, 3G (triangulation) and then WiFi. The current location can be set to auto-update in the settings every 30 seconds to 2 minutes. This is ideal if the user is driving in a vehicle and wants to automatically see an updated list of bridges without having to press the "Bridges near me" button.

Figure 20 shows a screen shot of Bridge Locator – several functionalities are provided for user interactivities including options for locating a bridge, listing of bridge location results that allows user to select a specific bridge and the option of changing the scope of radial bridge location. The bridges are displayed in a list. The following details are provided: 1) NBI Bridge ID, 2) Indication whether NBI inspection data is available for the bridge, 3) How far (in miles) the user is from the bridge, point-to-point ("as the crow flies"), 4) Indication whether the bridge is in the user's favorites list. Bridge Locator utilizes Google Map navigation capabilities; hence, driving directions to specific bridge can be indicated. Bridge location on Google Map in either map view or satellite view is also shown (Figure 21).

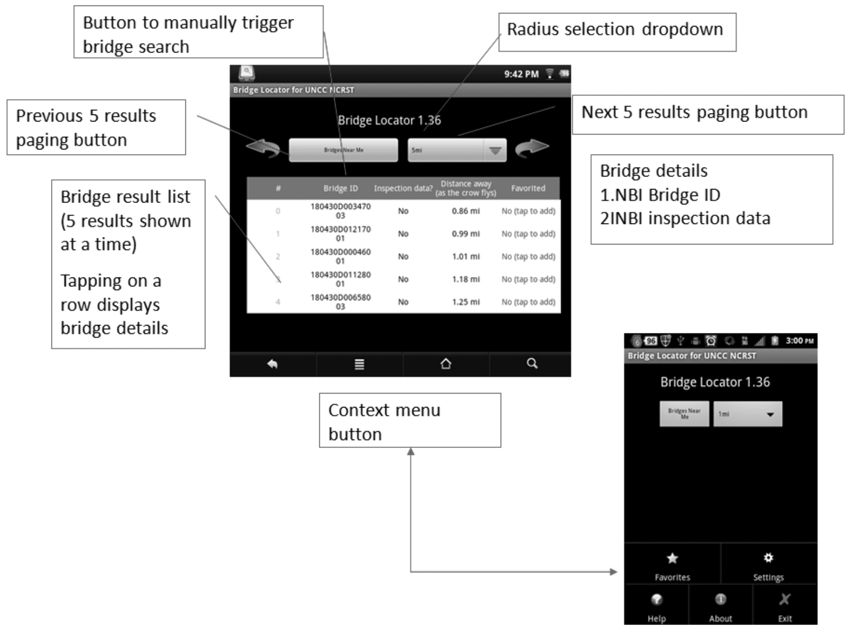


Figure 20 Bridge Locator for Locating of the Highway Bridges near a Citizen Sensor

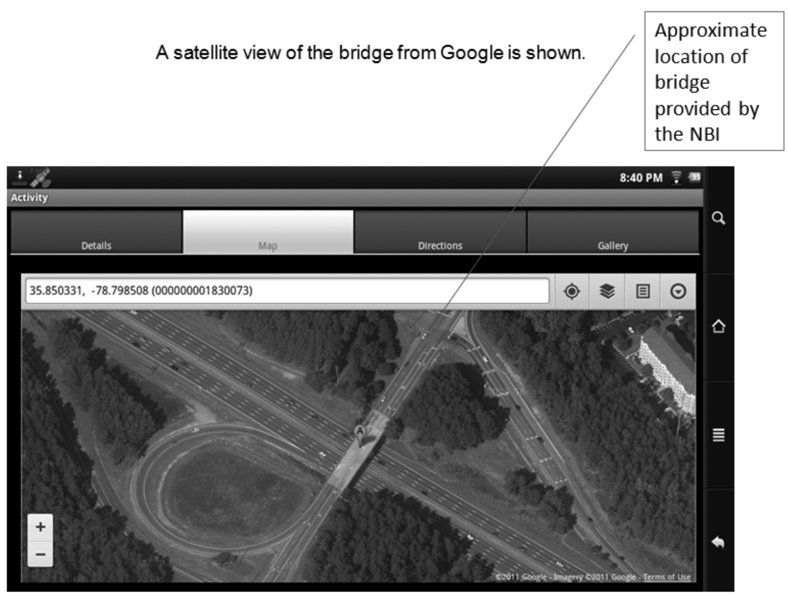


Figure 21 A Satellite View of the Selected Bridge is Shown

To capture data, Bridge Locator automatically verifies if the user is within 1 mile of the selected bridge. If so, Bridge Locator allows the user to capture a picture of the bridge using the phone camera. The image is then submitted to Bridge-WGI for approval (with notification via e-mail). The image is then stored in a photo album for either web-display or integrated into the bridge database. Figure 22 shows the data collection using the Activity function within Bridge Locator. Currently, Bridge Locator does not allow users to directly upload images from the gallery to the bridge database. The upload function is left to the bridge managers or to the database manager to operate.

Gallery

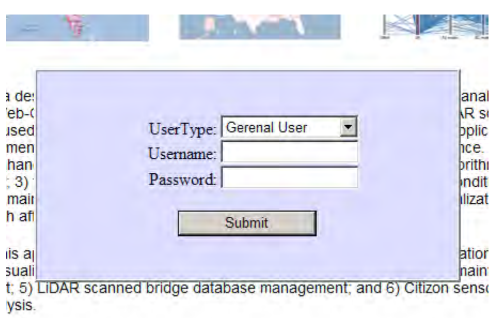
Allows user to capture a picture of the bridge using their phone's camera. The image then gets submitted to the Bridge-WGIprogram for approval (notification via e-mail), where it may end up in a photo album displayed on the website.

Figure 22 Bridge Locator Activity Including Bridge Imaging Using Camera Phone

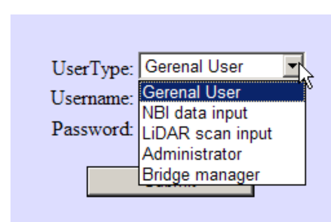
Bridge Locator has been designed as a firmware, so that users are automatically notified for upgrades and developer news.

4.6.5 Security

Internet security is very important issue for protecting the data and application. In the design we just apply the login to protect the website being misused by a person without the privilege. The login is designed for different users to access this application. The login interface is shown in Figure 23a, and the user can access the computer system by choosing a user-type, entering the username and the password. Different user can only access the pages which the user has the privilege (Figure 23b). The more security issues should be discussed in future study.



Login interface



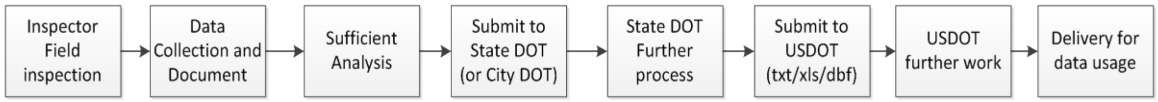
For different user

Figure 23. Login Interface

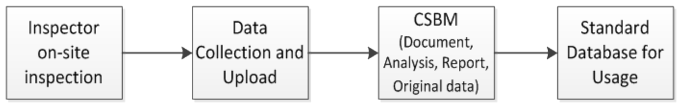
4.6.6 Advantages of Using Citizen Sensors

Current bridge inspection process is a multi-task procedure from the beginning when an inspector does a field inspection to final information usage for USDOT (Figure 24a).

This effort can take several months to complete. Supplementing with BRIDGE-WGI can significantly improve the process, which may include (Figure 24b):



a). Most current procedure of bridge inspection



b). BRIDGE-WGI procedure

Figure 24. The comparison between current procedure and BRIDGE-WGI procedure for bridge inspection

1) Increase efficiency. The Web-based BRIDGE-WGI system integrates all analytics and visualization, hence, can help enhance understanding of parametric inter-relations (Wang et al. 2010). All the time consuming works can then be focused on on-site inspection and related works for system maintenance.

2) Decrease the cost to inspect a bridge and use the use the money to repair bridges. The conventional procedure needs a group of personnel and several months to finish the work. So the cost is high. By using BRIDGE-WGI, the cost will be decreased, and the DOT can use the saved budget to improve the maintenance level for bridges.

3) Increase the flexibility to access and expand the monitoring capacity for national bridges. Most current bridge management systems are used in a stand-alone computer (workstation) and intranet or limited Internet access. Different States DOT own their own bridge management systems with different functionalities. By applying the BRIDGE-WGI framework, DOT personnel can view the information of any bridge nationwide anywhere and anytime with the technology of WebGIS.

4) Support ad-hoc inspection and improve the health of the bridge. Most current inspections are following a 2-year on-site inspection cycle. This may make the inspectors miss a special inspection for a bridge which may need to be inspected earlier than the 2-year cycle due to possible issues with the bridge. With the BRIDGE-WGI application, the decision making support will automatically generate pre-caution and suggest that inspectors do an inspection for a particular bridge and on which date. Thus, the ad hoc bridge inspection can help improve the safety of the bridge.

5) Dramatically increase amount of bridge data and expand the NBI database. Traditional procedure only use the data (include pictures) collected by the inspector to do further analysis. By using citizen as the sensors, the bridge information is larger and available in various formats (such as text, image, audio and video) and various categories (such as bridge damage, traffic jam, scene view and others). All the input data by public

will help further the study of the bridge and vehicle traffic by using data mining technologies.

6) Use the information from the BRIDGE-WGI for public safety. The information can be used by commercial trucking firms to create the safest routes by making sure that truck weights do not exceed current limits on bridges.

7) Educate citizen sensor. Citizens can be educated about the importance and difficulties in bridge maintenance and management, which can further motivate citizen responsibilities to assist DOTs in bridge management.

4.6.7 Summary

Citizen sensor represents a critical adaptation of the geography and spatial science (GSS) technologies. The motive to share data is critical to the citizen sensor concept: A fundamental question to ask in GSS is “What does geography and spatial science mean to different scientific applications?” Goodchild (1992) argued that spatial data handling provides what we do and how we do it, but does not answer why we do it.

Citizen sensors in BRIDGE-WGI are assumed to be people who are aware of bridge monitoring issues and are willing to volunteer efforts to capture bridge information (VGIs). Hence, by using controlled user interactivities and operations (software-based), citizens are envisioned to download specific apps for their smart phone and become active data provider. Bridge-WGI represents critical component in using GSS and citizen sensor technology for network-level bridge monitoring. Bridge-WGI requires the ability to capture multiple sensor data associated with bridge damage detection to provide meaningful information in the decision making process in assessing the structural health, preservation, and maintenance of the bridge. Hence, Bridge-WGI serves two critical roles concerning interaction with citizen sensors: 1) to assist and facilitate citizen sensors with bridge information upload, and 2) to enhance citizen sensors understanding of bridge management issues. As a result, significant involvements in geographic visualization are needed to transform data of thematic, multi-scale and multiple data formats into a “user-comfortable” level for the citizen sensors. Bridge-WGI allows citizen sensors to view NBI bridge data and “de-sensitized” bridge data. All visual analytic tools can be used by the public.

4.7 BRIDGE REMOTE SENSING DATA INTEGRATION AND VISUALIZATION

4.7.1 Introduction

Remote sensing is defined as the measurement of object properties on the earth's surface using data acquired from aircraft and satellites. Remote-sensing systems which deployed on satellites provide a repetitive and consistent view of the earth that is invaluable to monitoring short-term and long-term changes and the impact of human activities. The science of remote sensing in its broadest sense includes aerial, satellite, and spacecraft observations of the surfaces and atmospheres of the Earth. Remote sensing of the Earth has many applications including environmental assessment and monitoring, global change detection and monitoring, agriculture, nonrenewable resource exploration, renewable natural resources, meteorology, mapping, military surveillance and reconnaissance (Schowengerdt, 2010).

Many remote-sensing systems have been developed to offer a wide range of spatial, spectral, and temporal parameters. For the past fifty years, several Commercial remote sensing (CRS) and Spatial Information (SI) technologies for wide-bandwidth spectral information sensing and imaging have been developed integrally with satellite/airborne/ground-based surveillance platforms such as IKONOS, Quickbird, OrbView-3, SPOT, orthotropic and small-format aerial photography and LiDAR scans (Schowengerdt, 2010). Remote sensing technologies have several advantages of including large coverage area, large amount of information, cheap and up-to-date data collection, ease of manipulating with computer, and providing repeatable evaluation and inspection with high accuracy. The utilization of remote sensing technologies for bridge monitoring can be an alternative solution for bridge monitoring and maintenance. The bridge managers can have the capability to increase the efficiency and potential for monitoring a large amount of bridges simultaneously. The development of automatic bridge inspection and management system based on remote sensing data also standardize the inspection procedure and save investigation and inspection time (Liu, 2010).

This proposed application is about using Web-GIS visualization system integrating the remote sensing data including LiDAR scan and fly-over aerial image for NBI bridge monitoring. A database application of bridge images including LiDAR scan and fly-over photo of the bridge are designed and implemented. This database helps the bridge managers to do further application with these images.

4.7.2 Remote sensing technologies

Typically, remote sensing refers to imagery and image information taken by airborne and satellite systems. Liu (2010) discusses the remote sensing systems of space borne/airborne and ground base remote sensing systems. In this system, the satellite image, LiDAR scan and aerial photography are discussed and implemented.

The map shows the location of the bridge

b) The close top-view of the bridge in map

c) The street view under the bridge

Figure 25. The satellite image

4.7.2.1 Satellite image

Considering the spatial resolution, satellite data are classified as coarse resolution data and high resolution data. Ranging from dozens of meters to several hundred kilometers, coarse resolution satellite data are mainly used for large scale problems (Glantz et al. 2009). Satellite image is applicable for showing the bridge location and environment of the bridge. Satellite image provides a very clear geospatial location of a bridge and the highway network. In this application, the Google Map satellite images are used for the map view of the bridge and highway system (Figure 25).

4.7.2.2 LiDAR scan

LiDAR (Light Detection And Ranging) is a terrestrial 3D laser scanners with a shorter wavelength with an optical remote sensing technology. The LiDAR scanner can collect the surrounding surface information of object by rotating 360 degrees horizontally. The point clouds of the object surrounding surface information can be measured and recorded in a single scan. A typical scan is around 9,000×4,000 points are measured with 360˚ horizontally and 320˚ vertically (Liu, 2010). Due to the 3D data information, there are 3-D coordinates information of the scanned bridge, the LiDAR scan can be viewed in 3D coordinates system and can be zoomed and rotated. This 3D data feature of LiDAR scan is important and makes it possible for further research and analysis on the bridge, such as surface damage detection in bridge health monitoring.

(a) LiDAR scan

(b) 3D view of LiDAR scan

Figure 26. A LiDAR scan of bridge (a) and the 3D scene view (b)
(Bridge Inventory number: 1044659, New York State)

With the introduction of advanced land-based LiDAR systems new opportunities in structural analysis are presented. The result of a LiDAR scan is a large dataset of millions of measurements. With a large data set of measurements structural analysis methods could be performed. Previous studies have applied LiBE (LiDAR based Bridge Evaluation) methods to highway bridges to find damage, road clearance, and deflection (Liu, 2010). LiDAR technology has further more advantages. One advantage is that the 3D viewer model allows the engineer to review the structure directly without needing to return to the site or sorting through pages of bridge pictures. The other advantage is that a series of LiDAR scans can be connected into one global coordinate system. By combining several smaller scans a large structure can be modeled by one larger 3D model. Furthermore, LiDAR is the preferred tool of analysis because of future applications (Tong et al., 2010).

Figure 26a shows the LiDAR scan and the Figure 26b shows the 3D scene view of the LiDAR scan (The bridge is located in New York State and the bridge ID is 1044659). The two images are generated by FARO SCENE LT which is a product of FARO Technologies, Inc.

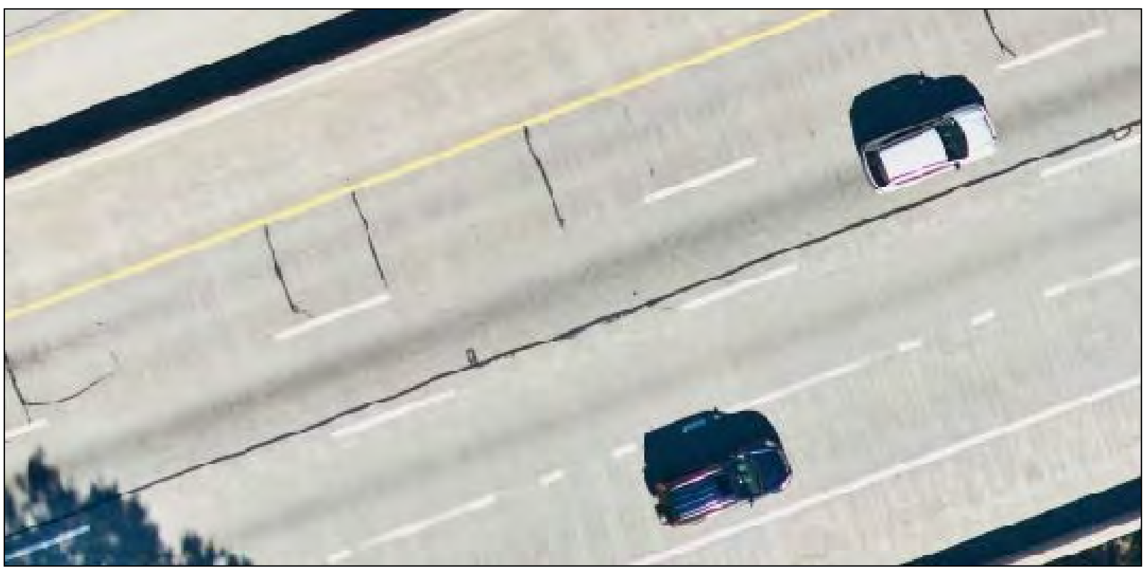
Liu (2010) discusses the LiDAR technology application for bridge monitoring, including the bridge clearance measurement, bridge displacement measurement and the bridge static load testing. All the applications can enhance the bridge health monitoring by applying the LiDAR scan.

4.7.2.3 Aerial Photography

High resolution aerial photo make it possible to detect the damage on the surface of the highway. This high resolution image is took by airplane which mounted a camera to capture the photo while the airplane flying over the bridge. Figure 27a shows zoom-out view of the aerial fly-over aerial image of the bridge (Bridge Inventory number 1044659 in New York State). Figure 27b shows a clear image which is the real size of part of the bridge image in Figure 27a. From this high resolution image, some damages of the bridges on the top the deck of bridge can be identified out. The top view of the bridge can help the bridge managers to get a whole picture of the bridge surface health condition. There is an obvious difference between the high resolution aerial photo (Figure 27b) and the satellite image (Figure 28), the fly-over aerial photo is much clear than the satellite image.

For further application with the fly-over bridge image, the image processing technologies can be applied to detect bridge damages for bridge health monitoring. There are numerous algorithms for image processing.

a). The high resolution aerial photo.



b). Part of the aerial photo

Figure 27. The high resolution aerial photo of bridges

Figure 28. The satellite image of the same area as in Figure 27 (b).

Liu (2010) discusses the possibiligy of bridge issues that can be detected from the high-resolution airborne images to enhance visual inspection that can be developed into further automatic detection methods. Some attributes such as sun shadows and rain dampness may cause some noise for the bridge condition analysis. Due to the resolution limitation of remote sensing technologies, there are limited capability for bridge damage assessment and only wide structural cracks (width ≥ 0.0048m) are able to be detected from satellite or airborne images (FHWA 2002). Therefore, the the detectable bridge damages may represent serious damages to the bridge structure which will help the bridge managers and engineers to inspect and maintain the bridge at an early time.

4.7.3 Implementation

The Web-GIS based visualization platform integrates the NBI bridge database and remote sensing image data for bridge information visualization and reporting. The goal of integration of remote sensing image with NBI bridge data is to assist national bridge monitoring and management, making it a robust and inclusive data collection system. The Google Map serves as the base map from this application. The related remote sensing bridge data include the LiDAR scan and the fly-over photos. A bridge analysis report of the detailed bridge information is also a part of this application. If a bridge is selected, the information page of this bridge is popup as shown in Figure 29. The information includes the general information and several remote sensing data, such as the bridge analysis report (the .doc document), the fly-over images, the LiDAR scan data (the .fls, and .fws documents) (Figure 29). By clicking the fly-over image, the large photo with high resolution will be displayed in a new webpage (Figure 30a). Figure 30b shows the real size of the image by zoom-in operation.

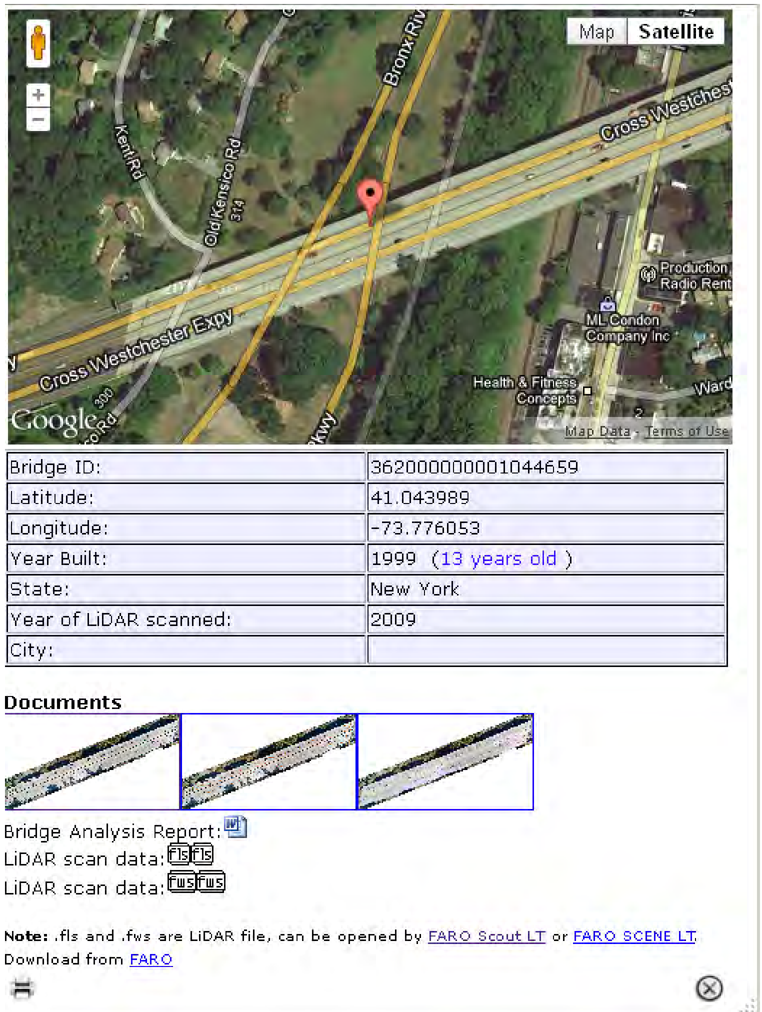


Figure 29. The information page of the bridge with remote sensing data

The bridge analsys report (Figure 31) shows the more detail information of the bridge, these remote sensing data will help bridge managers to obtain further bridge health information to improve the efficiency of bridge maintenance. The bridge inventory ID and the geographic location are important part for locating the bridge, some other bridge informaiton such as the authoritative agency of the bridge and the year built. The Visualization assistance part is several images about the bridge including photos taken by a general camera, the fly-over high resolution images, and the 3D view of the LiDAR scan data. All the images can assist the bridge managers for the bridge management. The bridge analysis reports for 86 bridges from states Alabama, California, Florida, Iowa, New York and North Carolina, are finished (Appendix C).

a) The high resolution fly-over image of the bridge

b) The real size of the fly-over image

Figure 30. The fly-over photo of the bridge

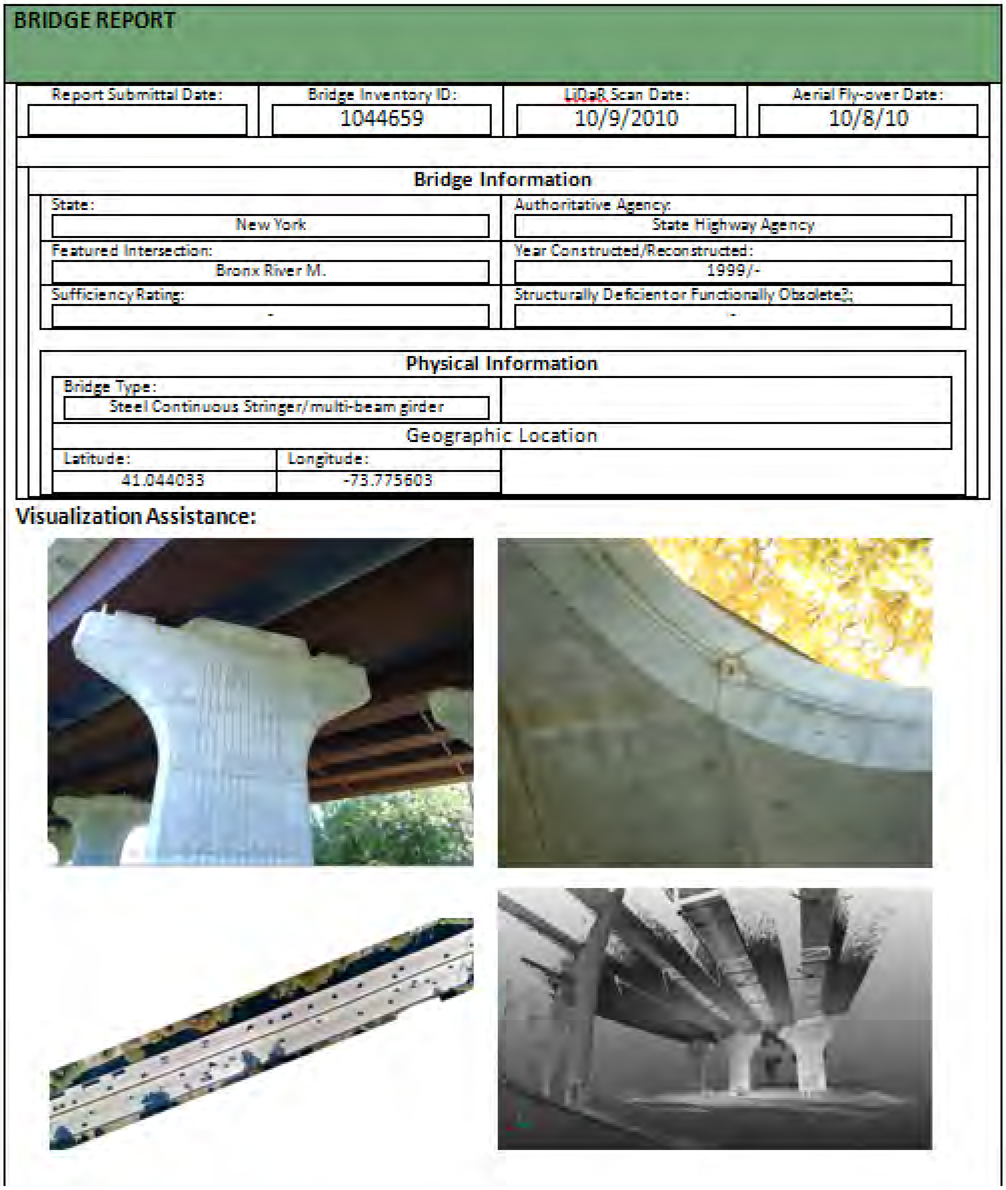


Figure 31. The bridge report

All those documents including images, bridge anaysis report, LiDAR scan documents can be downloaded for further analysis. The LiDAR scan document (.fls file) can be opened by FARO Scout LT or FARO Scene LT. FARO SCENE LT is designed for FARO laser scanner. FARO SCENE LT is a free viewer which enables the professional user to view existing FARO scans and workspaces. It is able to import CAD models in VRML format in order to compare them with the scan points (FARO, 2012) .

4.7.4 Summary

Remote sensing bridge data including LiDAR scan and fly-over photo can provide more information of the bridge for the bridge health condition inspection and evaluation. LiDAR scan can be used to detect the surface damage, bridge clearance rating, bridge displacement measurement and the bridge static load testing. Fly-over bridge photo can be analyzed for detect the damage on the top surface of the deck. The LiDAR scan mostly is about surface of the superstructure and substructure of the bridge. The integration of those two remote sensing technologies enhances the capability of bridge management and maintenance.

The integration of LiDAR scan and fly-over photo can assist manage to detect the most part of surface of the bridge and can provide useful bridge health related information that can be used for transportation infrastructure management. The 3D LiDAR scanner has many potential applications in structural health monitoring (Liu, 2010). Further application includes FE model creation by combining the bridge component dimension measurement and the LiDAR scan data.

The limitation of applying the remote sensing technologies is that there are few capabilities to detect the damage inside the bridge structure. To detect the damage inside the structure, some other technologies should be considered.

4.8 DISCUSSION

The Web-GIS based NBI bridge analytical visualization framework (Bridge-WGI), integrating current technologies including Internet, GIS, Visualization and bridge health monitoring, can provide useful functionalities for enhancing the national bridge management and maintenance. Compare to current bridge management systems, the advantages and the limitation of this implementation are discussed as follow.

(1) Save both time and cost and increase maintenance efficiency. Web-GIS framework relies on anywhere anytime connectivity hence can instantaneously complete data collection. Analysis and visualization can be performed using the same platform.

(2) Make less data entry errors and increase the reliability. The conventional procedure consists of many processes that are processed by different individuals resulted in high probability of human errors. Wrong data will make negative influence on the further bridge maintenance decision making. While Web-GIS framework makes a one-step entry, the inspector is the first and only person who collects and enters the data, no other person involved in the data entry. Since there is no entry error, future data checking is simplified.

(3) Increase the flexibility to access and expand the monitoring capacity for national bridges. Most current bridge management systems are used in a stand-alone computer (workstation) and intranet with limited Internet access. By applying Web-GIS framework, authorized people can view bridge information nationwide anywhere and anytime.

(4) Increase amount of the bridge data input dramatically and expand the NBI database. Traditional procedure only use the data (include pictures) collected by the inspector to do further analysis. By using volunteered sensors, the public help input bridge information in various formats (such as text, image, audio and video) and various categories (such as bridge damage, traffic jam, scene view and others). All the input data by public will help further study for the bridge and the traffic by using data mining technologies.

Citizen sensor represents a critical adaptation of the geography and spatial science (GSS) technologies. The motive to share data is critical to the citizen sensor concept. Citizen sensors and GSS technologies are critical technologies that have extensive applications in infrastructure monitoring. Almost every recent disaster event that has occurred in the US over the last twenty years, including the World Trade Center and Pentagon terrorist attacks, hurricane Katrina and more recently, the Louisiana Oil Spill, have been geo-referenced, spatially-analyzed, and displayed using aerial imaging and thematic satellite imaging. Notably, the images of the migration of hurricane Katrina, have been used in great detailed temporal demonstrations in geo-referenced contexts (Scharroo et al. 2005). Coupled with the availability of cell phone cameras and easy-access Internet, one can now view disaster pictures of every major event in the world beyond national boundaries.

Citizen sensors assumed to be people who are aware of bridge monitoring issues and are willing to volunteer efforts to capture bridge information. Hence, by using controlled user interactivities and operations (software-based), citizens are envisioned to download specific apps for their smart phone and become active data provider. Bridge-WGI represents critical component in using GSS and citizen sensor technology for network-level bridge monitoring. Bridge-WGI requires the ability to capture multiple sensor data associated with bridge damage detection to provide meaningful information in the decision making process in assessing the structural health, preservation, and maintenance of the bridge. Hence, Bridge-WGI serves two critical roles concerning interaction with citizen sensors: 1) to assist and facilitate citizen sensors with bridge information upload, and 2) to enhance citizen sensors understanding of bridge management issues. As a result, significant involvements in geographic visualization are needed to transform data of thematic, multi-scale and multiple data formats into a "user-comfortable" level for the citizen sensors. Thus, Bridge-WGI allows citizen sensors to view NBI bridge data and "de-sensitized" bridge data.

To ensure data security and avoid intentional abuses, the system security approach requires that a user register with the website and receives a password from the system operator. However, the security is only required for data input. Since the embedded database cannot be directly accessed by any unauthorized users, the potential of data corruption is deemed to be minimal. The gated data input component would allow system operator to regulate only legitimate users to upload data. By limiting users to a single bridge data website, we will also avoid possible system-level corruption. Bridge Locator, on the other hand, does not require user log in for image and data upload. Hence, citizen sensor can browse all images within the gallery.

Regardless of organized or non-organized citizen sensor system, the key issues are the accuracy and relevancy of the collected data. Organized citizen sensor should allow feedbacks to help improve on sensor accuracy – meaning to train citizen sensors to capture better information. Using controlled and secured GSS technologies, Bridge-WGI would have better quality control of uploaded data and ensure accuracy in bridge information.

More issues should be considered in the further application, including 1) The effects of graphic fluidity and visualization effect on current Bridge-WGI and citizen sensor integration; 2) Since Window8 is an open shared OS platform for tablet, Smart Phone and PC, the impact to Bridge-WGI of Window 8 should be considered; and 3) Future applications in cloud computing should be considered, such as upgrading Web-GIS to any potential future direction of bridge management software.

4.9 CONCLUSION

US National Bridge Inventory consists of near 600,000 bridges spreading over the country. To enhance the management of these bridges, volunteer sensor data applied for network-level bridge data collection is suggested. Using modern tools including Web-GIS and mobile device, volunteer sensors can be established. Analytical visualization techniques are applied for NBI database visualization to make a better presentation. Visualization enhances the bridge management system. The bridge maintenance decision making support module helps the bridge managers to maintain the bridge effectively and efficiently with limited funding. The conclusion of this research is summarized as following.

(1). The Web-GIS based bridge analytical visualization framework is developed and implemented for bridge management and bridge maintenance. The framework provides a multi-functionality application which can assist the bridge managers and bridge engineers to view the bridge information and to make decision for maintaining the bridge structure. The centralized framework maintains the national bridge data and offers standard management tools for managing the national bridges.

(2). Internet and GIS technologies are applied in Bridge-WGI to implement a more efficient and more effective solution for bridge management. Internet technology makes it possible to view the information of the bridges anywhere-anytime with the access to Internet which is widely used by both the government and the public. GIS has the capability to display the bridge by geographic location which means geospatial analysis can be performed on the bridge data.

(3). Visualization technology provides a new way to interpret the bridge health information and the distribution of the bridge condition rating nationwide and statewide. The applied analytical visualization technologies can present the bridge data in different way so that the bridge managers can obtain a clear knowledge of the bridge from different views. Various observations about the bridge conditions may be generated from the analytical visualization technologies.

(4). Decision making support module provides alternative approach to existing bridge evaluation. Most of the current BMS are based on visual or subjective condition assessment, and do not predict optimum maintenance requirements based on balancing life-cycle cost and bridge system reliability requirements (Frangopol et al. 2000). Bridge-WGI provides the framework allows further module development.

(5). Citizen sensing application provides a dramatic data collection resource for bridge condition inspection. Volunteers can act as a bridge information collector and upload the data to bridge database so that the bridge health information increases dramatically and expand the NBI database.

(6). Remote sensing data is integrated into Bridge-WGI allowing alternate bridge condition information resource for assistance to bridge management and maintenance. The currently integrated bridge remote sensing data include LiDAR and Aerial images.

4.10 FURTHER STUDY

This WebGIS-based framework for volunteer sensing data enhances the national bridge management. Future extensions of the conceptual model can provide further process support mechanisms. More precise decision-making models can be integrated on this framework. Some technologies such as data mining, predictive analytics, and estimation could be applied for further research on the national bridge management. By integrating various bridge condition data from multiple innovative sensing technologies, new approaches can be designed for solve the bridge safety issues more effectively. Further development of the work based on this research may also include three-dimensional models for viewing the LiDAR scan, and more functionality for bridge health visualization with the citizen sensor.

REFERENCES

Aktan, A.E., Farhey, D.N., Helmicki, A.J., Brown, D.L., Hunt, V.J., Lee, K.L. and Levi, A. (1997) "Structural Identification for Condition Assessment: Experimental Arts," Journal of Structural Engineering, 123(12), 1674-1686.

ASCE (2009). "Infrastructure report card 2009," American Society of Civil Engineering.

Batty, M. and Xie Y.(1994) "Urban Analysis in a GIS Environment: Population Density Modeling Using ARC/INFO," in A.S. Fotheringham and P.A. Rogerson (Eds.) Spatial Analysis and GIS, Taylor and Francis, London, 189-219.

Burdziej, Jan, (2011). "A Web-based spatial decision support system for accessibility analysis—concepts and methods," Applied Geomatics.

Chase, S.B., (1995). "NDE for Steel Bridges," Civil Engineering, 65(5), 49-51.

Chase, S.B., Nutakor, C. and Small P.E.P.(1999). "An In-Depth Analysis of the National Bridge Inventory".

Chen, C. (2010), Information visualization. Wiley Interdisciplinary Reviews: Computational Statistics, 2: 387–403. doi: 10.1002/wics.89

Chen, S.E. Rice, C. Boyle, C. and Hauser, E.(2011) "Small Format Aerial Photography for Highway Bridge Monitoring," ASCE J. Performance of Constructed Facilities, 25(2), 105-112.

Chen, S.E., X. Wang, R. Vatcha, W. Du, S. Lee, R. Chang, E. Hauser, W. L. Tolone, W. Ribarsky.(2010) "IRSV, An Integrated Visual Analytics Bridge Management System," TRB, Washington DC.

Esch, G., Scott, M. and Zhang, E.(2009)."Graphical 3D visualization of highway bridge ratings," Journal of Computing in Civil Engineering.

FARO (2012). http://www.faro.com/focus/us/software

FHWA (1995). "Recording and Coding Guide for the Structure Inventory and Appraisal of the National Bridges, U.S." Department of Transportation, Federal Highway Administration, Report No. FHWA-PD-96-001.

FHWA. (2002). Bridge Inspector's Reference Manual. Federal Highway Administration, U.S. Department of Transportation, No. FHWA NHI 03-002.

FHWA. (2006a). Bridge Inspector's Reference Manual, U.S. Department of Transportation,Federal Highway Administration, Publication No. FHWA NHI 03-001, revision 2006.

Frangopol, D.M, Enright, M.P and Estes, A.C. (2000) “Integration of maintenance, repair, and replacement decisions in bridge management based on reliability, optimization, and life-cycle cost”, Transportation Research Circular, IBMC 99-003, TRB, NRC, Washington, DC, G-1, 498 (II) , pp. 1–13

Glantz P, ED Nilsson, W Hoyningen-Huene. (2009) Estimating a relationship between aerosol optical thickness and surface wind speed over the ocean. Atmospheric Research 92(1): 58-68.

Goodchild, M. F.,(2007) “Citizens as sensors: The world of volunteered geography,” GeoJournal, 69(4), 211–221.

Goodchild, MF, Guoqing, S. and Shiren, Y.,(1992) “Development and Test of an Error Model for Categorical Data,” Int. Journal of Geographical Information Systems, 6, 87-104.

GoogleMap (Google MapAPI). (2011). http://code.google.com/apis/maps/documentation/javascript (retrieved in 2011)

GoogleMap, (2012) Google Maps. http://en.wikipedia.org/wiki/Google_Maps Retrieved 2012-01-20. (Retrieved 2012)

Grivas, D.A. and Shen, Y.C. (1995). “Design of a Database system for Bridge Management”. Computer in civil engineering; proceedings of the Second Congress held in conjunction with A/E/C System ’95, 899-906.

Gucunski, N., Consolazio, G.R. and Maher, A.,(2006) “Concrete Bridge Deck Delamination Detection by Integrated Ultrasonic Methods,” Internatrional Journal of Material and Product Technology, Special Issue on NDT and Failure Preventive Technology, 26(1/2), 19-34.

Hawk, H (1999). BRIDGIT: USER FRIENDLY APPROACH TO BRIDGE MANAGEMENT. Eighth Transportation Research Board Conference on Bridge Management, F-7, IBMC-072 13p.

Hearn, G., Purvis, R.L., Thompson, P.D., Bushman, W.H., McGhee, K.K. and McKeel, W.T. (2000). Bridge maintenance and management: a look to the future, the Proce. of the TRB 81st Annual Meeting: A3C06:Structures Maintenance and Management (2000), pp. 1–7.

InSiteful Imagery.(2011) http://www.insitefulimagery.com/about.htm (Retrieved 2011)

Iyengar, A. and Challenger, J.(1997). Improving web server performance by caching dynamic data, Proceedings of the USENIX Symposium on Internet Technologies and Systems on USENIX Symposium on Internet Technologies and Systems, p.5-5, December 08-11, Monterey, California

Kingston, R., Carver,S., Evans,A. and Turton, I.(2000).“Web-based public participation geographicalinformation systems: an aid to local environmental decision-making,” Computers, Environment and Urban Systems 24, pp109-125.

Liu, W. (2010). “Terrestrial LiDAR-based bridge evaluation”, Ph.D. Dissertation, University of North Carolina at Charlotte, Charlotte, North Carolina.

Liu, W.Q., Chen, S.E. and Hauser, E. (2010). “LiDAR-Based Bridge Structure Defect Detection,” Experimental Techniques, DOI: 10.1111/j.1747-1567.2010.00644.x.

Nagarajan, M., Gomadam, K., Sheth, A.P., Ranabahu, A., Mutharaju, R. and Jadhav, A (2009).“Spatio-Temporal-Thematic Analysis of Citizen Sensor Data: Challenges and Experiences,” Web Information Systems Engineering, Lecture Notes in Computer Science, 5802, 539-553.

OGC (2012). "Web Map Service". Open Geospatial Consortium. Retrieved 2012-01-20 http://www.opengeospatial.org/standards/wms

Peeters, B. and Ventura, C.E.(2003).“Comparative Study of Modal Analysis Techniques for Bridge Dynamic Characteristics,” Mechanical Systems and Signal Processing, 17(5), 965-988.

Robert, W., Marshall, A., Shepard, R., Aldayuz, J. (2003). Pontis Bridge Management System – State of Practice in Im-plementation and Development. Proceedings of the 9th In-ternational Bridge Management Conference: 49-60.

Rossow, M. (2011) Overview of Bridge Inspection Programs (BIRM), Course No: S01-001.http://www.cedengineering.com/upload/Bridge%20Inspection%20Programs.pdf (Retrieved in 2011).

Sack, D.A. and Olson, L.D.(1995).“Advanced NDT Methods for Evaluating Concrete Bridges and Other Structures,” NDT and E International, 28(6), 349-357 .

Saito, M. (1988). “Development of a statewide network level bridge management system,” PhD thesis, Purdue Univ., West Lafayette, Ind.

Scharl, A and Tochtermann, K.(2007). The Geospatial Web: How Geobrowsers, Social Software and the Web 2.0 are Shaping the Network Society. Springer. pp. 225. ISBN 1846288266.

Schowengerdt, R.A.(2010). “Remote Sensing: Models and Methods for Image Processing” 3rd edition, Elsevier Inc.

She, T. H., Aouad,G. and Sarshar, M. (1999). “A Geographic Information System (GIS)–Based Bridge Management System,” Computer-Aided Civil and Infrastructure Engineering, 14: 417–427.

Stone, W.C., Juberts, M., Dagalakis, N., Stone, J. and Gorman, J. (2004). Performance Analysis of Next-Generation LADAR for Manufacturing, Construction, and Mobility, Report NISTIR 7117, National Institute of Standards and Testing, U.S. Department of Commerce.

Sugumaran, R. and Meyer, J. (2003). "Building a Web-Based Spatial Decision Support System (WEBSDSS) for Environmental Planning and Management", at URL DSSResources.COM.

Tong, Y., Bian, H., Watson, C., Dai, K., Liu, W. and Chen, S. (2010). "LiDAR Scan Applications for Bridge Condition Validation Post-Blast Load and Construction," NDE/NDT for Highways and Bridges: Structural Materials Technology (SMT) 2010, 16-20 August 2010, New York, NY.

Wang, X., Dou, W., Chen,S.E., Ribarsky,W. and Chang, R. (2010). "An Interactive Visual Analytics System for Bridge Management," Computer Graphics Forum, 29(3), 1033-1042.

Washer, G.A.(1998)."Developments for the Non-Destructive Evaluation of Highway Bridges in the USA," NDT & E International, 31(4), 245-249.

Zhu, B. and Chen, H. (2005). "Information Visualization", Annual Review of Information Science and Technology, vol. 39.

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APPENDIX

Appendix A.

A1. Code for bridge condition rating (deck, superstructure and substructure)

Code	Description
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION - no problems noted.
7	GOOD CONDITION - some minor problems.
6	SATISFACTORY CONDITION - structural elements show some minor deterioration
5	FAIR CONDITION - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour.
4	POOR CONDITION - advanced section loss, deterioration, spalling or scour.
3	SERIOUS CONDITION - 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 CONDITION - 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 it may be necessary to close the bridge until corrective action is taken.
1	IMMINENT FAILURE CONDITION - 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 CONDITION - out of service - beyond corrective action.

A2. Functional classification of roadway

Code	Description
	Rural
1	Principal Arterial - Interstate
2	Principal Arterial - Other
6	Minor Arterial
7	Major Collector
8	Minor Collector
9	Local
	Urban
11	Principal Arterial - Interstate
12	Principal Arterial - Other Freeways or Expressways
14	Other Principal Arterial
16	Minor Arterial
17	Collector
19	Local

A3. Damage code for upload data by public.

Code	Description
0	Bridge collapsed
1	Large area damage, bridge may collapse
2	Large area damage, bridge will not collapse
3	small damage
9	No sudden damage

Appendix B.

NBI Record Format (http://www.fhwa.dot.gov/bridge/nbi/format.cfm)

With the conversion to metric and the addition of new items it is required to expand the size of the NBI record to 432 characters. The following format will be used to submit data to the FHWA.

ITEM NO	ITEM NAME	ITEM POSITION
1	State Code	1-3
8	Structure Number	4-18
5	Inventory Route	19 - 27
5A	Record Type	19
5B	Route Signing Prefix	20
5C	Designated Level of Service	21
5D	Route Number	22 - 26
5E	Directional Suffix	27
2	Highway Agency District	28 - 29
3	County (Parish) Code	30 - 32
4	Place Code	33 - 37
6	Features Intersected	38 - 62
6A	Features Intersected	38 - 61
6B	Critical Facility Indicator	62
7	Facility Carried By Structure	63 - 80
9	Location	81 - 105
10	Inventory Rte, Min Vert Clearance	106 - 109
11	Kilometerpoint	110 - 116
12	Base Highway Network	117
13	Inventory Route, Subroute Number	118 - 129
13A	LRS Inventory Route	118 - 127
13B	Subroute Number	128 - 129
16	Latitude	130 - 137
17	Longitude	138 - 146
19	Bypass/Detour Length	147 - 149
20	Toll	150
21	Maintenance Responsibility	151 - 152
22	Owner	153 - 154
26	Functional Class Of Inventory Rte.	155 - 156
27	Year Built	157 - 160
28	Lanes On/Under Structure	161 - 164
28A	Lanes On Structure	161 - 162
28B	Lanes Under Structure	163 - 164
29	Average Daily Traffic	165 - 170
30	Year Of Average Daily Traffic	171 - 174
31	Design Load	175
32	Approach Roadway Width	176 - 179

ITEM NO	ITEM NAME	ITEM POSITION
33	Bridge Median	180
34	Skew	181 - 182
35	Structure Flared	183
36	Traffic Safety Features	184 - 187
36A	Bridge Railings	184
36B	Transitions	185
36C	Approach Guardrail	186
36D	Approach Guardrail Ends	187
37	Historical significance	188
38	Navigation Control	189
39	Navigation Vertical Clearance	190 - 193
40	Navigation Horizontal Clearance	194 - 198
41	Structure Open/Posted/Closed	199
42	Type Of Service	200 - 201
42A	Type of Service On Bridge	200
42B	Type of Service Under Bridge	201
43	Structure Type, Main	202 - 204
43A	Kind of Material/Design	202
43B	Type of Design/Construction	203 - 204
44	Structure Type, Approach Spans	205 - 207
44A	Kind of Material/Design	205
44B	Type of Design/Construction	206 - 207
45	Number Of Spans In Main Unit	208 - 210
46	Number Of Approach Spans	211 - 214
47	Inventory Rte Total Horz Clearance	215 - 217
48	Length Of Maximum Span	218 - 222
49	Structure Length	223 - 228
50	Curb/Sidewalk Widths	229 - 234
50A	Left Curb/Sidewalk Width	229 - 231
50B	Right Curb/Sidewalk Width	232 - 234
51	Bridge Roadway Width Curb-To-Curb	235 - 238
52	Deck Width, Out-To-Out	239 - 242
53	Min Vert Clear Over Bridge Roadway	243 - 246
54	Minimum Vertical Underclearance	247 - 251
54A	Reference Feature	247
54B	Minimum Vertical Underclearance	248 - 251
55	Min Lateral Underclear On Right	252 - 255
55A	Reference Feature	252
55B	Minimum Lateral Underclearance	253 - 255
56	Min Lateral Underclear On Left	256 - 258
58	Deck	259
59	Superstructure	260
60	Substructure	261
61	Channel/Channel Protection	262

ITEM NO	ITEM NAME	ITEM POSITION
62	Culverts	263
63	Method Used To Determine Operating Rating	264
64	Operating Rating	265 - 267
65	Method Used To Determine Inventory Rating	268
66	Inventory Rating	269 - 271
67	Structural Evaluation	272
68	Deck Geometry	273
69	Underclear, Vertical & Horizontal	274
70	Bridge Posting	275
71	Waterway Adequacy	276
72	Approach Roadway Alignment	277
75	Type of Work	278 - 280
75A	Type of Work Proposed	278 - 279
75B	Work Done By	280
76	Length Of Structure Improvement	281 - 286
90	Inspection Date	287 - 290
91	Designated Inspection Frequency	291 - 292
92	Critical Feature Inspection	293 - 301
92A	Fracture Critical Details	293 - 295
92B	Underwater Inspection	296 - 298
92C	Other Special Inspection	299 - 301
93	Critical Feature Inspection Dates	302 - 313
93A	Fracture Critical Details Date	302 - 305
93B	Underwater Inspection Date	306 - 309
93C	Other Special Inspection Date	310 - 313
94	Bridge Improvement Cost	314 - 319
95	Roadway Improvement Cost	320 - 325
96	Total Project Cost	326 - 331
97	Year Of Improvement Cost Estimate	332 - 335
98	Border Bridge	336 - 340
98A	Neighboring State Code	336 - 338
98B	Percent Responsibility	339 - 340
99	Border Bridge Structure Number	341 - 355
100	STRAHNET Highway Designation	356
101	Parallel Structure Designation	357
102	Direction Of Traffic	358
103	Temporary Structure Designation	359
104	Highway System Of Inventory Route	360
105	Federal Lands Highways	361
106	Year Reconstructed	362 - 365
107	Deck Structure Type	366
108	Wearing Surface/Protective System	367 - 369
108A	Type of Wearing Surface	367
108B	Type of Membrane	368

ITEM NO	ITEM NAME	ITEM POSITION
108C	Deck Protection	369
109	AVERAGE DAILY TRUCK TRAFFIC	370 - 371
110	DESIGNATED NATIONAL NETWORK	372
111	PIER/ABUTMENT PROTECTION	373
112	NBIS BRIDGE LENGTH	374
113	SCOUR CRITICAL BRIDGES	375
114	FUTURE AVERAGE DAILY TRAFFIC	376 - 381
115	YEAR OF FUTURE AVG DAILY TRAFFIC	382 - 385
116	MINIMUM NAVIGATION VERTICAL CLEARANCE VERTICAL LIFT BRIDGE	386 - 389
	FEDERAL AGENCY INDICATOR	391
	Washington Headquarters Use	392 - 426
	STATUS	427
n/a	Asterisk Field in SR	428
SR	SUFFICIENCY RATING (select from last 4 positions only)	429 - 432

Status field:
1 = Structurally Deficient;
2 = Functionally Obsolete;
0 = Not Deficient;
N = Not Applicable

Appendix C: Individual Database Reports

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	000198	5/18/2010	3/2/10

Bridge Information

State:	Authoritative Agency:
Alabama	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Hwy. 211 over RR	1922/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
47.6	FO

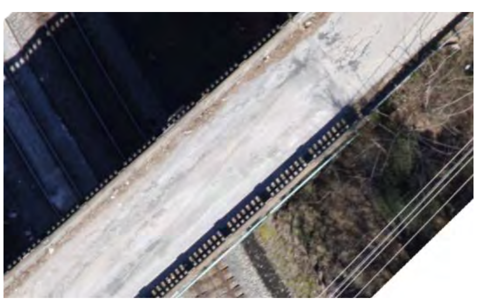
Physical Information

Bridge Type:	
Concrete Strigner/Multiple Beam/Girder	

Geographic Location

Latitude:	Longitude:
33.12633	-86.75379

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	000933	5/19/2010	3/9/10

Bridge Information

State: Alabama	Authoritative Agency: County Highway Agency
Featured Intersection: Hwy. 280 over Cooper Creek	Year Constructed/Reconstructed: 1931/-
Sufficiency Rating: 50.4	Structurally Deficient or Functionally Obsolete?: -

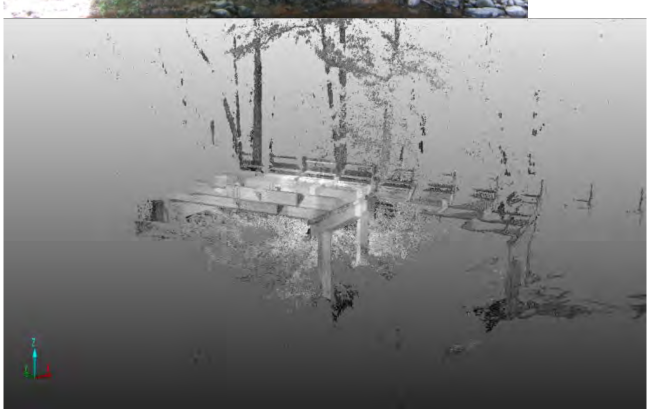
Physical Information

Bridge Type: Concrete Tee Beam	

Geographic Location

Latitude:	Longitude:
33.35131	-86.65657

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	000935	5/19/2010	3/10/10

Bridge Information

State: Alabama	Authoritative Agency: County Highway Agency
Featured Intersection: HWY. 280 over Yellowleaf Creek	Year Constructed/Reconstructed: 1931/-
Sufficiency Rating: 46.4	Structurally Deficient or Functionally Obsolete?: -

Physical Information

Bridge Type: Concrete Strigner/Multiple Beam/Girder	

Geographic Location

Latitude:	Longitude:
33.34734	-86.6417

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	000941	5/19/2010	3/11/10

Bridge Information

State:	Authoritative Agency:
Alabama	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
HWY. 280 over Muddy Prong Creek	1931/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
49.2	-

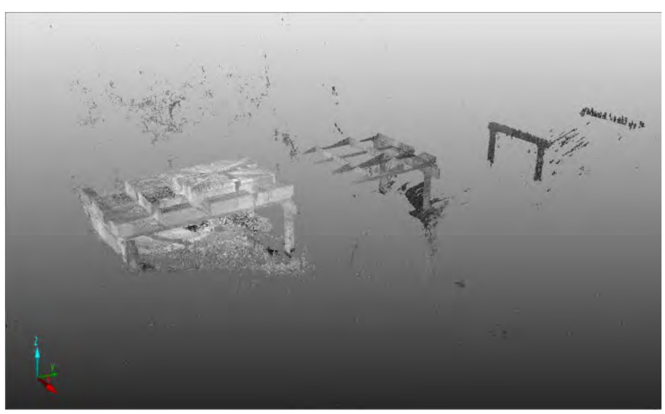
Physical Information

Bridge Type:	
Concrete Tee Beam	

Geographic Location

Latitude:	Longitude:
33.35313	-86.52643

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	002380	5/18/2010	3/3/10

Bridge Information

State: Alabama	Authoritative Agency: County Highway Agency
Featured Intersection: HWY. 52 over Cahaba River	Year Constructed/Reconstructed: 1940/-
Sufficiency Rating: 52	Structurally Deficient or Functionally Obsolete?: FO

Physical Information

Bridge Type: Steel Continuous Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
33.28464	-86.88268

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	003267	5/18/2010	3/4/10

Bridge Information

State: Alabama	Authoritative Agency: County Highway Agency
Featured Intersection: HWY. 52 over Buck Creek	Year Constructed/Reconstructed: 1948/-
Sufficiency Rating: 42	Structurally Deficient or Functionally Obsolete?: FO

Physical Information

Bridge Type: Concrete Strigner/Multiple Beam/Girder	

Geographic Location

Latitude:	Longitude:
33.27881	-86.79644

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	005369	5/19/2010	3/5/10

Bridge Information

State:	Authoritative Agency:
Alabama	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
CO. HWY. 441 over FOURMILE CREEK	1955/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
26.9	FO

Physical Information

Bridge Type:
Timber Stringer/multi-beam girder

Geographic Location

Latitude:	Longitude:
33.2597	-86.46764

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	005480	5/18/2010	3/6/10

Bridge Information

State: Alabama	Authoritative Agency: County Highway Agency
Featured Intersection: US 43 over Branch	Year Constructed/Reconstructed: 1956/-
Sufficiency Rating: 67	Structurally Deficient or Functionally Obsolete?: -

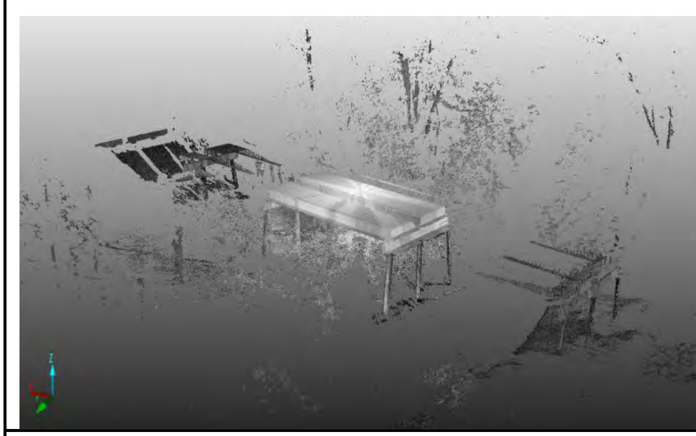
Physical Information

Bridge Type: Concrete Culvert	

Geographic Location

Latitude:	Longitude:
34.50796	-87.71727

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	006952	5/18/2010	3/7/10

Bridge Information

State:	Authoritative Agency:
Alabama	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Dry Creek	1960/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
39.3	FO

Physical Information

Bridge Type:	
Concrete Strigner/Multiple Beam/Girder	

Geographic Location

Latitude:	Longitude:
33.10496	-86.83832

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	007390	5/18/2010	3/8/10

Bridge Information

State:	Authoritative Agency:
Alabama	County Highway Agency
Featured Intersection:	**Year Constructed/Reconstructed:**
Cahaba River	1961/-
Sufficiency Rating:	**Structurally Deficient or Functionally Obsolete?:**
61	FO

Physical Information

Bridge Type:
Steel Continuous Stringer/multi-beam girder

Geographic Location

Latitude:	Longitude:
33.41562	-86.7403

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	010357	5/19/2010	2/28/10

Bridge Information

State:	Authoritative Agency:
Alabama	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
HWY. 55 over RR	1970/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
38.9	FO

Physical Information

Bridge Type:	
Steel Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
33.34763	-86.53644

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	011015	5/18/2010	3/1/10

Bridge Information

State:	Authoritative Agency:
Alabama	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Buck Creek	1973/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
50.2	FO

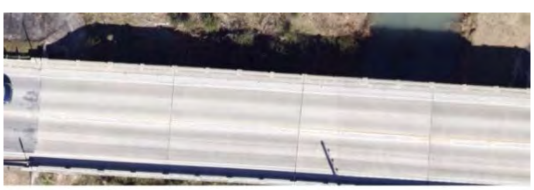
Physical Information

Bridge Type:	
Concrete Strigner/Multiple Beam/Girder	

Geographic Location

Latitude:	Longitude:
33.22379	-86.82984

Visualization Assistance:



Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C0431	3/5/2011	7/8/10

Bridge Information

State:	Authoritative Agency:
California	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Puente Creek	1956/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
86.8	-

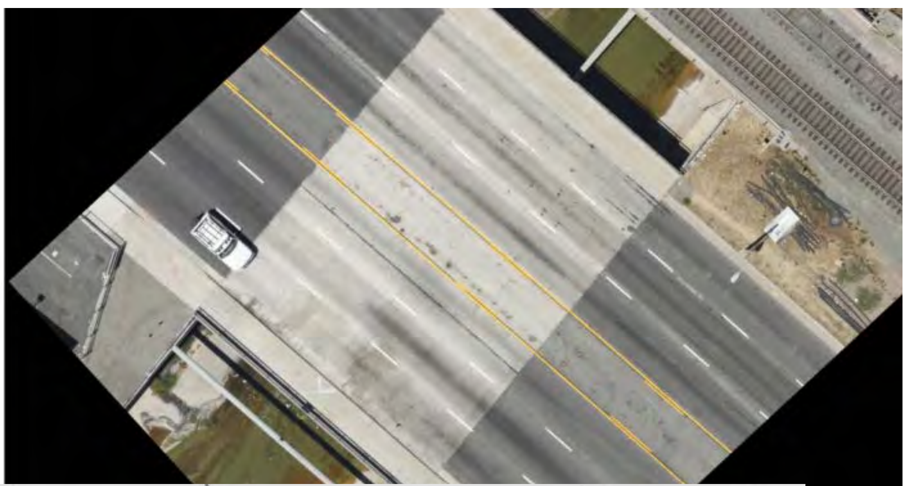
Physical Information

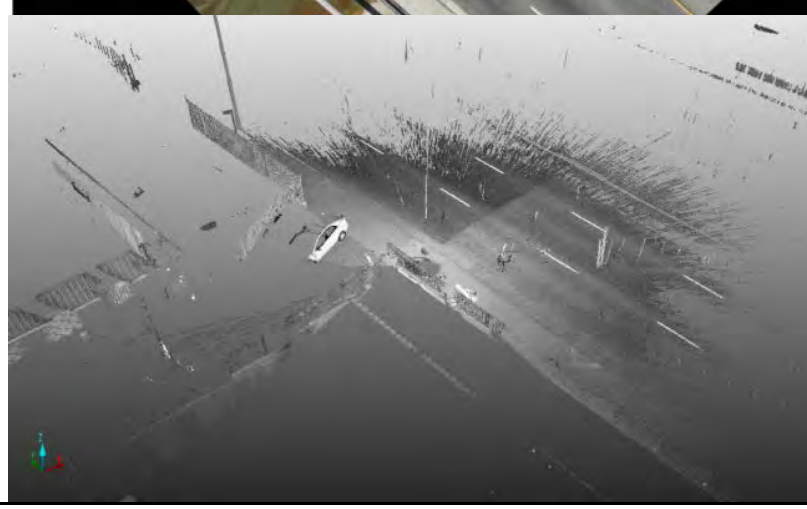
Bridge Type:	
Concrete Slab	

Geographic Location

Latitude:	Longitude:
34.03	-117.96833

Visualization Assistance:





Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C0470	3/4/2011	7/8/10

Bridge Information

State: California	Authoritative Agency: County Highway Agency
Featured Intersection: Leffingwell Cr.	Year Constructed/Reconstructed: 1963/-
Sufficiency Rating: 95.6	Structurally Deficient or Functionally Obsolete?: -

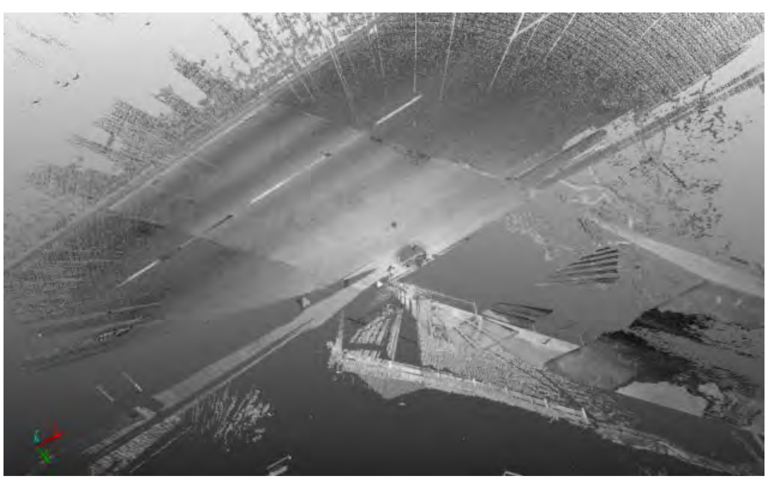
Physical Information

Bridge Type: Concrete Slab	

Geographic Location

Latitude:	Longitude:
33.93667	-118.01

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C0602	3/4/2011	7/8/10

Bridge Information

State: California	Authoritative Agency: County Highway Agency
Featured Intersection: Ballona Cr.	Year Constructed/Reconstructed: 1937/-
Sufficiency Rating: 61	Structurally Deficient or Functionally Obsolete?: SD

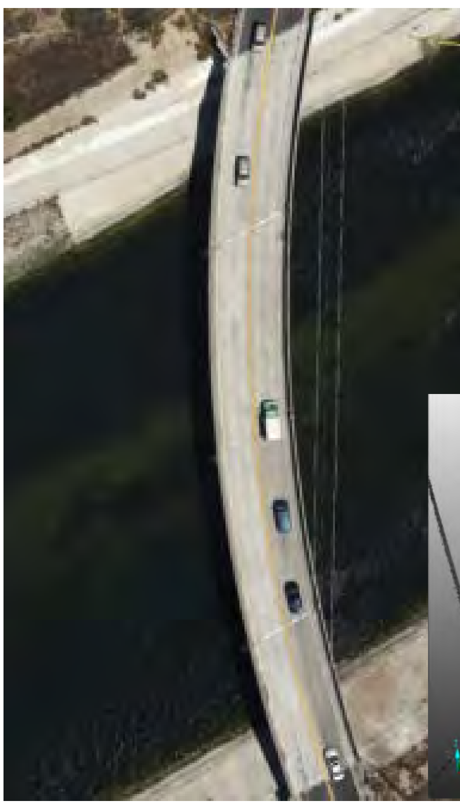
Physical Information

Bridge Type:
Steel Stringer/multi-beam girder

Geographic Location

Latitude:	Longitude:
33.975	-118.43333

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C0617	3/4/2011	7/8/10

Bridge Information

State: California	Authoritative Agency: County Highway Agency
Featured Intersection: San Gabriel River at Peck Road	Year Constructed/Reconstructed: 1952/-
Sufficiency Rating: 70.8	Structurally Deficient or Functionally Obsolete?: FO

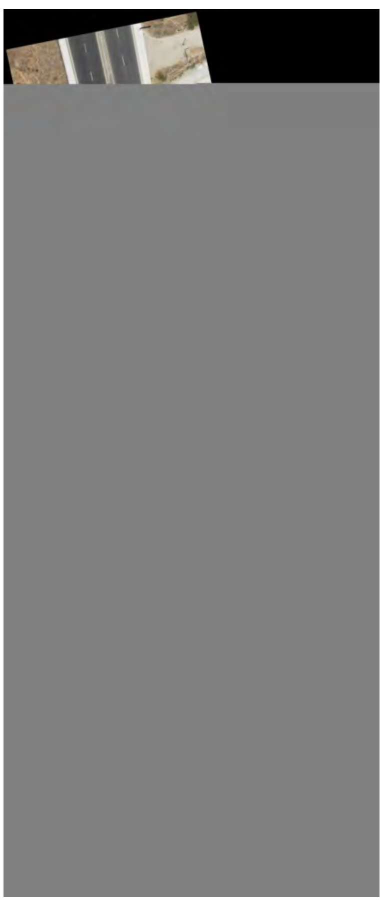
Physical Information

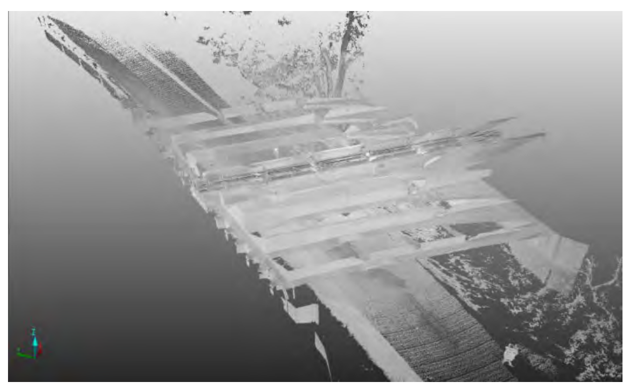
Bridge Type: Concrete Tee	

Geographic Location

Latitude:	Longitude:
34.03333	-118.03667

Visualization Assistance:





BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C0620	3/4/2011	7/8/10

Bridge Information

State: California	Authoritative Agency: County Highway Agency
Featured Intersection: Malibu Creek	Year Constructed/Reconstructed: 1953/-
Sufficiency Rating: 60	Structurally Deficient or Functionally Obsolete?: SD

Physical Information

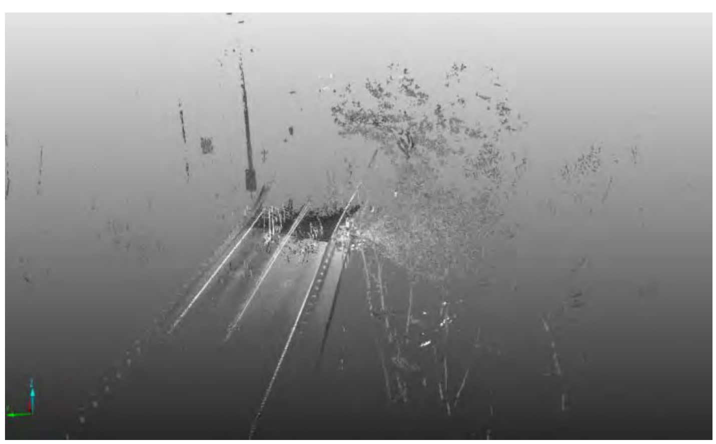
Bridge Type: Concrete Tee	

Geographic Location

Latitude:	Longitude:
34.08167	-118.70333

Visualization

Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C0625	3/4/2011	7/8/10

Bridge Information

State:	Authoritative Agency:
California	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Compton Cr.	1953/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
95	-

Physical Information

Bridge Type:	
Steel Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
33.92333	-118.25167

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C0642	3/3/2011	7/8/10

Bridge Information

State: California	Authoritative Agency: County Highway Agency
Featured Intersection: Angeles Forest Hwy. OH SP	Year Constructed/Reconstructed: 1961/-
Sufficiency Rating: 80.5	Structurally Deficient or Functionally Obsolete?: SD

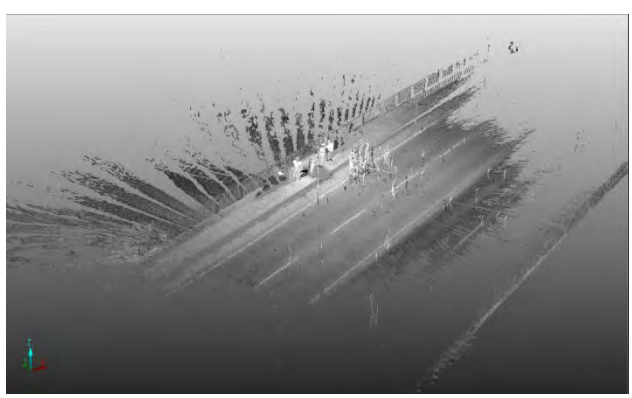
Physical Information

Bridge Type: Steel Stringer/multi-beam girder

Geographic Location

Latitude:	Longitude:
34.50833	-118.11

Visualization Assistance:



Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C0775	3/4/2011	7/8/10

Bridge Information

State: California	*Authoritative Agency:* County Highway Agency
Featured Intersection: Triunfo Cr.	*Year Constructed/Reconstructed:* 1962/1994
Sufficiency Rating: 93.6	*Structurally Deficient or Functionally Obsolete?:* -

Physical Information

Bridge Type: Concrete Tee

Geographic Location

Latitude:	*Longitude:*
34.11833	-118.78

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C0825	3/4/2011	7/8/10

Bridge Information

State: California	Authoritative Agency: County Highway Agency
Featured Intersection: Vermont Avenue OH RR	Year Constructed/Reconstructed: 1970/-
Sufficiency Rating: 81.6	Structurally Deficient or Functionally Obsolete?: FO

Physical Information

Bridge Type:	
Prestressed String/multi-beam girder	

Geographic Location

Latitude:	Longitude:
33.805	-118.29

Visualization Assistance:

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C0981	3/3/2011	7/8/10

Bridge Information

State:	Authoritative Agency:
California	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
OLD TOPANGA CREEK	1937/1963
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
67.5	-

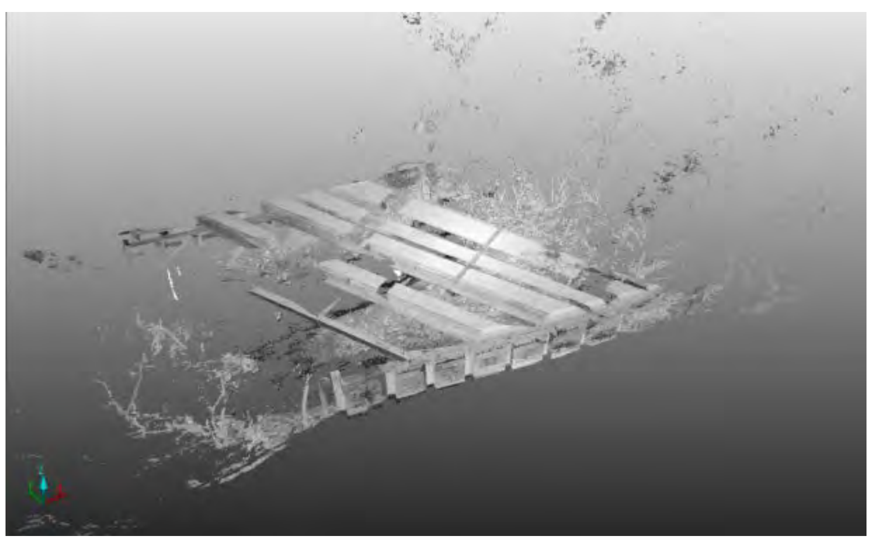
Physical Information

Bridge Type:	
Steel Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
34.09333	-118.60667

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C1008	3/5/2011	7/8/10

Bridge Information

State: California	Authoritative Agency: Municipal Highway
Featured Intersection: PUENTE CREEK	Year Constructed/Reconstructed: 1953/1994
Sufficiency Rating: -	Structurally Deficient or Functionally Obsolete?: -

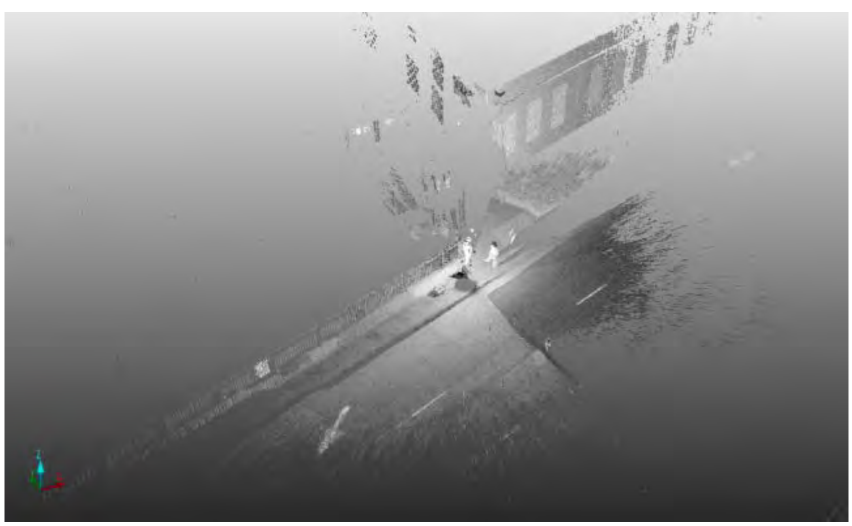
Physical Information

Bridge Type: Continuous Concrete Slab

Geographic Location

Latitude:	Longitude:
34.028333	-117.971667

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	53C1527	3/3/2011	7/8/10

Bridge Information

State: California	Authoritative Agency: County Highway Agency
Featured Intersection: Marek Canyon Wash	Year Constructed/Reconstructed: 1970/-
Sufficiency Rating: 88.8	Structurally Deficient or Functionally Obsolete?: -

Physical Information

Bridge Type: Concrete Slab	

Geographic Location

Latitude:	Longitude:
34.29333	-118.36

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	110026	-	6/1/2010

Bridge Information

State:	Authoritative Agency:
Florida	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Little Lake Harris	1950/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
74.9	-

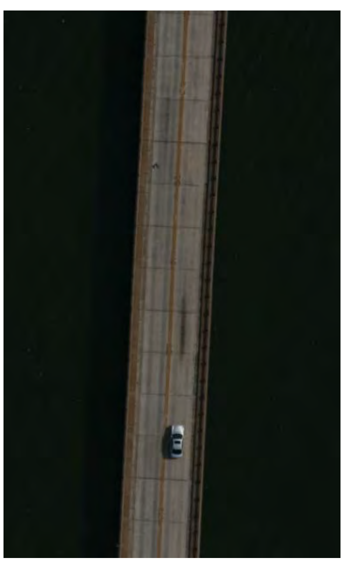
Physical Information

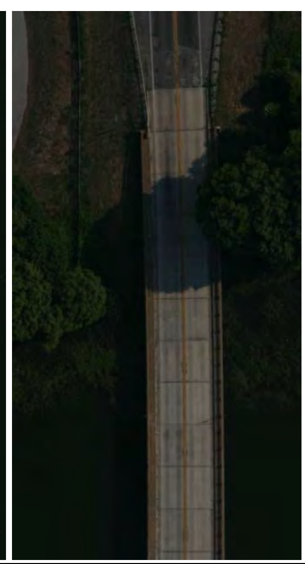
Bridge Type:	
Steel Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
28.73556	-81.76861

Visualization Assistance:





BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	790172	-	6/1/2010

Bridge Information

State:	Authoritative Agency:
Florida	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
IWW Indian River	1997/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
90.3	FO

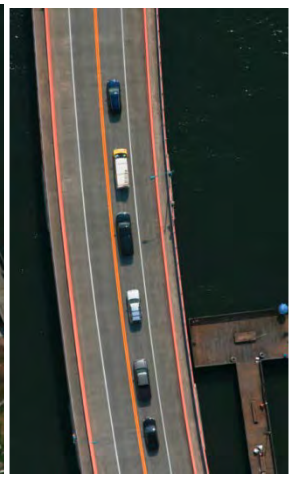
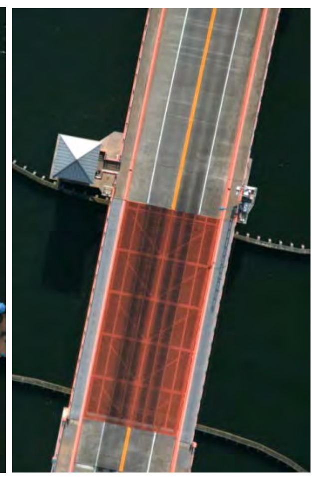
Physical Information

Bridge Type:	
Steel Movable Bascule	

Geographic Location

Latitude:	Longitude:
29.038611	-80.908333

Visualization Assistance:


Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	790196	-	6/1/2010

Bridge Information

State: Florida	Authoritative Agency: State Highway Agency
Featured Intersection: US-17-92 St. Johns River	Year Constructed/Reconstructed: 2002/-
Sufficiency Rating: 93	Structurally Deficient or Functionally Obsolete?: -

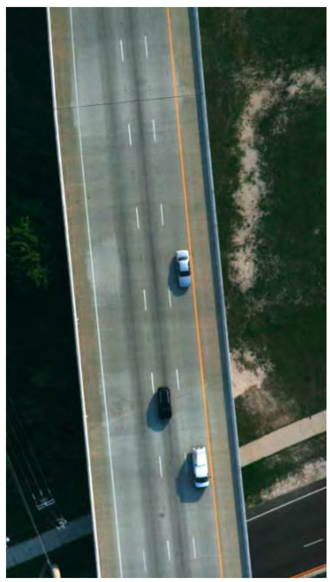
Physical Information

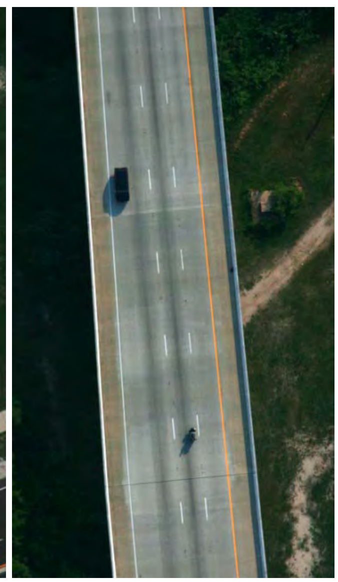
Bridge Type: Prestressed Concrete - Stringer/Multiple Beam/Girder	

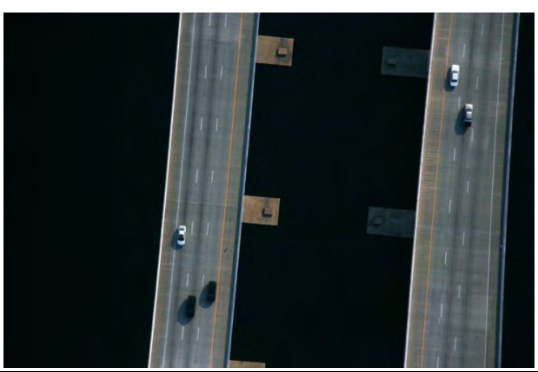
Geographic Location

Latitude:	Longitude:
28.83333	-81.32333

Visualization Assistance:







BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	790197	-	6/1/2010

Bridge Information

State:	Authoritative Agency:
Florida	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
US-17-92 St. Johns River	2003/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
93	-

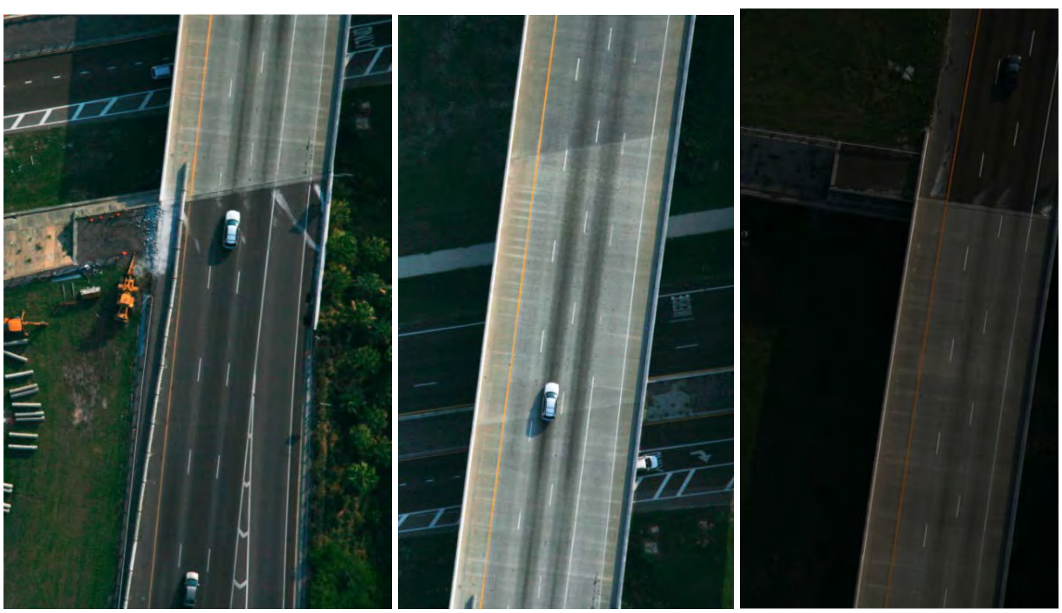
Physical Information

Bridge Type:	
Prestressed Concrete - Stringer/Multiple Beam/Girder	

Geographic Location

Latitude:	Longitude:
28.8325	-81.32139

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	924038	-	5/1/2010

Bridge Information

State: Florida	Authoritative Agency: County Highway Agency
Featured Intersection: Partin Canal	Year Constructed/Reconstructed: 1973/-
Sufficiency Rating: 64.9	Structurally Deficient or Functionally Obsolete?: FO

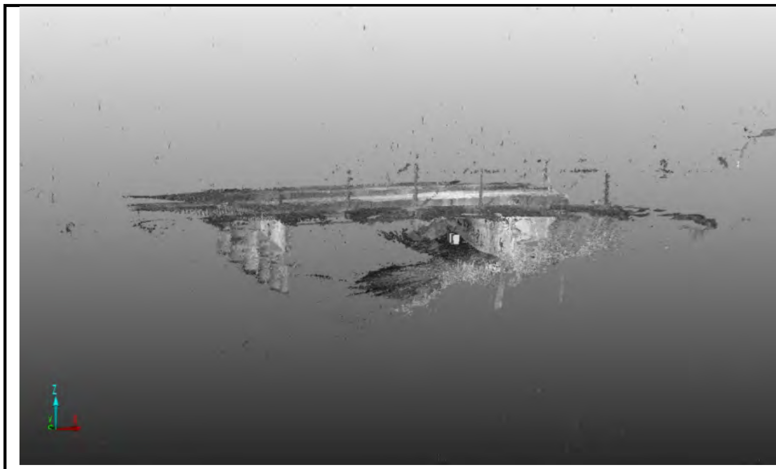
Physical Information

Bridge Type: Steel Stringer/multi-beam girder

Geographic Location

Latitude:	Longitude:
28.27917	-81.375

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	924046	-	5/1/2010

Bridge Information

State:	Authoritative Agency:
Florida	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Pennywash Creek	1956/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
82	-

Physical Information

Bridge Type:	
Concrete Slab	

Geographic Location

Latitude:	Longitude:
28.18194	-80.89528

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	924049	-	5/1/2010

Bridge Information

State:	Authoritative Agency:
Florida	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
St. Cloud Canal C-31	1957/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
53.4	FO

Physical Information

Bridge Type:	
Concrete Slab	

Geographic Location

Latitude:	Longitude:
28.25389	-81.32694

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	924145	-	unrecorded

Bridge Information

State: Florida	Authoritative Agency: County Highway Agency
Featured Intersection: Shingle Creek Trib.	Year Constructed/Reconstructed: 1983/-
Sufficiency Rating: 98.1	Structurally Deficient or Functionally Obsolete?: -

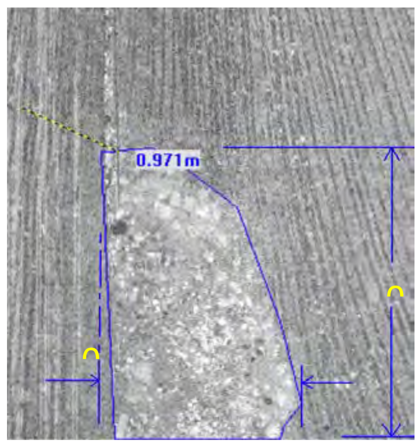
Physical Information

Bridge Type: Prestressed Concret Slab	

Geographic Location

Latitude:	Longitude:
28.26694	-81.44833

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	924150	-	5/1/2010

Bridge Information

State:	Authoritative Agency:
Florida	County Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
canal	1981/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
85.3	-

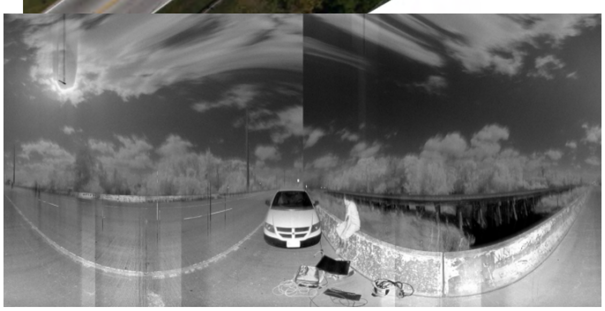
Physical Information

Bridge Type:	
Prestressed Concrete Slab	

Geographic Location

Latitude:	Longitude:
28.27389	-81.47556

Visualization Assistance:



Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	003826	12/21/2010	10/24/10

Bridge Information

State: Iowa	Authoritative Agency: State Highway Agency
Featured Intersection: -	Year Constructed/Reconstructed: 1969/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?: -

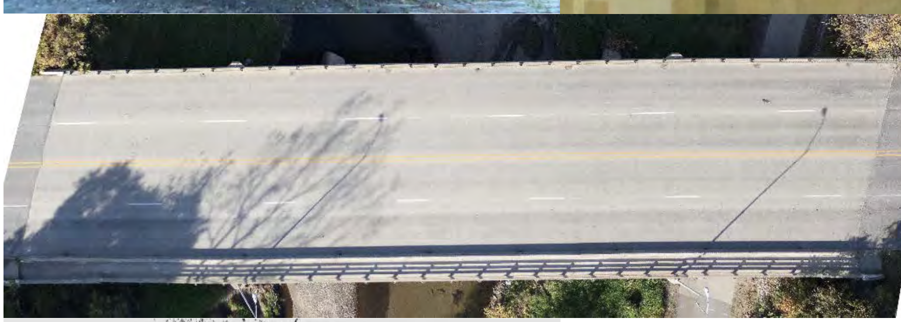
Physical Information

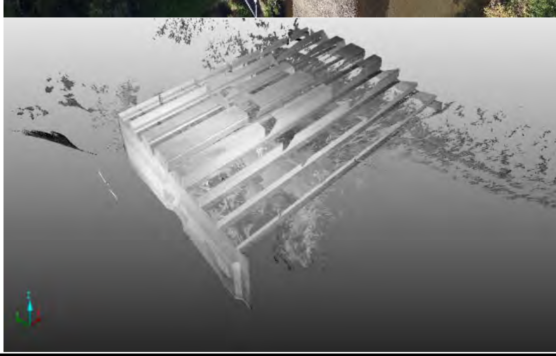
Bridge Type: Prestressed Concrete Stringer/Multi Beam Girder

Geographic Location

Latitude:	Longitude:
41.986111	-94.175

Visualization Assistance:





Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	012491	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
W University over I-35 and I-80	2004/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
85	-

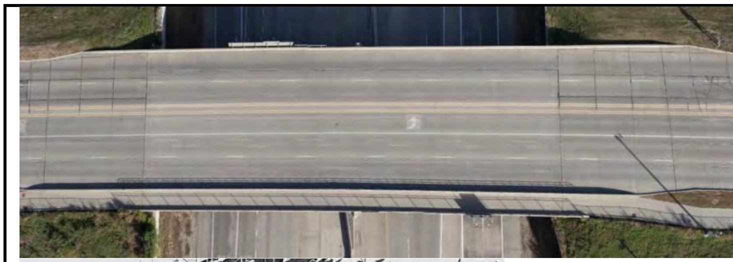
Physical Information

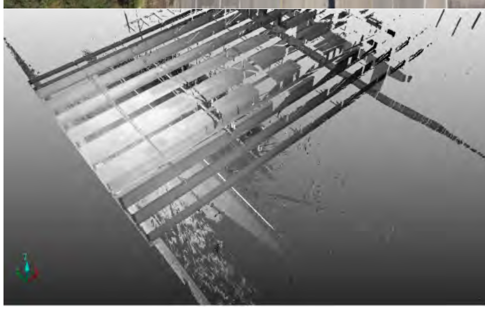
Bridge Type:	
Steel Continuous Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
42	-94.302778

Visualization Assistance:





Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	040390	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
W University over I-35 and I-80	1969/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
78.2	-

Physical Information

Bridge Type:	
Concrete Continuous Slab	

Geographic Location

Latitude:	Longitude:
42.030556	-94.219444

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	040510	10/20/2010	10/24/10

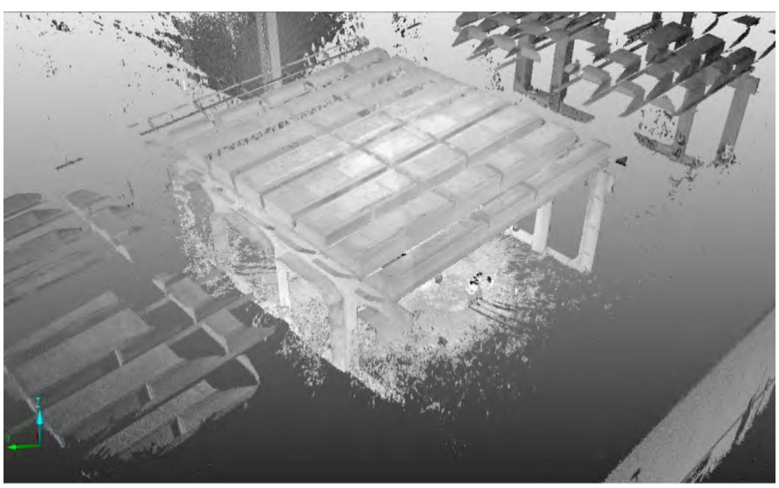
Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
US 69 over RR Yard and Scott Ave.	1937/1973
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
52	SD/FO

Physical Information

Bridge Type:	
Steel Continuous Stringer/multi-beam girder	
Geographic Location	
Latitude:	Longitude:
41.980556	-94.002778

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	041300	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
NB-I35/EB-I80 over US 6	1958/1989
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
86	-

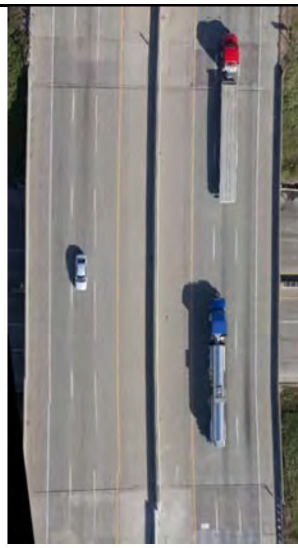
Physical Information

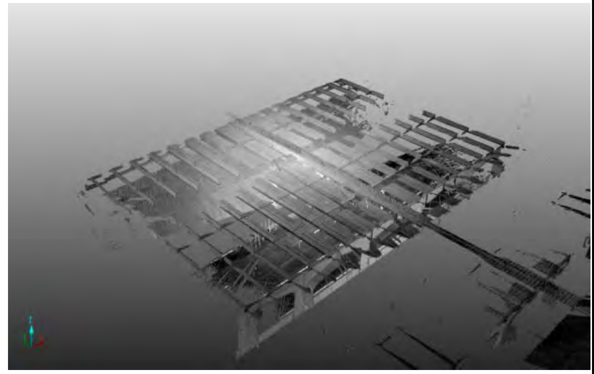
Bridge Type:	
Steel Continuous Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
41.614967	-93.776708

Visualization Assistance:





BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	041310	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
NB-I35/EB-I80 over US 6	1958/1989
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
85	-

Physical Information

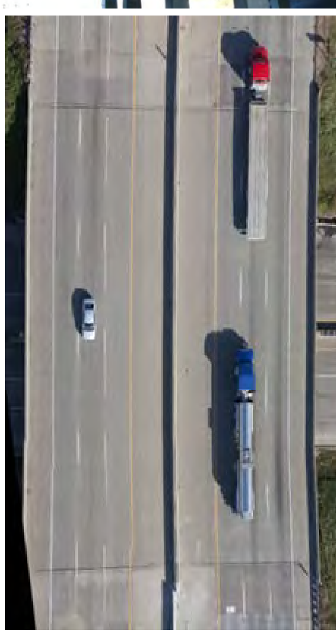
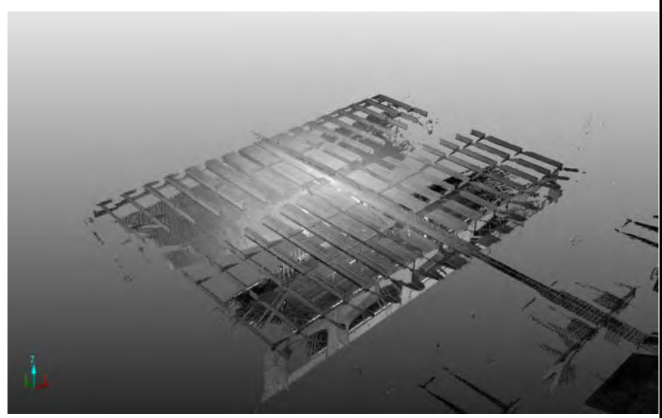
Bridge Type:	
Steel Continuous Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
41.614967	-93.77695

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	042300	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
EB I-235 over Cummins Parkway	1967/1986
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
90	FO

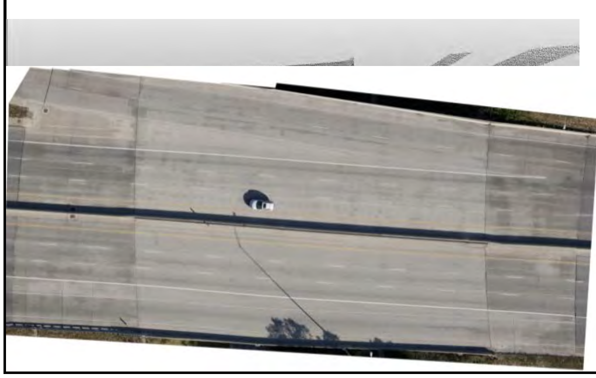
Physical Information

Bridge Type:	
Concrete Continuous Slab	

Geographic Location

Latitude:	Longitude:
41.592811	-93.699658

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	042310	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
WB I-235 over Cummins Parkway	1967/2005
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
92	-

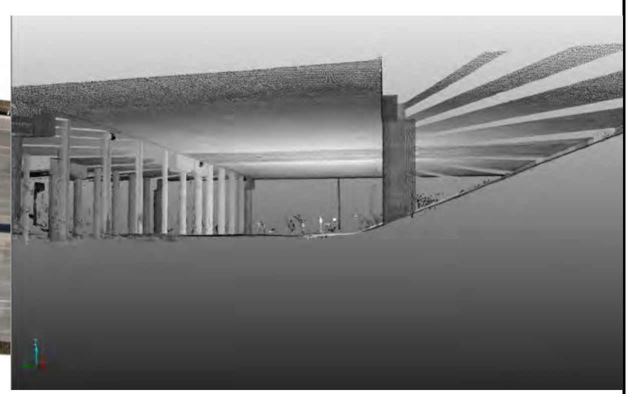
Physical Information

Bridge Type:
Concrete Continuous Slab

Geographic Location

Latitude:	Longitude:
41.592972	-93.699678

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	042381	10/21/2010	10/24/10

Bridge Information

State: Iowa	Authoritative Agency: State Highway Agency
Featured Intersection: EB I-235 over 35th Street	Year Constructed/Reconstructed: 2004/-
Sufficiency Rating: 93	Structurally Deficient or Functionally Obsolete?: -

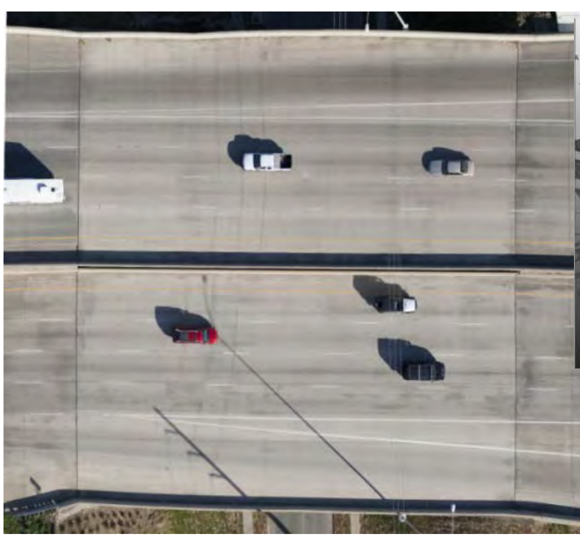
Physical Information

Bridge Type:	Prestressed Concrete Stringer/Multi Beam Girder

Geographic Location

Latitude:	Longitude:
41.991667	-94.111111

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	042391	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
EB I-235 over 35th Street	2005/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
100	-

Physical Information

Bridge Type:	
Prestressed Concrete Stringer/Multi Beam Girder	

Geographic Location

Latitude:	Longitude:
41.991667	-94.111111

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	042401	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
31st Street over I-235	2005/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
82	-

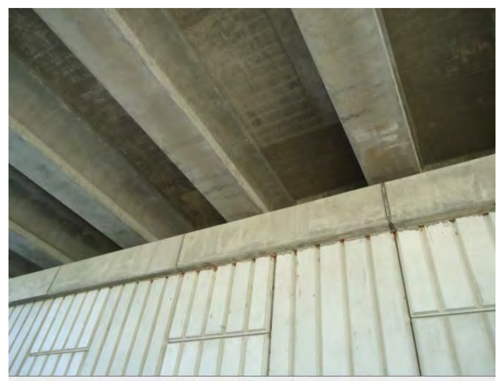
Physical Information

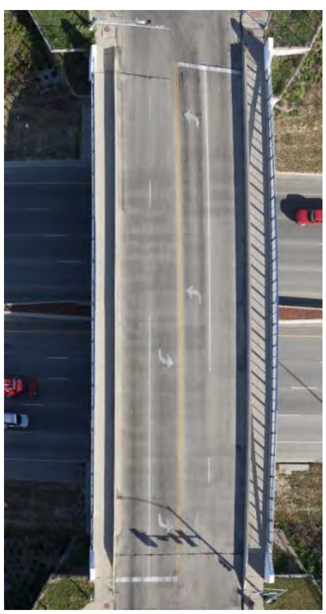
Bridge Type:	
Prestressed Concrete Stringer/Multi Beam Girder	

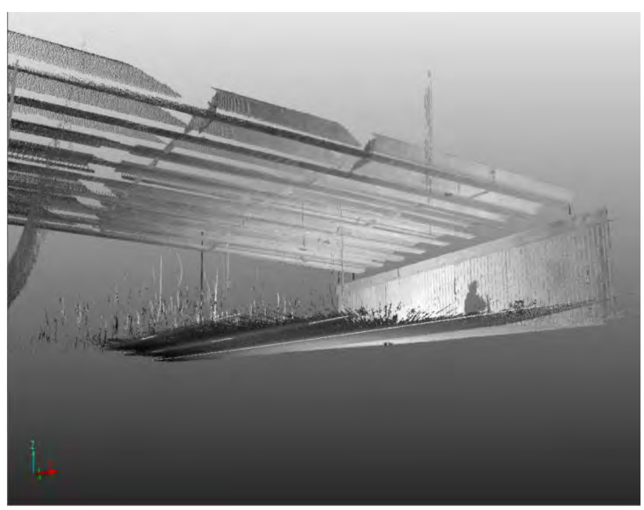
Geographic Location

Latitude:	Longitude:
41.991667	-94.108333

Visualization Assistance:







BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	042761	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
2nd Ave EB Ramp over West River Drive	2003/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
95	FO

Physical Information

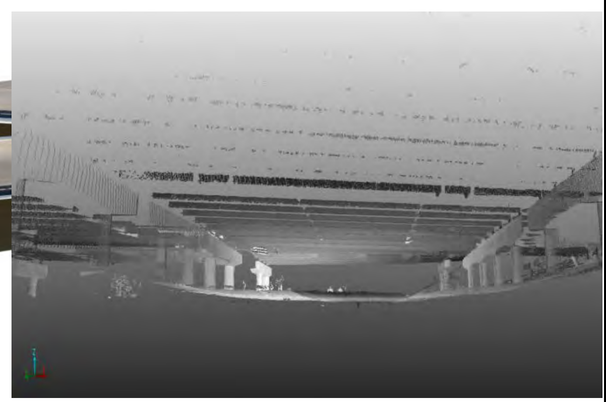
Bridge Type:
Steel Continuous Stringer/multi-beam girder

Geographic Location

Latitude:	Longitude:
41.594444	-93.619444

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	504480	10/21/2010	10/24/10

Bridge Information

State: Iowa	Authoritative Agency: City or Municipal Highway Agency
Featured Intersection: Westown Parkway over I-80/I-35	Year Constructed/Reconstructed: 1997/-
Sufficiency Rating: 94	Structurally Deficient or Functionally Obsolete?: -

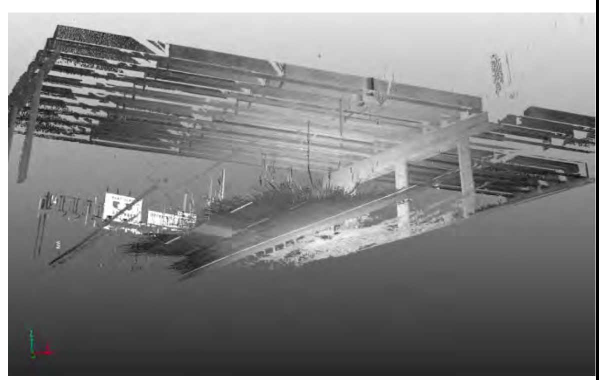
Physical Information

Bridge Type: Prestressed Concrete Stringer/Multi Beam Girder

Geographic Location

Latitude: 41.997222	Longitude: -94.3

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	605405	10/21/2010	10/24/10

Bridge Information

State: Iowa	Authoritative Agency: State Highway Agency
Featured Intersection: NB Ramp to Univ over Ramp H	Year Constructed/Reconstructed: 1984/-
Sufficiency Rating: 88	Structurally Deficient or Functionally Obsolete?: -

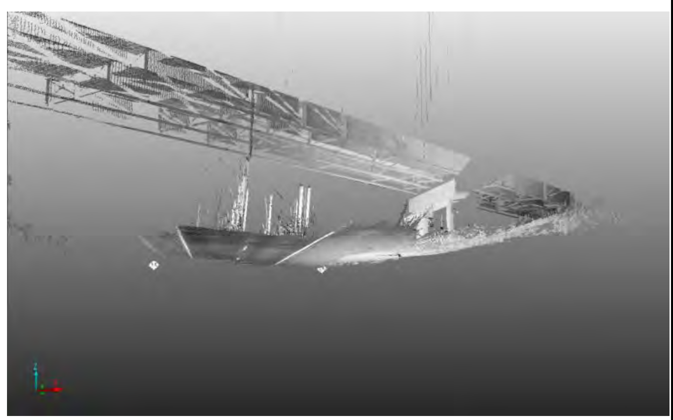
Physical Information

Bridge Type: Steel Continuous Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
42.005556	-94.3

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	608345	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
SW Connector over IA 5	2002/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
96	-

Physical Information

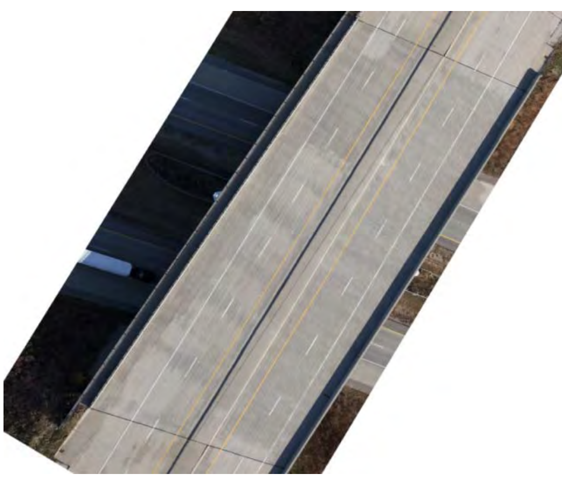
Bridge Type:	
Prestressed Concrete Tee Beam	

Geographic Location

Latitude:	Longitude:
41.869444	-94.202778

Visualization Assistance:






BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	608575	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
South 42nd Street	2002/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
96	FO

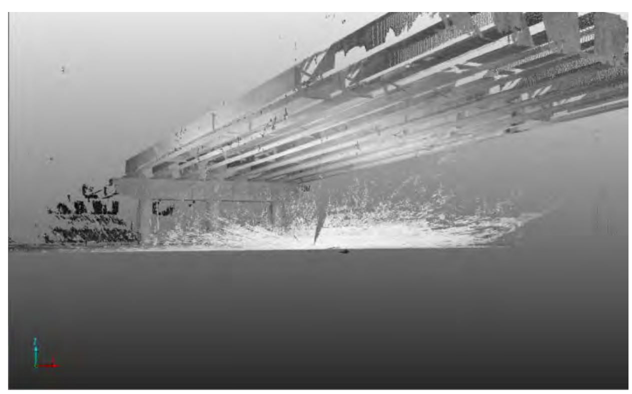
Physical Information

Bridge Type:	
Prestressed Concrete Stringer/Multi Beam Girder	

Geographic Location

Latitude:	Longitude:
41.875	-94.269444

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	608580	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
22nd Street	2002/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
93	FO

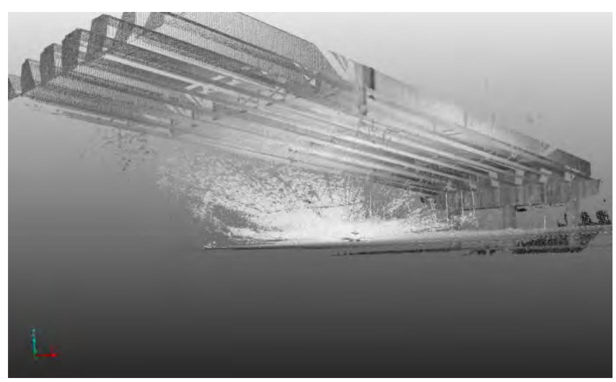
Physical Information

Bridge Type:	
Prestressed Concrete Stringer/Multi Beam Girder	

Geographic Location

Latitude:	Longitude:
41.872222	-94.236111

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	608660	10/21/2010	10/24/10

Bridge Information

State: Iowa	Authoritative Agency: State Highway Agency
Featured Intersection: IA 5 SB/EB over 8th Street	Year Constructed/Reconstructed: 2002/-
Sufficiency Rating: 88	Structurally Deficient or Functionally Obsolete?: FO

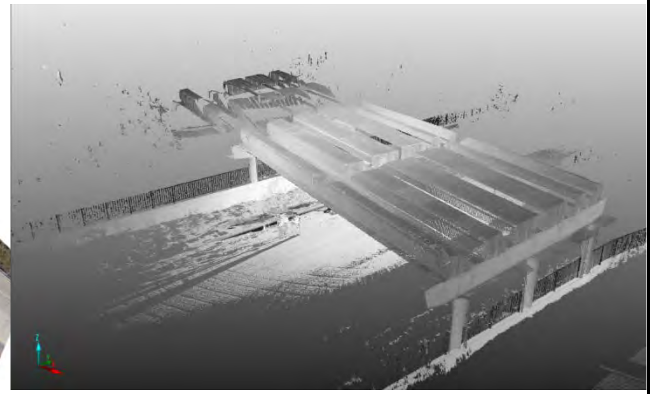
Physical Information

Bridge Type: Prestressed Concrete Tee Beam	

Geographic Location

Latitude:	Longitude:
41.863889	-94.191667

Visualization Assistance:



Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	608665	10/21/2010	10/24/10

Bridge Information

State:	Authoritative Agency:
Iowa	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
IA 5 SB/EB over 8th Street	2002/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
96	-

Physical Information

Bridge Type:	
Prestressed Concrete Tee Beam	

Geographic Location

Latitude:	Longitude:
41.863889	-94.188889

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1005220	10/11/2010	10/8/10

Bridge Information

State: New York	Authoritative Agency: State Highway Agency
Featured Intersection: Wappinger Lake	Year Constructed/Reconstructed: 1990/-
Sufficiency Rating: 96	Structurally Deficient or Functionally Obsolete?: -

Physical Information

Bridge Type:	Prestressed Concrete Box Beam

Geographic Location

Latitude:	Longitude:
41.608172	-73.911428

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1006370	10/11/2010	10/8/10

Bridge Information

State:	Authoritative Agency:
New York	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Hunter Creek	1984/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
84.9	-

Physical Information

Bridge Type:	
Prestressed Concrete Slab	

Geographic Location

Latitude:	Longitude:
41.585356	-73.922408

Visualization Assistance:

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1007140	10/9/2010	10/8/10

Bridge Information

State: New York	Authoritative Agency: State Highway Agency
Featured Intersection: Cedar Pond	Year Constructed/Reconstructed: 1922/2009
Sufficiency Rating: 71.1	Structurally Deficient or Functionally Obsolete?: -

Physical Information

Bridge Type: Steel Continuous Stringer/multi-beam girder

Geographic Location

Latitude:	Longitude:
41.22806	-73.98722

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1007150	10/9/2010	10/8/10

Bridge Information

State:	Authoritative Agency:
New York	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
9W over Popolopen Creek	1937/1992
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
-	-

Physical Information

Bridge Type:	
Steel Truss Deck	

Geographic Location

Latitude:	Longitude:
41.323656	-73.989786

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1007260	10/10/2010	10/8/10

Bridge Information

State: New York	Authoritative Agency: State Highway Agency
Featured Intersection: Moodna Creek	Year Constructed/Reconstructed: 1932/1983
Sufficiency Rating: 55.1	Structurally Deficient or Functionally Obsolete?: FO

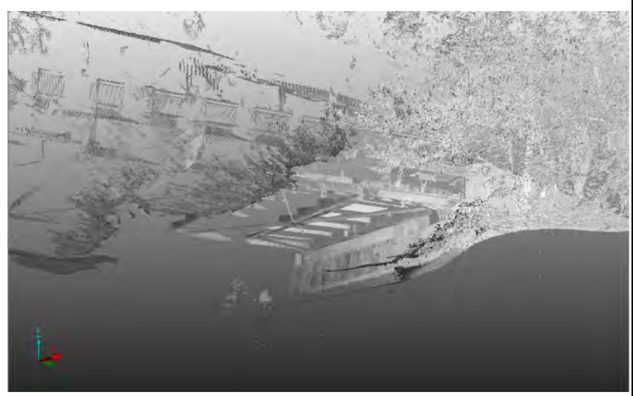
Physical Information

Bridge Type: Steel Truss Though	

Geographic Location

Latitude:	Longitude:
41.45889	-74.02361

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1013960	-	10/8/10

Bridge Information

State:	Authoritative Agency:
New York	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
MNRR PJ Line	1949/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
81.9	-

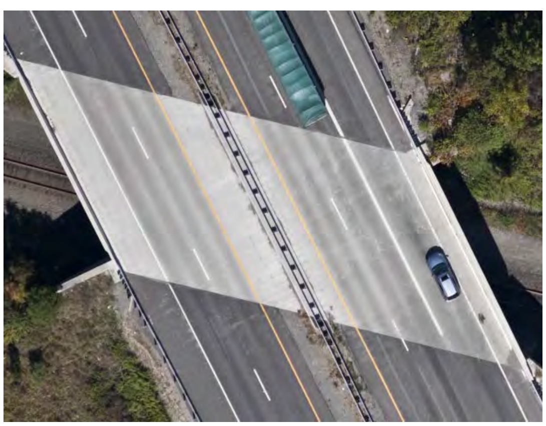
Physical Information

Bridge Type:	
Concrete Frame	

Geographic Location

Latitude:	Longitude:
41.457525	-74.3759

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1014090	10/10/2010	10/8/10

Bridge Information

State: New York	Authoritative Agency: State Highway Agency
Featured Intersection: Wawayanda Creek	Year Constructed/Reconstructed: -/1981
Sufficiency Rating: 95.3	Structurally Deficient or Functionally Obsolete?: -

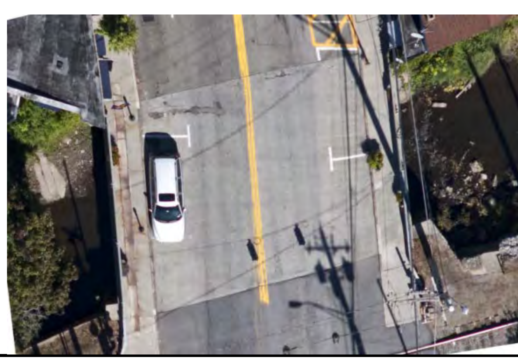
Physical Information

Bridge Type: Prestressed Concrete Box Beam	

Geographic Location

Latitude:	Longitude:
41.256244	-74.360214

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1022310	-	10/8/10

Bridge Information

State:	Authoritative Agency:
New York	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Rondout Creek	1934/2009
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
59.3	-

Physical Information

Bridge Type:	
Steel Truss Though	

Geographic Location

Latitude:	Longitude:
41.84583	-74.07417

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1026680	-	10/8/10

Bridge Information

State:	Authoritative Agency:
New York	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Wallkill River	1934/2004
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
80	-

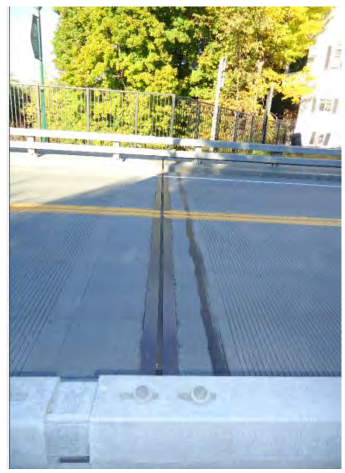
Physical Information

Bridge Type:	
Concrete Arch Deck	

Geographic Location

Latitude:	Longitude:
41.56111	-74.19389

Visualization Assistance:



Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1027090	10/10/2010	10/8/10

Bridge Information

State:	Authoritative Agency:
New York	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Rondout Creek	1929/1984
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
55.6	FO

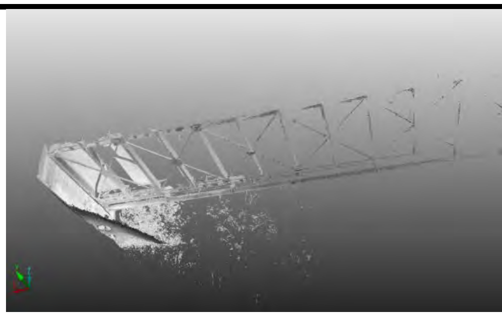
Physical Information

Bridge Type:	
Pony Truss Steel	

Geographic Location

Latitude:	Longitude:
41.75722	-74.38083

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1034880	10/10/2010	10/8/10

Bridge Information

State:	Authoritative Agency:
New York	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Highway 94 over Creek	1976/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
-	-

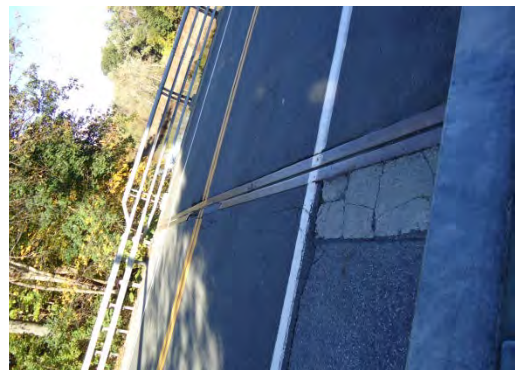
Physical Information

Bridge Type:	
Prestressed Concrete Box Beam	

Geographic Location

Latitude:	Longitude:
41.419553	-74.175142

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1044659	10/9/2010	10/8/10

Bridge Information

State:	Authoritative Agency:
New York	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Bronx River M.	1999/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
-	-

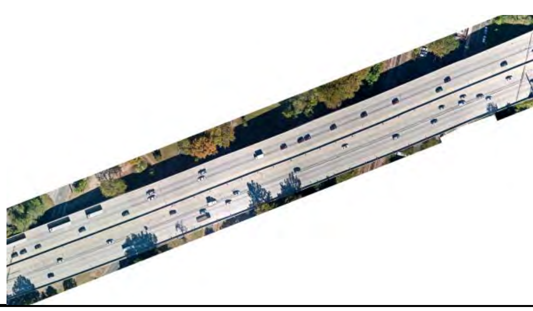
Physical Information

Bridge Type:	
Steel Continuous Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
41.044033	-73.775603

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1052842	10/11/2010	10/8/10

Bridge Information

State: New York	Authoritative Agency: State Highway Agency
Featured Intersection: Croton River	Year Constructed/Reconstructed: 1970/-
Sufficiency Rating: -	Structurally Deficient or Functionally Obsolete?: -

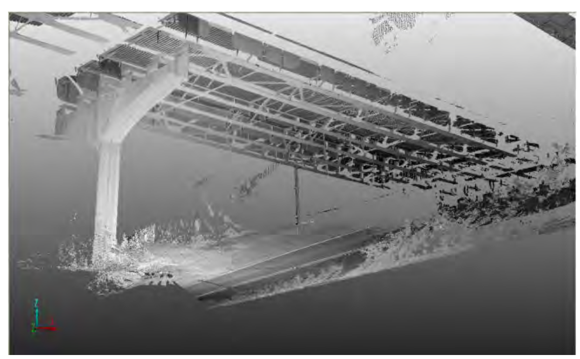
Physical Information

Bridge Type: Steel Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
41.398183	-73.600764

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1069749	10/10/2010	10/8/10

Bridge Information

State:	Authoritative Agency:
New York	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
FERRY STREET, RONDOUT CR	1997/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
-	-

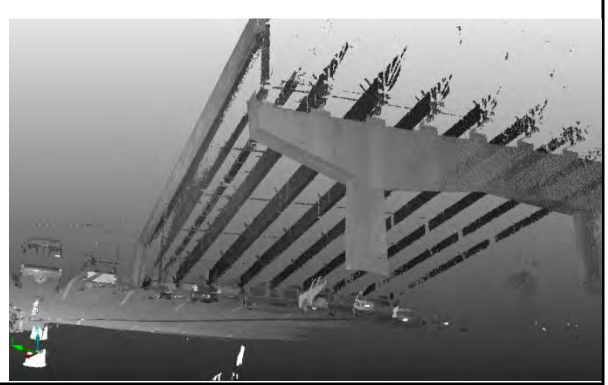
Physical Information

Bridge Type:	
Continuous Steel Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
41.918003	-73.981489

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1070139	10/11/2010	10/8/10

Bridge Information

State:	Authoritative Agency:
New York	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
EX-NY NH & H RR	1979/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
-	-

Physical Information

Bridge Type:	
Prestressed Concrete Continuous Slab	

Geographic Location

Latitude:	Longitude:
41.697572	-73.8856

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590038	2/7/2009	Unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: Greasy Creek	Year Constructed/Reconstructed: 1945/-
Sufficiency Rating: 29.8	Structurally Deficient or Functionally Obsolete?: SD/FO

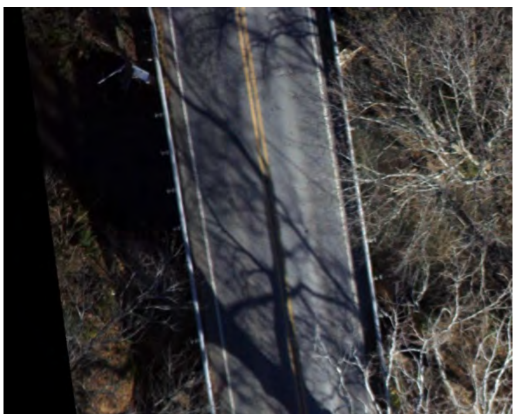
Physical Information

Bridge Type: Steel Stringer/Multi-beam or Girder

Geographic Location

Latitude:	Longitude:
35.22442	-80.86553

Visualization Assistance:




BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590049	2/12/2009	Unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: Little Sugar Creek	Year Constructed/Reconstructed: 1926/1961
Sufficiency Rating: 47.5	Structurally Deficient or Functionally Obsolete?: FO

Physical Information

Bridge Type: Concrete Tee Beam

Geographic Location

Latitude:	Longitude:
35.07933	-80.88522

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590059	2/6/2009	unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: Reedy Creek	Year Constructed/Reconstructed: 1976/-
Sufficiency Rating: 11.5	Structurally Deficient or Functionally Obsolete?: SD

Physical Information

Bridge Type: Steel Stringer/Multi-beam or Girder

Geographic Location

Latitude:	Longitude:
35.25128	-80.68953

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590084	2/28/2007	unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: Mallard Creek	Year Constructed/Reconstructed: 2004/-
Sufficiency Rating: 79.8	Structurally Deficient or Functionally Obsolete?: FO

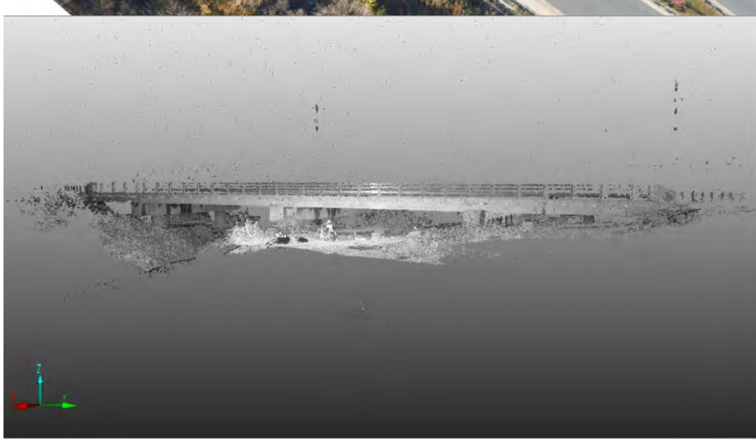
Physical Information

Bridge Type: Prestressed Concrete Slab

Geographic Location

Latitude:	Longitude:
35.32222	-80.73167

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590108	2/12/2009	Unrecorded

Bridge Information

State:	Authoritative Agency:
North Carolina	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Southern Railroad	2005/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
100	-

Physical Information

Bridge Type:

Steel Stringer/Multi-beam or Girder

Geographic Location

Latitude:	Longitude:
35.23742	-80.83742

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590161	3/9/2009	Unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: Backwater Catawba	Year Constructed/Reconstructed: 1961/-
Sufficiency Rating: 62.3	Structurally Deficient or Functionally Obsolete?: FO

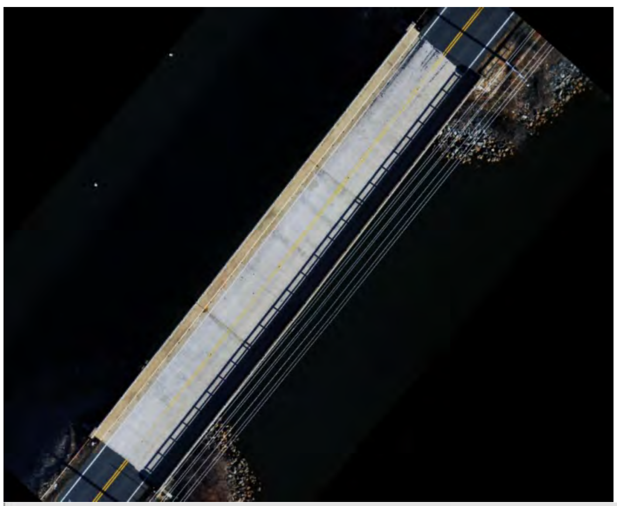
Physical Information

Bridge Type: Steel Stringer/Multi-beam or Girder	

Geographic Location

Latitude:	Longitude:
35.14586	-80.00214

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590165	3/9/2009	Unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: Coffey Creek	Year Constructed/Reconstructed: 1975/-
Sufficiency Rating: 4	Structurally Deficient or Functionally Obsolete?: SD/FO

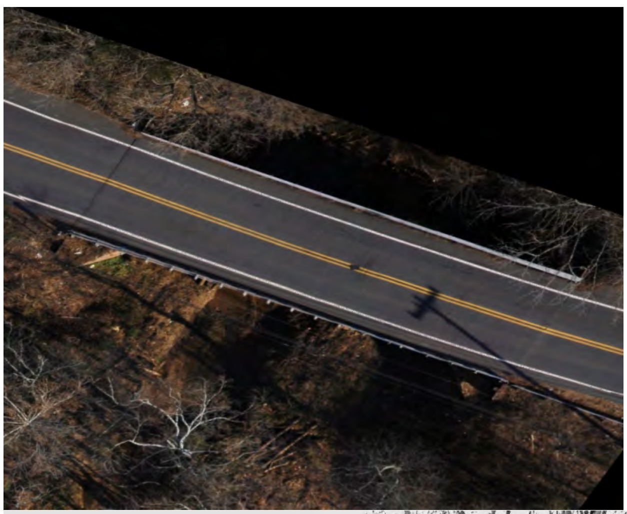
Physical Information

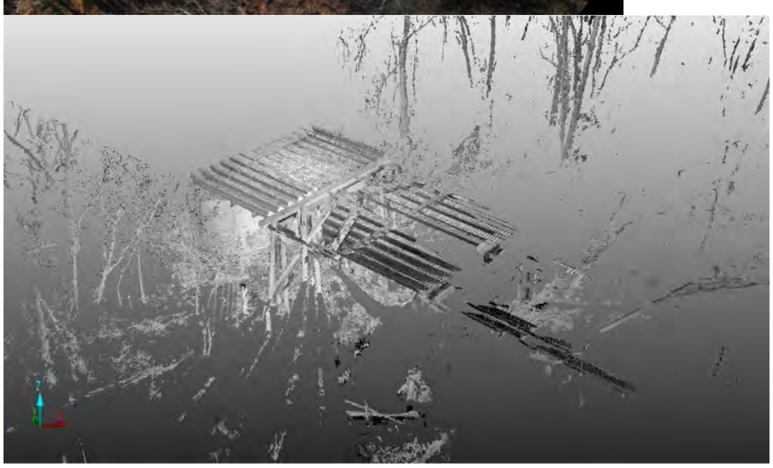
Bridge Type: Steel Stringer/Multi-beam or Girder

Geographic Location

Latitude:	Longitude:
35.16314	-80.93056

Visualization Assistance:





BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590176	11/12/2009	Unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: SR2004	Year Constructed/Reconstructed: 1955/-
Sufficiency Rating: 44.6	Structurally Deficient or Functionally Obsolete?: SD/FO

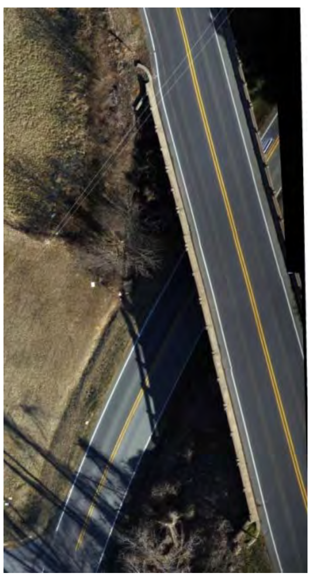
Physical Information

Bridge Type: Steel Stringer/Multi-beam or Girder

Geographic Location

Latitude:	Longitude:
35.41492	-80.85128

Visualization Assistance:



Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590177	2/7/2009	unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: Reedy Creek	Year Constructed/Reconstructed: 1970/2011
Sufficiency Rating: 99.8	Structurally Deficient or Functionally Obsolete?: SD/FO

Physical Information

Bridge Type: Steel Stringer/Multi-beam or Girder

Geographic Location

Latitude:	Longitude:
35.25914	-80.66333

Visualization Assistance:

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590179	1/19/2008	unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: A, C & Western RR	Year Constructed/Reconstructed: 1937/1968
Sufficiency Rating: 59.7	Structurally Deficient or Functionally Obsolete?: FO

Physical Information

Bridge Type: Concrete Tee Beam

Geographic Location

Latitude:	Longitude:
35.24686	-80.78736

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590239	1/19/2008	unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: A, C & Western RR	Year Constructed/Reconstructed: 1966/-
Sufficiency Rating: 78.1	Structurally Deficient or Functionally Obsolete?: -

Physical Information

Bridge Type: Steel Stringer/Multi-beam or Girder	

Geographic Location

Latitude:	Longitude:
35.24694	-80.78806

Visualization Assistance:

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590255	7/15/2008	unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: County or Municipal Highway Agency
Featured Intersection: Sou. RR, Brevard St.	Year Constructed/Reconstructed: 1969/-
Sufficiency Rating: 76.4	Structurally Deficient or Functionally Obsolete?: FO

Physical Information

Bridge Type: Steel Stringer/Multi-beam or Girder

Geographic Location

Latitude:	Longitude:
35.24621	-80.81336

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590376	-	unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: City or Municipal Highway Agency
Featured Intersection: Irwin Creek	Year Constructed/Reconstructed: 1960/-
Sufficiency Rating: 23.4	Structurally Deficient or Functionally Obsolete?: SD

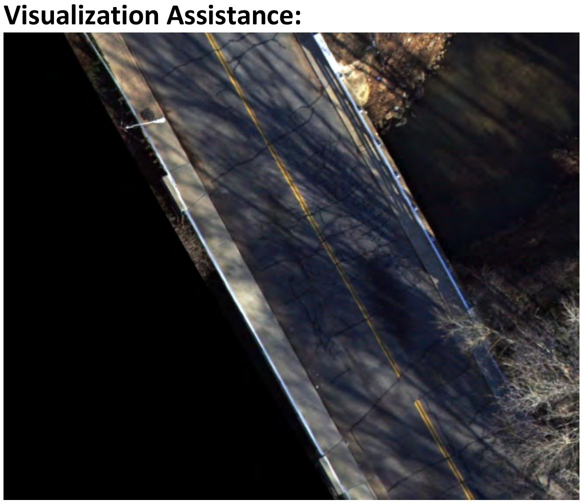
Physical Information

Bridge Type: Steel Stringer/Multi-beam or Girder

Geographic Location

Latitude:	Longitude:
35.20783	-80.883

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590379	7/16/2008	unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: City or Municipal Highway Agency
Featured Intersection: Stewart Creek Tributary	Year Constructed/Reconstructed: 1965/-
Sufficiency Rating: 61	Structurally Deficient or Functionally Obsolete?: SD

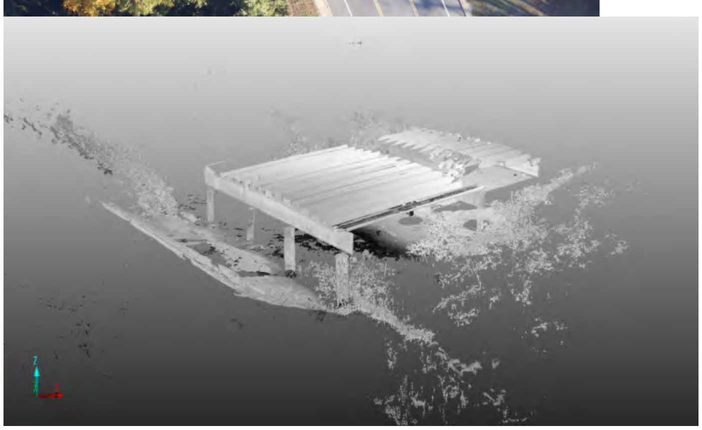
Physical Information

Bridge Type: Prestressed Concrete Channel Beam	

Geographic Location

Latitude:	Longitude:
35.24733	-80.86883

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590511	5/23/2008	unrecorded

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: NC49	Year Constructed/Reconstructed: 1987/-
Sufficiency Rating: 80.7	Structurally Deficient or Functionally Obsolete?: SD

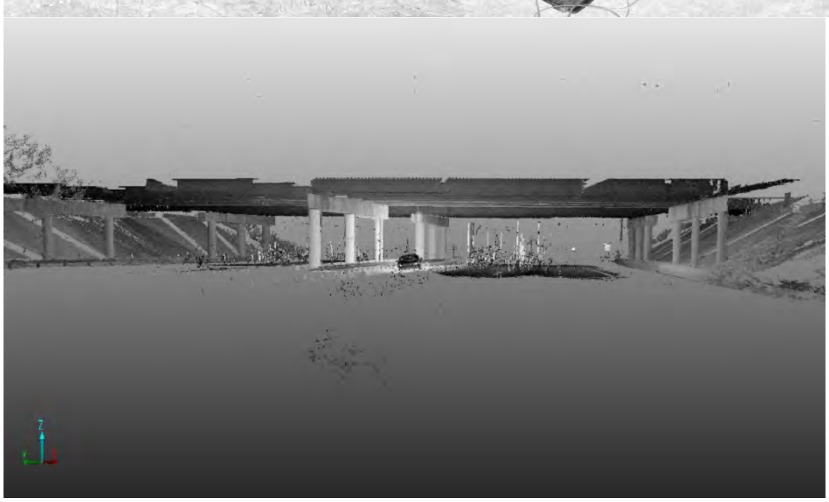
Physical Information

Bridge Type: Steel Stringer/Multi-beam or Girder

Geographic Location

Latitude:	Longitude:
35.29578	-80.74336

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	590704	2/26/2009	

Bridge Information

State: North Carolina	Authoritative Agency: City or Municipal Highway Agency
Featured Intersection: CSX RR, Seigle Avenue	Year Constructed/Reconstructed: 1996/-
Sufficiency Rating: -	Structurally Deficient or Functionally Obsolete?: -

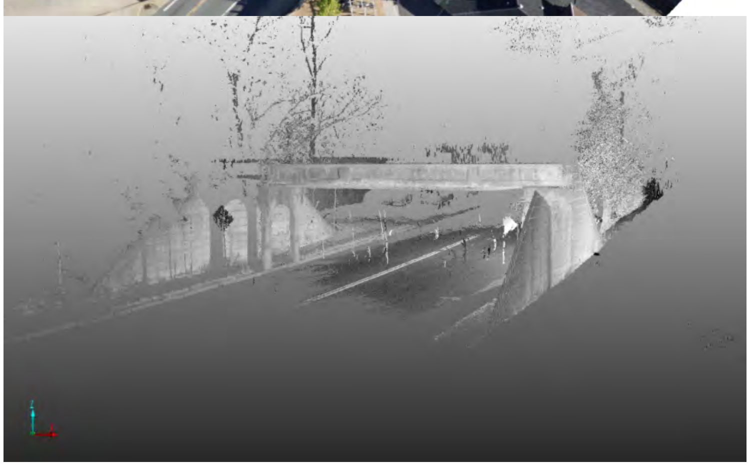
Physical Information

Bridge Type: Concrete Slab

Geographic Location

Latitude:	Longitude:
35.22703	-80.82375

Visualization Assistance:



BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	970007	6/29/2011	-

Bridge Information

State: North Carolina	Authoritative Agency: State Highway Agency
Featured Intersection: 1.2 MI. W. JCT. SR1502	Year Constructed/Reconstructed: 1957/-
Sufficiency Rating: 76.6	Structurally Deficient or Functionally Obsolete?: FO

Physical Information

Bridge Type: Steel Continuous Stringer/multi-beam girder

Geographic Location

Latitude:	Longitude:
35.743072	-81.075364

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1190447	5/5/10	2/3/10

Bridge Information

State:	Authoritative Agency:
North Carolina	City or Municipal Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
Colony Road/Briar Creek	1950/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
97.7	-

Physical Information

Bridge Type:	
Concrete Culvert	

Geographic Location

Latitude:	Longitude:
35.17307	-80.83185

Visualization Assistance:

BRIDGE REPORT

Report Submittal Date:	Bridge Inventory ID:	LiDaR Scan Date:	Aerial Fly-over Date:
	1190512	12/4/2009	-

Bridge Information

State:	Authoritative Agency:
North Carolina	State Highway Agency
Featured Intersection:	Year Constructed/Reconstructed:
0.49 MI. E. JCT. SR2968 Harris BLVD	1987/-
Sufficiency Rating:	Structurally Deficient or Functionally Obsolete?:
79.7	-

Physical Information

Bridge Type:	
Steel Stringer/multi-beam girder	

Geographic Location

Latitude:	Longitude:
35.295917	-80.743403

Visualization Assistance: