D R A F T

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

-PHASE TWO-

VOLUME 1

OUTREACH and COMMERCIALIZATION OF IRSV PROTOTYPE

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16. Abstract
The Integrated Remote Sensing and Visualization System (IRSV) was developed in Phase One of this project in order to accommodate the needs of today's Bridge Engineers at the state and local level. Overall goals of this project are:

- Better understanding and enforcement of a complex inspection process that can bridge the gap between evidence gathering and decision making through the implementation of two technologies, LiDAR and Small Format Aerial Photography (SFAP);
- Aggregation, representation and fusion of complex multi-layered heterogeneous data (i.e. aerial photos and ground-mounted LiDAR etc.) with domain application knowledge to support an understandable process for decision-making;
- Robust, interactive, large scale, visual analytics that support users' decision making;
- Integration of these needs through a flexible Service-oriented Architecture (SOA) framework to compose and provide services on-demand; and
- Outreach, information sharing, and partnership development that will sustain the IRSV concept going forward, providing state and local bridge management and preservation units a valuable tool to use in these tasks.

The specific objectives of the project are to:

- Enhance the National Bridge Inspection System (NBIS);
- Provide opportunities for state and local DOTs to develop remote sensing and visualization applications for Bridge Management and Preservation Systems;
- Provide temporal bridge condition tracking;
- Enable agencies to make more precise damage assessments; and
- Provide better and more systematic data interpretation through parallel data displays.

This first Volume of Phase Two describes the development of the IRSV Outreach and Commercialization component for management review and understanding. Our intent is to ultimately establish a component of an on-going nationwide dialogue in order to upgrade bridge management and preservation systems in state and local transportation agencies.

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Commercial Remote Sensing, Infrastructure Management, Asset Management, High-resolution Aerial Surveys, Bridge Management Systems, Outreach, Partnerships

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The Integrated Remote Sensing and Visualization System (IRSV) described in this draft final report was designed by a team led by the University of North Carolina at Charlotte to address the needs of today's bridge engineers at the state and local level from the following issues:

- Better understanding and enforcement of the federal mandate of a complex inspection process to bridge the gap between evidence gathering and decision making through the implementation of two technologies: LiDAR and Small Format Aerial Photography (SFAP);
- Aggregation, representation and fusion of complex multi-layered heterogeneous data (i.e. aerial photos and ground-mounted LiDAR etc.) with domain application knowledge to support an understandable process for decision-making;
- Robust, interactive, large scale, visual analytics that support users' decision making;
- Integration of these needs through a flexible Service-oriented Architecture, whose framework composes and provides services on-demand; and
- Outreach, information sharing, and partnership development that will sustain the IRSV concept going forward toward commercialization, providing state and local bridge management and preservation units a valuable tool to use in these tasks.

The specific objectives of the combined first and second phases of this project (2008 until the present) were to:

- Enhance the utility of the National Bridge Inspection System (NBIS) by developing a stronger link between database management and decision-making ;
- Provide opportunities for state and local DOTs to develop the visualization and system requirements for their own Bridge Management Systems (BMS) and Bridge Preservation Systems (BPS);
- Provide temporal bridge condition tracking;
- Enable agencies to make more precise damage assessments; and
- Provide better and more systematic data interpretation through parallel data displays.

This first Volume based on the Phase Two project describes the Outreach and Commercialization components as a summary for management review and understanding by state and local highway/bridge agencies. Our intent is to ultimately establish and take part in an on-going nationwide dialogue and upgrade our bridge management and preservation systems in state and local transportation agencies.

Acknowledgements

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We also acknowledge and appreciate the excellent reviews and input provided by our National Advisory Committee: Sreenivas Alampalli, New York State DOT; Mrinmay (Moy) Biswas, North Carolina DOT; Ahmad Abu-Hawash, Iowa DOT; K. T. Thirumalai, STI International (Phase One participant); Dan Turner, University of Alabama; George Connor, Alabama DOT; Phillip Yen, FHWA Turner-Fairbank Research Center; and the following Phase Two members of the Committee: Jim Edgerton, AgileAssets, Inc.; Steve Varnedoe, Michigan State University/AgileAssets; and Earl Dubin, North Carolina Division, FHWA.

Partners in this Phase Two outreach and commercialization 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, the Charlotte Visualization Center, Boyle Consulting Inc., plus consultants Kelley Rehm, P.E, and Dr. C. Michael Walton, P.E.

1.1 Introduction

The intent of this Two-Phase, multi-year research project was to develop and validate Commercial Remote Sensing (CRS) and Spatial Information (SI) applications that can enhance current bridge management systems (BMS) and bridge preservation systems (BPS). It is part of a number of university-led consortia funded by a Cooperative Agreement with RITA. Federal mandates require that all bridges of a certain length be inspected by their owners every other year. The current National Bridge Inspection System (NBIS) does not include remote sensing data or similar image-based data. Hence, a bridge data management system, Integrated Remote Sensing and Visualization (IRSV), has been developed at UNC Charlotte to accommodate geospatial and remote sensing data. The IRSV can also serve as a remote sensing data management and decision-making tool.

A longer-range objective over the past four years has been to enable the IRSV components to be integrated into state and local BMSs and BPSs. IRSV contains a high resolution visual database using, in part, on-site bridge inspection data that has been collected by states, local governments and other bridge owners and operators. IRSV addresses this deficiency by including remote sensing data developed within this project. Upon more intensive outreach contacts that ultimately included representatives from all 50 states and several local governments provided the following conclusion was reached: the Phase Two results suggested that both LiDAR imaging, as well as Small Format (sub inch) Aerial Photography (SFAP) have demonstrated a distinct power for enhancing currently utilized BMS/BPSs. At a less robust level of study and investigation, Infrared Imaging was also studied early in this project, but dropped in Phase Two.

Our goal for IRSV is to alleviate limitations in current bridge management systems by uncovering potential Commercial Remote Sensing applications that address complex issues in data fusion of multiple formats, particularly in time series data that are not always available. IRSV can provide temporal data transformation and detailed bridge damage information to enhance our understanding and quantification of various types of bridge damage, both on bridge decks and in structural members. As another considered conclusion, it is apparent that LiDAR, although possible as a CRS technology to detect and measure bridge deck flaws, is more appropriately used to scan superstructure. Similarly, our recommendation for scanning of bridge decks is more efficient and cost-effective by using Small Format Aerial Photography (SFAP).

To ensure a practical, cost-effective product that is able to be integrated into system-wide implementation, the IRSV development has been enhanced by including documentation for all 50 state highway agencies. Over the four years of investigation on this project, and similar research elsewhere, it is apparent that state and local highway agencies are beginning to be receptive of using LiDAR (in particular), and SFAP (in general) as test sites. Among the highway agencies included as partners in this project include the North Carolina DOT, City of Charlotte DOT, New York State DOT, Iowa DOT, Alabama DOT, CALTRANS, Kentucky Transportation Cabinet, Florida DOT Division 5 and Osceola County, county highway agencies in Iowa, New York, and Alabama, and the Los Angeles County Department of Public Works. From these agencies, 79 bridge decks have been scanned utilizing SFAP flyovers, and approximately 20 bridge superstructures scanned utilizing LiDAR. The database created from

SFAP data collected on these sites is shown in Table 1. The Sufficiency Ratings were derived from an analysis of the data collected from scanning the 79 bridge decks, and calculated from SFAP data.

Table 1. Database for Comparative Analysis (Sufficiency Rating) derived from SFAP scans

Bridge No.	Bridge Deck Sufficiency Rating (SFAP) *(see note below)	Estimated NBIS Bridge Rating ** (see note below)	NBIS Deck Rating (only)	Yr. Built/ Rebuilt	Yrs. in Service
590038	29.8	20	60	1945	67
590049	47.5	60	50	1961	51
590059	11.5	40	60	1976	36
590084	79.8	60	80	2004	8
590108	100.0	90	70	2005	7
590140	66.7	60	60	1951	61
590147	59.4	60	60	1938	74
590161	62.3	60	50	1961	51
590165	4.0	20	40	1975	37
590176	44.6	20	70	1955	57
590177	99.8	90	80	2011	1
590179	59.7	60	60	1968	44
590239	78.1	90	60	1966	46
590255	76.4	60	50	1969	43
590376	23.4	40	50	1960	52
590379	61.0	90	50	1965	47
590511	80.7	90	70	1987	25
590512	80.4	90	70	1987	25
002380	52.0	60	60	1940	72
003267	42.0	60	60	1948	64
005480	67.0	90	0	1956	56
005369	26.9	60	50	1955	57
010357	38.9	60	70	1970	42
006952	39.3	60	60	1960	52
007390	61.0	60	60	1961	51
011015	50.2	60	50	1973	39
110026	74.9	90	50	1950	62
790172	90.3	60	60	1997	15
790196	93.0	90	70	2002	10

790197	93.0	90	80	2003	9
924038	64.9	60	60	1973	39
924046	82.0	90	50	1956	56
924049	53.4	60	70	1957	55
924145	98.1	90	70	1983	29
924150	85.3	90	70	1981	31
012491	85.0	90	80	2004	8
040390	78.2	90	50	1969	43
040510	52.0	20	50	1973	39
041300	86.0	90	70	1989	23
041310	85.0	90	70	1989	23
042300	90.0	60	60	1986	26
042310	92.0	90	60	2005	7
042381	93.0	90	90	2004	8
042391	100.0	90	90	2005	7
042401	82.0	90	90	2005	7
042761	95.0	60	90	2003	9
504480	94.0	90	80	1997	15
605405	88.0	90	70	1984	28
608345	96.0	90	80	2002	10
608575	96.0	60	90	2002	10
608580	93.0	60	90	2002	10
608660	88.0	60	70	2002	10
608665	96.0	90	70	2002	10
1005220	96.0	90	70	1990	22
1006370	84.9	90	70	1984	28
1007140	71.1	90	90	2009	3
1007260	55.1	60	60	1983	29
1013960	81.9	90	70	1949	63
1014090	95.3	90	50	1981	31
1022310	59.3	90	90	2009	3
1026680	80.0	90	90	2004	8
1027090	55.6	60	50	1984	28
53C1527	88.8	90	60	1970	42
53C0981	67.5	90	70	1963	49
53C0825	81.6	60	70	1970	42
53C0775	93.6	90	60	1994	18
53C0642	80.5	40	40	1961	51
53C0625	95.0	90	50	1953	59

53C0620	60.0	40	40	1953	59
53C0617	70.8	60	60	1952	60
53C0602	61.0	40	50	1937	75
53C0470	95.6	90	70	1963	49
53C0431	86.8	90	60	1956	56
350034	10.9	40	60	1972	40
1090266	83.0	90	80	1991	21
1090050	56.7	90	60	1961	51
350091	23.0	40	50	1968	44
970007	76.7	60	60	1957	55
1190512	79.7	90	70	1987	25
Averages	71.6	72	64		35

* Bridge deck ratings calculated from flyover data collected in calendar years 2009, 2010, 2011, from six states (including local bridges in some states)
** Rough Order of Magnitude (ROM) approximation of a bridge's sustainability for comparison of Functionally Obsolete or FO (index value of 60), Structurally Deficient or SD (index of 40), both FO and SD (index of 20), or no NBI rating (index value of 90, with the assumption that the bridge with a value of 90 is neither Functionally Obsolete nor Structurally Deficient)

Table 2 shows the correlation matrix developed from the sample of 79 bridges that had SFAP ratings calculated from bridge deck scans, NBIS estimates, and the number of years placed in service. The rating measurements were comparisons of the calculated SFAP values compared to estimations of NBIS ratings based on the application of numerical values representing Functionally Obsolete bridges and/or Structurally Deficient bridges. Further information on why these two measurements (FO and SD) were estimated as they are is shown at the end of Table 1 above. The other comparison shows the NBIS data (from current values) and the number of years in service. Number of years is shown from the year each bridge was placed in service OR the number of years since a repair project was completed for that bridge.

Correlations can range from negative one (- 1.0) to positive one (+ 1.0). If the correlation is positive, it means that when one variable increases, the other tends to increase. This relationship would be expected when comparing SFAP ratings and NBIS estimates. On the other hand, if the correlation is negative, it means that when one variable increases, the other tends to decrease. This relationship is expected between years in service and the other two values. Statistical significance can range from zero (0.0) to one (1.0) and is a measure conveying the likelihood that a correlation occurred by coincidence or chance. For example, a statistical significance of 0.05 means that in only 5 chances out of a 100 could this correlation have happened by chance.

Table 2. Correlation Matrix comparing SFAP, NBIS estimates, and Years in Service

	SFAP	NBIS-Bridge	NBIS – Deck Only	Years in Service
a) SFAP	1.0			
b) NBIS – Complete Bridge	0.7037	1.0		
Statistical Significance	0.0000			
Sample size	79			
c) NBIS – Deck Only	0.4272	0.3344	1.0	
Statistical Significance	0.0001	0.0026		
Sample Size	79	79		
d) Years in Service	-0.5158	-0.4152	-0.6597	1.0
Statistical Significance	0.0000	0.0001	0.0000	
Sample size	79	79	79	

Using the information highlighted in Table 2, the following paragraph details the purpose and meaning of this analysis. The first number (0.7037) represents the correlation between the column variable (SFAP) and the row variable (NBIS). More specifically, it means that for every one (1.0) unit increase in SFAP, the NBIS increases by 0.7037. The next number (0.0000) represents the statistical significance of the correlation or the likelihood that the correlation occurred randomly or by chance. Given that the statistical significance is zero, this means that there is no chance that the observed correlation between SFAP and NBIS ratings occurred by chance. The third and last number shown is the number of observations used in calculating the correlation. In this case, there were 79 bridges that had a SFAP rating, an estimated NBIS value for the complete bridge and for the deck by itself, and a known number of years in service. Similar logic can be used to examine the relationships between SFAP and Years in Service and between NBIS estimates and Years in Service. The correlation between SFAP and Years in Service (-0.5158) indicates a stronger negative relationship than the correlation between NBIS estimates and Years in Service (-0.4152). However, the statistical significance of the correlation between NBIS estimates and Years in Service (0.0000), indicates a more significant correlation than is found between the SFAP and Years in Service (0.0001).

The specific objectives of this particular calculation within this project were to: 1) enhance the National Bridge Inspection System (NBIS), 2) provide opportunities for state and local DOTs to develop the visualization and system requirements for their own BMS; 3) provide temporal bridge condition tracking; 4) enable agencies to make more precise damage assessments; and 5) provide better and more systematic data interpretation through parallel data displays. Such correlations were made in the Visual Analytics portrayal of analyses such as these. An example of these visual analytics is shown below.

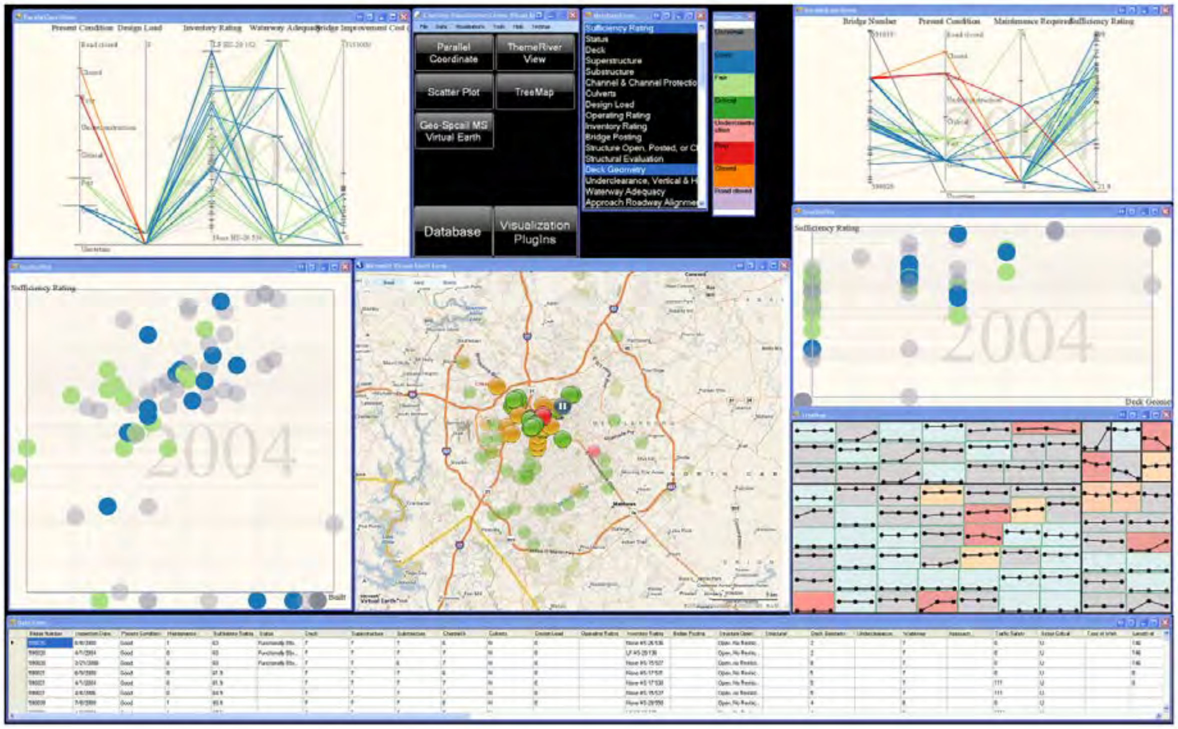

Figure 1. Overview of IRSV Visual Analytics

The description of the outreach and commercialization activities associated with this project have been documented in the following chapters:

1.2 Review of IRSV Prototype Development Process

The IRSV is a data management system that uses an integration of multiple types of collected bridge data, such as textual data, sensor images, aerial images, and geospatial notations. Satellite imaging was explored in the early phases of the research (ca. 2007 - 2008) and determined to NOT provide sufficient resolution to be used in developing the IRSV prototype. Generating results from the conventional database query process can be time-consuming or even ineffective, especially when the database contains a large number of heterogeneous data sets.

As it has evolved over the past four years, the use of the IRSV system will enable users to retrieve bridge data directly from the database using Semantic Matching Operation (SMO) provided by a Problem Domain Ontology (PDO), which was developed in Phase One of the project. There remain some scalability issues, however:

- Generating results from the conventional database query process can be a time consuming effort, especially if the database has a large number of variables (which our database does).

- The query process does not guarantee a solution to a given problem and may require multiple queries and manual intervention in order to produce a "sensible" output.

This approach has enabled the creation of meaningful and useful Web-based queries through interactive knowledge acquisition with a subject matter expert (e.g., bridge management/ preservation engineers). The formulated conceptual space bridges the gap between evidence gathering that can be understood by the combination of the complex data with domain knowledge in a decision making process. The complex data-space must be mapped automatically to easily comprehend the conceptual space.

By introducing an enhanced domain knowledge modeling technique, IRSV will enable bridge inspectors to raise the level of their analyses from a data level to a conceptual level by leveraging their domain knowledge understanding and its associated representation.

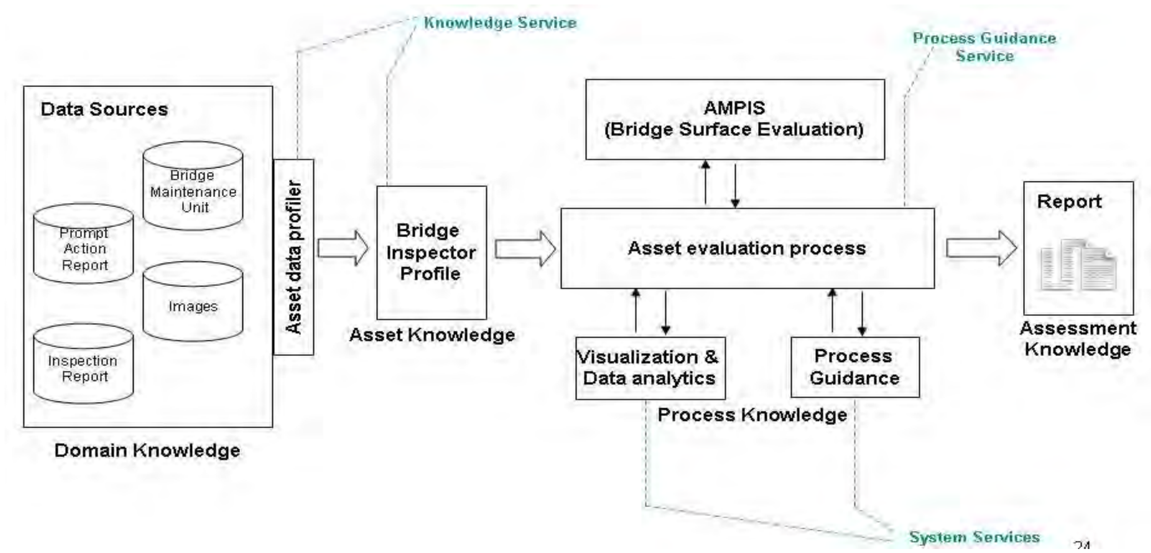

Figure 2. IRSV Conceptual Model (2009 edition - Phase One)

1.3 Initial Outreach and Partnering

In the latter half of 2008, the Research Team recruited and invited several experts in various phases of bridge design, management, and preservation. These committee members are listed in the Acknowledgements section of this report. The objectives and charge to this committee was primarily to keep the research team "grounded," and review QPRs and Interim Reports, meet with the Research Team periodically, and offer suggestions and recommendations to clarify draft materials, model output, and suggest connections with other bridge research projects going on around the country. The major contribution of this committee, however, was in helping guide the research and development component of the work into a "marketable" product that would be understood and accepted by Bridge Management/Preservation Engineers across the country.

Even though cost-effectiveness study was not included in the Phase One project, the different CRS technologies proposed presented different market potentials. The Advisory Committee was instrumental in providing advice and counsel to look "down the road" at the big picture and what the useable output of the project would be. One major difference in potential "marketability" between the use of aerial flyovers (SFAP) process and LiDAR scans is that aerial flyover equipment including aircraft and advanced photographic equipment are readily available throughout the country. LiDAR equipment, on the other hand, although gaining in utility by highway agencies across the country, are not as readily available and not as readily understood and accepted among the bridge engineering community.

Demonstrations of this technology – both SFAP and LiDAR - were viewed as necessary on a wide scale basis in order to be understood and accepted. Asset Management programs in DOTs and state highway agencies (SHAs) began to provide potential partners in promoting the concept of LiDAR use in Bridge Management as well as Pavement Management. Given the capabilities of LiDAR scanning, there is considerable room for acceptance. However, as an economical method of obtaining data on the detailed damage and condition of bridge decks, the SFAP aerial photography developed in this project presents a much more cost-effective tool.

Output from four different data sources populated the interim IRSV system at the end of the Phase One effort. At that time, it appeared that all four approaches to providing a quantitative assessment of overall bridge sustainability should be included in an overall bridge performance index. Primary attention began to be focused on assessing and maintaining a record of the condition of bridge decks. The sources if data for this comparative analysis included:

- NBIS Bridge Inspection Data, with the compiled output for all analyzed bridge elements being characterized as Structurally Deficient (SD) and/or Functionally Obsolete (FO);
- LiDAR, which has gained acceptance by highway agencies to scan bridge decks and roadways, usually mounted on large vehicles such as modified vans and SUVs;
- AMBIS (Automated Management of Bridge Information System), a model previously developed by ImageCat, Inc. to apply to Pavements, under a contract with the FHWA; and

- High-resolution, small format aerial photography (SFAP), an innovative “flyover” approach to scanning bridge decks and parapets, and available throughout most of the country by several active members of the Professional Aeronautical Photography Association

For the latter three data sources, the following “distress” metrics were analyzed for 21 bridges in North Carolina:

- Deck cracking (Aerial photos and AMBIS output measure type and amount of distress, e.g., block cracking, longitudinal cracking, etc.);
- Joint displacements (Aerial photos and AMBIS output measure percent displacement relative to allowable separation by bridge type);
- Distress on substructure (LiDAR output described as mass loss and severity);
- Load rating (LiDAR output); and
- Bridge clearance from pavement or surface below the deck (LiDAR output)

The individual metrics for SFAP, AMBIS, and LiDAR were defined for each of the initial 21 bridges with an equal weight. When combined with the actual measurements for each metric, it was considered that weights given to each measurement would produce a single index that can serve as an overall rating of the bridge. As we moved into Phase Two in early 2010, we observed both subtle and not so subtle differences among our Advisory Committee and the various state and local partners that they represented. Overall, the results from this analysis was a scale comparable to the 1 to 99, which is a scale that most states use to rate the overall condition of their bridges. This one metric is also a combination of metrics that are collected in the bi-annual Bridge Inspection process, for comparison with IRSV output.

In summary, as we concluded Phase One IRSV Prototype, we tested and validated this approach to measuring defects on bridges maintained by the NCDOT in Mecklenburg County plus a few maintained by the City of Charlotte DOT. The research team has had communications and agreement with other states and local governments to continue with the testing and upgrading of the “proof of concept” IRSV Prototype that has thus far been developed. The Advisory Committee felt the project was on track, but had not as yet developed a meaningful “Integration” of the various components of the IRSV.

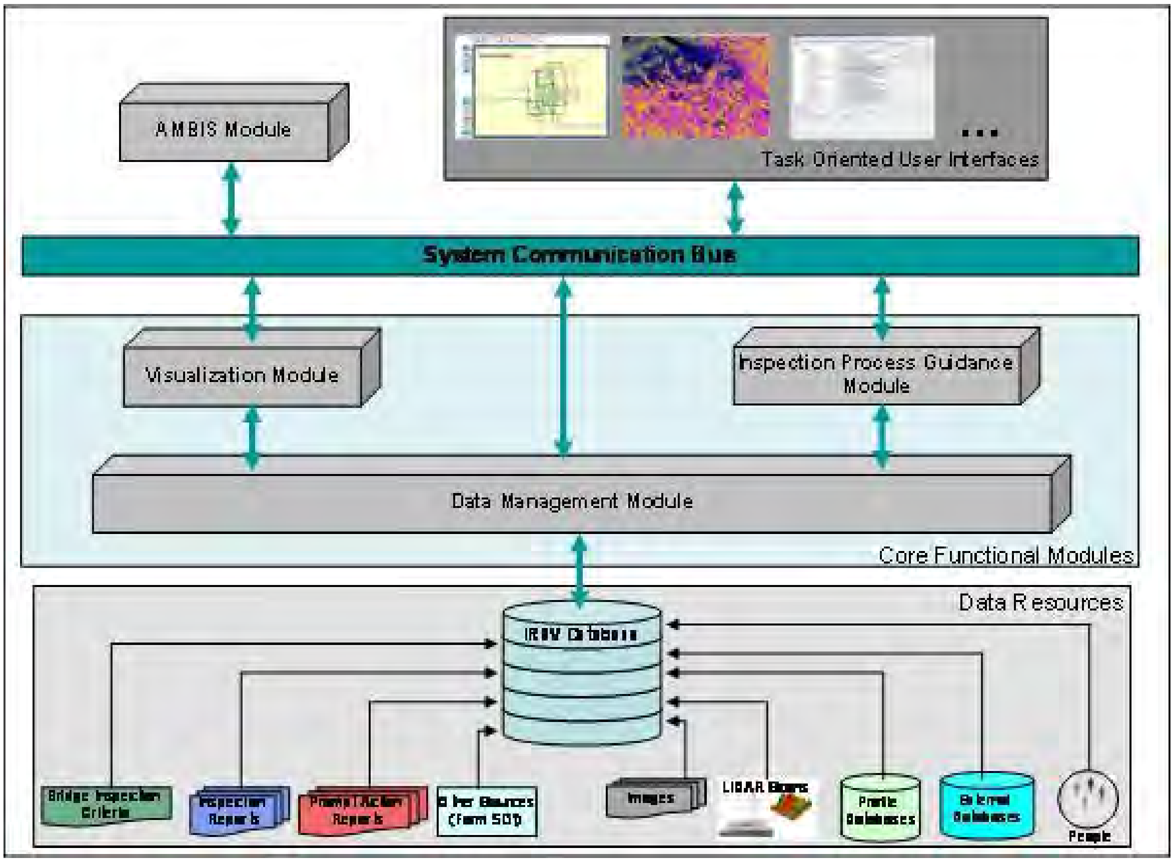

Figure 3. High Level IRSV System Architecture, ca. 2010

Figure 4. NCDOT Maintained Bridge from which SFAP values were calculated

1.4 Extension of Partnering Process to Nationwide Audience

As the IRSV Prototype appeared to be ready to move on into the Commercialization phase, it first became apparent that the study team needed to understand how State and Local Governments are incorporating new technologies into their bridge inspection and asset management procedures. Several outreach activities helped to secure contacts with State Departments of Transportation (DOT) Bridge offices. The following outlines outreach efforts throughout this phase of the project.

1.4.1. Overview

In 2010, members of the team attended several bridge preservation and bridge management workshops and conferences where the project was presented and feedback was received.

- Pontis User Group Meeting – Newport, RI, September 20th-22th
- Northeast Bridge Preservation Partnership meeting – Hartford, CT, October 28-30th
- Midwest Bridge Preservation Partnership meeting – Detroit, MI, October 12-14th

Feedback was also solicited from several experts in the field after presentations were given at the above meetings Feedback from the conferences included the need to provide small format aerial photographs on the bridges being piloted for use in the FHWA Long Term Bridge Performance Program (LTBPP). Barton Newton, the newly appointed State Bridge Engineer in California, suggested partnering with the LTBPP to do deck monitoring for the long term, such as flyovers 1-2 times per year for 10 years.

Other feedback from State DOT's included a suggestion from the California State Bridge Engineer's office that the small format aerial photography would be very useful for his inventory of sound walls and retaining walls to monitor displacement on these structures. He is including these structures as part of the NJ Asset Management plan. Connecticut also mentioned that they have a bridge joint measurement program where, in the past, they have been taking joint measurements for over 100 bridges every summer and winter to measure movement. Recently, though, because of lack of staff and expense and traffic control issues they are only monitoring around 35 bridges annually. They suggested using the SFAP to monitor joint displacements on additional bridges.

Interviews were also conducted during this time and further feedback from California was considered. Michael Johnson is the chair or the AASHTO Pontis Users Group as well as the chair of the TRB (AHD00) Joint Subcommittee on Bridge Preservation. He is also the co-author of the new *AASHTO Guide Manual for Bridge Element Inspection*. Mr. Johnson made the following suggestions for implementing the results of recent research from various organizations nationwide.

1) It would be beneficial to see some comparisons of the aerial photography technology with traditional health monitoring equipment, such as strain gauges, displacement gauges, and acceleration gauges. How do they compare in effectiveness, ease of use and cost?

2) The deck crack monitoring capabilities of the small format aerial photography looks to be the most practical use of the remote sensing techniques. He would like to see more information on costs of the flyovers as well as the time and cost of the analysis to remove "noise" and identify cracks.

4) Bridge deck cracking determined by aerial means fits directly into the current practice and documentation of element level inspections techniques. The new *AASHTO Guide Manual for Bridge Element Inspection* includes a discussion of the use of technologies other than just visual and notes that many different processes can be used to assess the condition of elements including bridge decks.

5) It would be beneficial to discuss thermal imaging or Ground Penetrating Radar (GPR) as a way to detect deck delaminations, and to add value to the photography.

Initial contacts and states reached during this outreach period included the following organizations and individuals.

Table 3. Outreach Presentations, 2010

(NOTE - all numbers can be verified on attendance lists for each meeting at www.tsp2.org)	**Number of Attendees**	**States Represented**	
Midwest Bridge Preservation Partnership meeting – Detroit, MI, October 12-14th (Kelley Rehm)	Approx 85	13 States	ND, MI, NE, SD, IN, OH, KY, IO, IA, OK, KS, IL, MN
Northeast Bridge Preservation Partnership meeting – Hartford, CT, October 28-30th (Kelley Rehm)	Approx 75	12 States	CT, ME, NY, DC, NJ, DE, NH, CA, VT, MA, PA, RI
Western Bridge Preservation Partnership meeting – Sacramento, CA, December 1-2nd (Edd Hauser)	Approx 85	11 States	AZ, OR, CO, ID, CA, UT, MT, NV, NM, HI, AK

Contacts Made During Networking

Name / Affiliation	**Contact Info**
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Jay Ruohonen (Talon Research - "Bridgeguard") - research partnerships	jay@talonresearch.com
David Steele (Kentucky Transportation Cabinet Bridge Maintenance Engineer) – feedback	david.steele@ky.gov
Dan Farrell (Kentucky Transportation Cabinet - Contact for LiDAR program) – feedback	dan.farrell@ky.gov
Tom Styrbicki (MN Bridge Main. Engineer - LiDAR Program Contact) – feedback	tom.styrbicki@state.mn.us
Dick Dunne (now Retired - NJ State Bridge Engineer - currently with Michael Baker) – feedback	richard.dunne@mbakercorp.com
Merritt Hanson (Kwik Bond Polymers) - research partnership	merritt@kwikbondpolymers.com
Robert Zaffetti (Manager of Bridge Safety and Evaluation - CT) - feedback and possible partnership	robert.zaffetti@po.state.ct.us
Paul Jensen (MT State Bridge Maintenance Engineer) – feedback	pjensen@mt.gov

This type of outreach extended throughout 2011, and has been documented through Quarterly Progress Reports. After evaluating the feedback from States and also from other industry, a more in-depth study was initiated to evaluate the climate of acceptance of new technology within State governments.

The biggest stumbling block to using new bridge management technologies and inspection techniques does not seem to be the lack of experimenting with various technologies, nor a lack of in-house research. Instead, the issues seem to lie in the area of implementation and acceptance of new technologies within government bridge divisions. We might ask, why aren't we implementing the research that has been done and the technology that is available? One recent NCHRP study looked into the acceptance of available bridge decision making tools within state Departments of Transportation (DOTs). The study, "Use of Bridge Management for Transportation Agency Decision-Making"(Markow, 2009) concludes that there is no procedure that is being used consistently throughout the states for bridge management and that:

"a large percentage of transportation departments use their BMS as a repository for bridge inspection data and do not use the BMS capabilities for planning, programming and budgeting. There appears to be no single reason why states do not use the full capabilities of their BMS. Some of the reasons offered included the following: not enough resources to train people to use the BMS fully; a perception that the BMS is a black box, and the opinion that the BMS produces results different than recommendations of inspectors and structural engineers. More work on bridge management systems needs to occur to ensure they are not merely glorified repositories of bridge inspection data but provide analysis that enhances the ability of top management to make decisions and makes it easier to allocate resources within the planning, programming and budgeting processes."
(Markow, 2009)

There appears to be implementation issues with new bridge inspection technologies as well. In an August 2007 survey done by the American Association of State Highway and Transportation Officials (AASHTO) after the I35W bridge collapse, it was reported by 30 responding states that DOTs are using some non-destructive techniques but believe that more research is needed before NDE techniques become more widely used over visual / audio inspection. Figure XX shows that while all states use visual / hands-on inspection techniques on a regular basis, many states are still in the introductory stages of using more technology in bridge management and preservation.

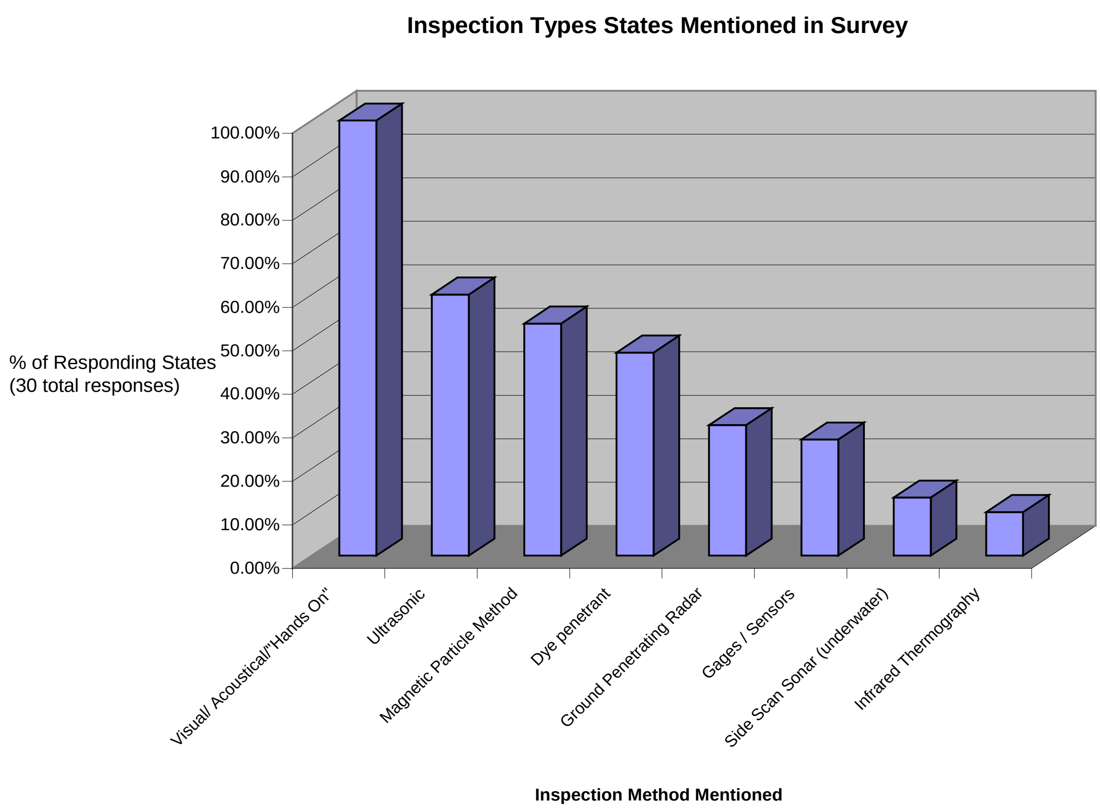


Figure 5. Inspection Tools Used by State DOTs (Source: AASHTO, 2007)

Research and policy analysis in several states has resulted in an identification of stumbling blocks during implementation. These may be overcome in order to successfully market and implement new bridge inspection technologies and management systems to government agencies making decisions about bridge inspection, preservation and management. Case studies of three state DOTs that have implemented a remote sensing technique to monitor bridge vertical clearance or are in the process of piloting and implementing similar programs were included. Conclusions were drawn from these case studies and recommendations made on how to facilitate easier acceptance and implementation of new technologies in government bridge offices.

In today's economy, states and local governments are working with fewer people, less funding and tighter schedules. Because of this squeeze on these organizations, it is becoming harder and harder to implement new programs and technologies. Implementing new technologies, such as remote sensing technologies, into existing bridge management systems requires training, adaption of software and generally takes away from production initially. The benefits of these new technologies and processes must outweigh the costs to be fully accepted and implemented.

Some recent research has focused on acceptance of new technologies and processes within government agencies. In the paper "Effective Transfer of Research Results" (Elrahman, 2004), it is noted that the successful transfer of research is not obtained through the mere delivery of a report. This paper notes that, much like a bridge, a "solid foundation" of acceptance is needed, along with an effective "infrastructure" in order to achieve a successful transfer. A solid foundation is built with 1) top management commitments to the new technology, 2) human and financial resources committed to the efforts, and 3) the organizational culture embraces change and works to dissolve resistance to the new technology. An effective transfer infrastructure uses "seamless communication" among all parties involved including the researchers, the implementers, and the users.

According to Elrahman, the important steps to successful transfer are "transfer preparation" and "transfer follow-through" by the researchers or providers. Preparation includes providing instructions to users that are clear, simple, straightforward and free of ambiguities or complexities. Preparation also includes planning for technical support that will be accessible to users as they implement the new technology. Technology Transfer follow-through involves promotion and delivery of new technology, and close coordination and communication with the users. The adaption of the product to meet the users' needs must also be an option in the follow-through process. Because of these things, it is important that the provider possess interpersonal communication skills, technical competence, marketing experience and available time to focus specifically on the users' needs. (Elrahman, 2004)

It is also important to note an organization's internal and external constraints when looking at the ease of implementing a change or new technology. The principal constraints are:

- People – The norms and values the workforce bring to the job
- Structure – the lines of communication and power, both formal and informal
- Environment – the technologically driven forces that inhibit or propel change

- Costs and Benefits – the financial resources required or anticipated to make the change (Montana, 2000)

These four areas must be addressed when looking at introducing new technology or changes in procedures. People will often show push back against an idea unless there is an in-depth explanation showing advantages of the change or there is a well respected champion of the change in a position of power (structure). People are also more accepting of change if they are involved in drafting the policy or change. If the environment for technology change is right to propel the new technology, worker morale should actually increase with the implementation and production should also increase, resulting in lower costs and higher benefits. (Montana, 2000)

One very recent study done as part of the Transportation Research Board's Strategic Highway Research Program (SHRP2) is called "Institutional Architectures to Advance Systems Operations and Management" (TRB Webinar, 2010). This IRSV Prototype was designed to outline the process organizations go through to implement "best practices" and optimize existing processes within the systems operations arena. Many of the barriers that bridge managers, as well as decision-makers higher up in the organization experience are fragmented organizational frameworks, and significant competition for resources.

As stated in the SHRP2 study, challenges of getting acceptance of new technology within DOT's or local governments are that they often are champion dependent. Where there are no suitable or easy to measure performance measures, there is often a fragmented or decentralized organizational framework, and there is much competition for resources. The SHRP2 study outlines a set of four levels that organizations go through when first implementing new processes or technology:

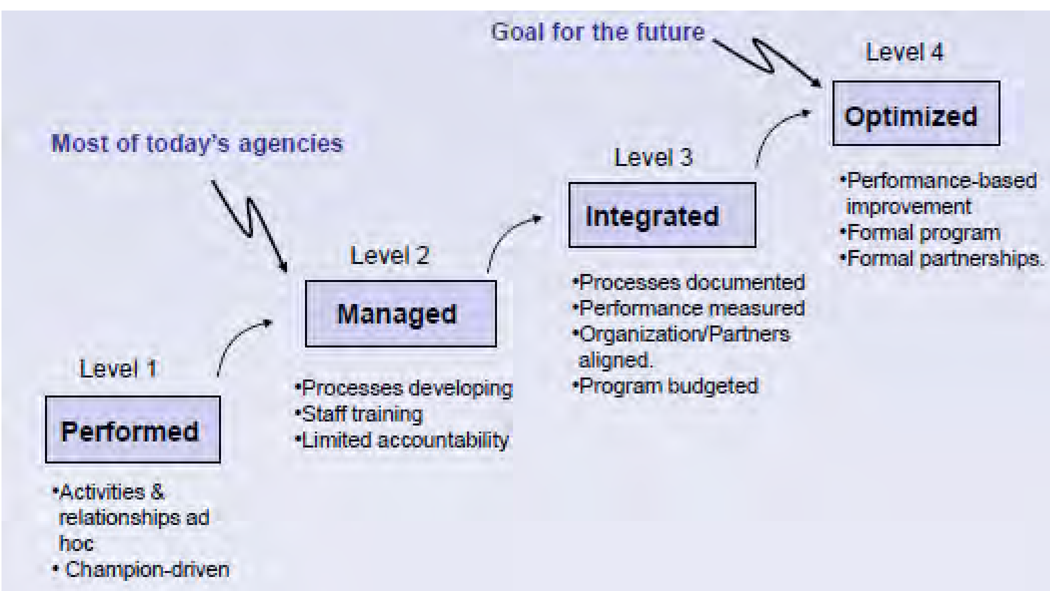


Figure 6. Steps to Implementation of a New Process or Technology

(Source: Institutional Architectures to Advance Systems Operations and Management, 2010)

The key in successfully implementing a new program in most transportation agencies is for the process to make it past the "managed" level and into the "integrated" level. Many programs never make it past the managed level in most of today's agencies, and therefore, do not produce successful results over the long term. Many new technologies, however, never even make it to the "performed" level since trials and research reports often are "shelved" and never implemented. For new technology to make it to the "performed" level, a champion is often needed. A product champion facilitates processes to overcome the organizational and financial barriers, and motivate upper management to test the new technology. (Mogavero, 1982).

According to the SHRP2 study, the use of new inspection tools such as remote sensing technology must first have a champion and then progress through the levels of this model to become a 'formal program' within a government agency. The missing step in the process is the relationship between the researcher, the technology provider and the champion. As mentioned in a study by Elrahman, successful technology transfer and implementation is highly dependent on communication between the researcher, product provider, champion and end users.

Communicating with the best available champion, at the right level in the organization, is one of the most important steps in acceptance of new processes or technology and steps should be taken to determine who would best fill that role. In order to recruit a successful champion, the researcher or provider must first be able to market the process or product to the targeted champion. The key to having a successful marketing plan is to promote understanding of the process or technology, promote the benefits of that technology clearly and concisely, promote the benefits of the technology over other alternatives, and then measure success and continue to promote that success with follow-through (Eixenberger, 2010). This process can be simplified into the following four steps:

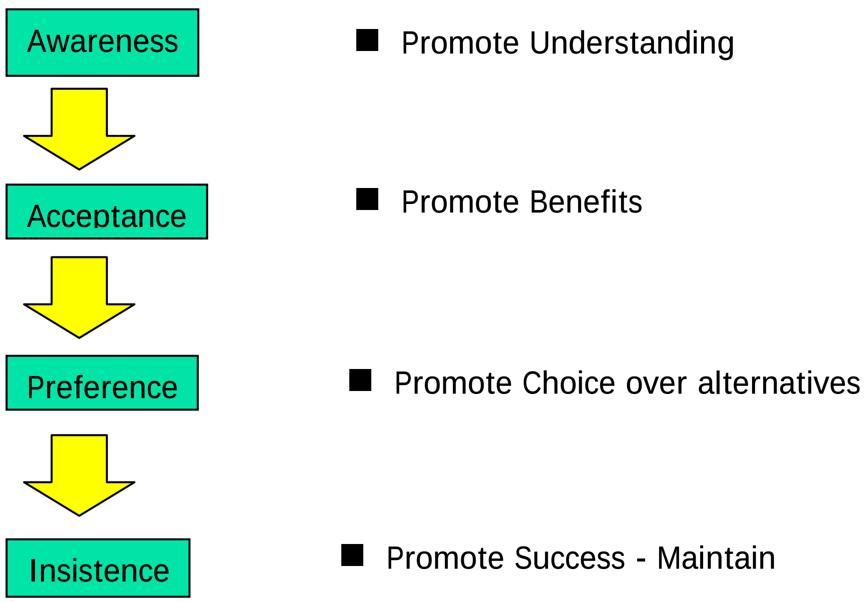


Figure 7. Marketing Plan Flow of Acceptance (Source Eixenberger, 2010**)**

The most important issue to investigate when developing a marketing plan is to know who the target audience is and understand their needs. For example, questions that should be asked when developing the marketing plan are: who is the best champion of the product, who will the champion be working with to promote the product and what is the organization structure and culture of those employees? Equally important is to know the other factors that are going to influence the marketing. For example, questions that may be asked are: how easy is the product to obtain, how much will it cost to purchase and operate, and how much will the training cost in funding and time? (Eixenberger, 2010)

From the study team's experience in developing the IRSV Prototype, we have discovered that the implementation process must start first with the researchers and providers of new technology with preparation and marketing processes. The researchers and technology providers must maintain consistent relationships with the users through the entire implementation process until it is fully integrated into the government systems. Using the SHRP2 model of implementation as a foundation, as well as the ideas outlined in previous research as discussed above, the following process is theorized as a best practice of technology transfer and implementation in government bridge offices.

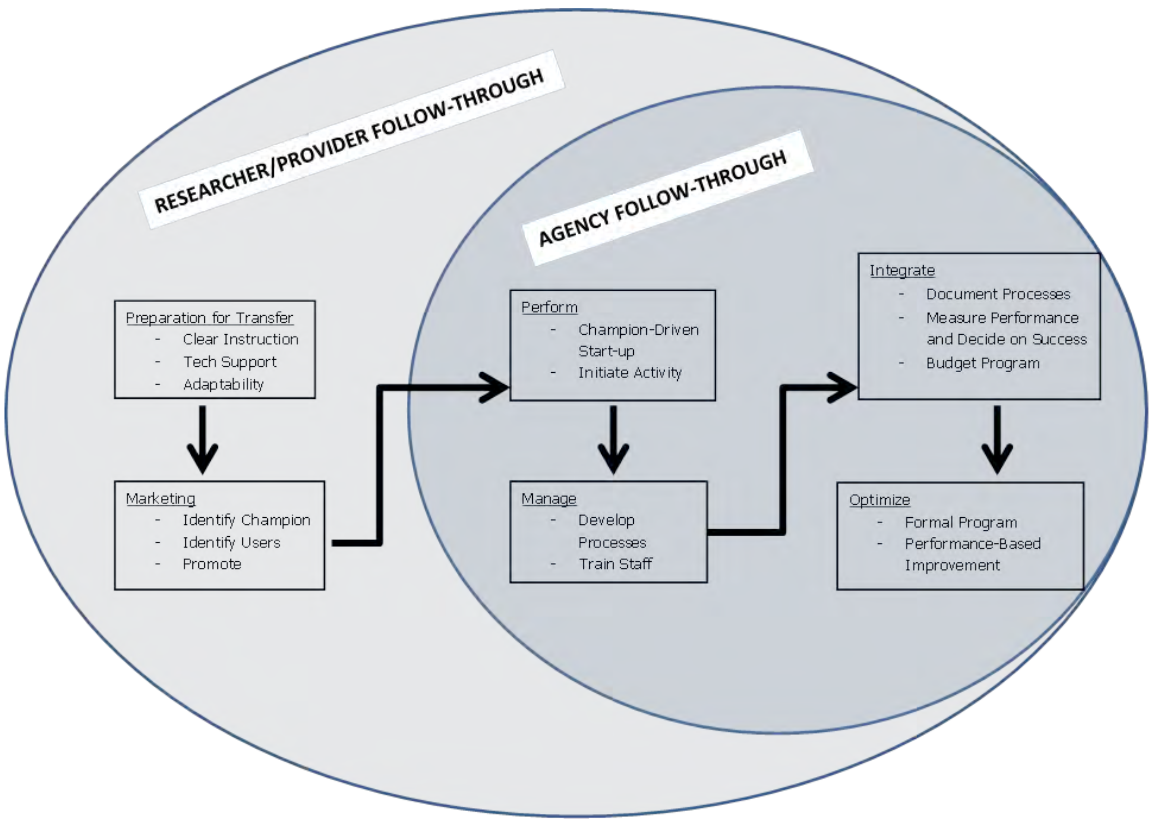


Figure 8. Model for Implementation of New Technology and Process

The most important thing to note is that the researcher and technology provider's participation follows throughout the entire process, even into the final "optimize" phase. To build a good foundation for the technology transfer and implementation, the researchers and technology providers must be prepared to offer clear, concise instruction on how the product or processes work and allot time and budget to provide technical support throughout the start-up phases and possibly even into integration and optimization phases. The researchers must also decide how adaptable the product or process can be to the intended end user as well as decide how much time or funding is available for this type of adaptation.

Researchers, innovators, and technology providers must also fill the role of marketer. Important steps in the marketing process are discussed above, but the initial and most important steps include identifying and communicating with the innovative champion, and also identifying and communicating with end-users.

The process then moves forward with state and federal responsibilities, particularly including AASHTO, although researchers and providers must continue with their follow-through. This part of the model is based on the SHRP2 project model as mentioned above, moving through the four levels of implementation: Perform, Manage, Integrate, and Optimize.

The research team examined various levels of this management/policy model to determine what successful states are doing to implement new processes. Minnesota DOT was contacted to determine how they were able to implement LiDAR technology into their bridge inventory and vertical clearance permitting systems. Kentucky and California were also interviewed to discuss their LiDAR pilot programs and the next steps they plan to take to fully implement the program across the state. This information was used to flush out detailed recommendations for next steps to implementation of new technology.

In talking with state DOT employees throughout the country at regional Bridge Preservation Partnership meetings, it became apparent that many states were already using newer technologies within their bridge evaluation programs. In discussions with California, it was discovered that they have completed a pilot project using LiDAR technology to scan bridge clearances. Kentucky also mentioned using LiDAR for surveying purposes with a demonstration project on bridges. Lastly, Minnesota described an in-house program where LiDAR is used for roadway, bridges, utilities and even tunnel scanning. These informal findings sparked interest and led to talking with these states more about their implementation of LiDAR to determine how they successfully were using new technologies in their organizations.

1.4.2. Case Studies

<u>Minnesota DOT</u>

The Minnesota DOT sent representatives from their bridge evaluation and maintenance offices to the Midwest Bridge Preservation Partnership meeting held in the Fall of 2010. During this meeting, Mr. Tom Styrbicki, Minnesota's State Bridge Construction and Maintenance Engineer, stated that Minnesota had been using LiDAR technology for several years and had an established program where remote sensing tools were owned by the state and used by experienced staff. This discussion led to an interest in talking with MNDOT more about this program.

In December 2010, a phone interview was held and included Mr. Styrbicki as well as MN DOT's Survey Manager, Mr. Gary Troge. During the interview, the MNDOT employees provided information on the organization of their bridge and survey offices. MNDOT is a decentralized organization with construction and operation of the transportation system being the responsibility of eight districts within Minnesota. There are approximately 110 employees in the MN Bridge office. The office conducts and coordinates all bridge planning, scoping, preliminary and final bridge design, as well as maintains the bridge standards and provides expertise in hydraulics, bridge safety inspection and houses the statewide bridge inventory and inspection database. MN DOT is responsible for the inspection and rating of about 20,000 bridges and the maintenance of about 5,000 bridges.

The Metro Survey Manager for Minneapolis, Mr. Bradley Canaday, first introduced LiDAR technology to the Department in 2009. During the investigation period, a survey of state was initiated to determine if mobile types of laser scanning were being used by other states. At the time of the survey, MNDOT found that many states were interested in using the technology, but that the start-up costs were the biggest hindrance. After finding that many states were doing demonstration projects with the technology, Mr. Canaday contacted vendors that were using the technology and set up a showcase of the equipment and software for DOT district and central office survey managers and designers.

After the showcase, discussions were held with each district office to convince the districts that funding from the statewide equipment budget should be used to purchase the LiDAR equipment and software. The showcase, along with visits from the Metro Survey office to each district convinced the state that the funding should be allotted and a Leica Geosystems package was purchased. This package included static tripod scanners and Cyclone software. The scanners are used at this time for bridge clearance measurement, pier locations, pier cap elevation measurements, used during roadway widening, and road surface DTM modeling. The scanners have also been used to collect information for emergency repair such as during rockslides and flood washouts. The Cyclone software is used to collect the scan data and then is able to clean up noise from traffic and can be exported into Geopak (Microstation) applications.

After the purchase of the equipment, it became clear that MNDOT would need to provide trained staff for its use. At this time, two full time staff within the Survey division is dedicated to the use of the equipment. The next step in the implementation of the technology is the upgrading of the equipment. The main advantage of using LiDAR cited by MN DOT is the accuracy of the data over the use of traditional aerial photography and survey techniques and the ease of use during emergencies where sites may not be reachable (remote investigation).

Overall, MNDOT had a successful implementation because of a dedicated in-house champion of the technology. Mr. Canaday was in a mid-manager position that allowed him to take the steps needed to introduce the technology to the Districts and then convince upper management that funding was needed. In addition, by using an established vendor, support was available to train in-house staff on the use of the equipment and software. In this case, however, the initiator of the successful implementation was from an in-house source and not initially by the researcher or vendor. The main take-away from MN DOT's process is that the researcher or vendor must stay in contact with those that have the ability to introduce the technology and champion it within the agency so that when the times comes to showcase the technology, the researcher or vendor will be ready to market what is available.

California DOT (Caltrans)

During discussions with Caltrans officials, it was discovered that the Caltrans Bridge Evaluation office was also initiating a pilot study to determine if LiDAR would be a useful tool for measuring bridge clearances. A personal interview was set up with Mr. Michael B. Johnson, who is the Chief of Specialty Investigation and Bridge Management. Information was provided on the organizational makeup of Caltrans. Caltrans is a decentralized agency and is geographically divided into 12 districts with two regional offices (North and Central Region). California has over 50,000 lane miles of roadway, 12,940 structures on the state highway system and almost as many on the local roads, as well as 26 tunnels, and 9 large bay crossing bridges. Unique to California is that it has 58 counties, in addition to MPO's and entities called "sales tax counties". These groups contribute $3.9 billion toward transportation in California in addition to the funds that come through the DOT and have individual contracting power, so the state is truly a decentralized organization.

Mr. Johnson described a pilot program that was initiated in the Summer of 2010. The pilot program was awarded to a Terrametrix, a contractor in Nebraska (terrametrix3d.com). Two routes were selected and all the bridges on those two routes were scanned for vertical clearance using high-speed truck mounted LiDAR. State Route 113 was one of the routes. An example of the vertical clearance bridge report can be seen in Appendix C. The scans were done with a $\pm$ 1 inch accuracy and the project cost came to approximately $100 per bridge. The pilot project was considered a success by the state, and Mr. Johnson has since initiated another demonstration project in southern California to scan 2,000 bridges (out of 20,000 total bridges in the region). This project has been contracted to Mandli Communications Incorporated (www.mandli.com).

Although the "point cloud" data results are currently just being used for vertical clearance data, Mr. Johnson's office is maintaining storage of all the data points to eventually use as baseline data for inspection. Plans are in the works to use "point cloud" data as a tool in time progression inspection techniques. The main advantage of LiDAR for Caltrans is the ability to keep workers out of danger on roadways. The prominent issue sited is the large amount of data that are produced and how they are stored.

Caltrans' survey data obtained on mobile LiDAR scanning revealed that: 1) Champions within the state (Mr. Johnson and staff within the office of Land Survey) realized the advantages of LiDAR technology for safety and efficiency: 2) equipment cost concerns and training concerns have prevented full implementation past the pilot stages; and 3) data storage and processing issues, along with accuracy questions, need to be fully addressed before implementation. The following is a quote from the Caltrans response to the survey:

Caltrans is not considering purchasing mobile laser scanning systems for several reasons:

- These systems are very expensive. California is experiencing difficult budget times and the $500,000 to $1,000,000 cost is unlikely to be funded at this time.
- - The skill set needed to operate the vehicle does not yet exist in Caltrans. We do not have anyone with GPS, IMU, scanning, processing, etc. experience or training at this time.
- Caltrans is researching mobile scanning. We tested stationary scanners before we purchased them. The research paid off by knowing which scanners to buy and how to use them. Caltrans has a research project with the University of California at Davis to evaluate mobile scanners.
- The mobile scanner market is very dynamic at this time. Will the company or system purchased now be around in a year? Who has the best system, support, and software for our needs?
- Would Caltrans' use of the data justify the cost? There are many potential demands for the point cloud but Caltrans has been slow to fully use stationary scan data.

Potential benefits using mobile scanning at Caltrans:

- Safety. Many of our highways have heavy traffic flows that are dangerous to work on.
- Lane closures are restricted on busy highways and limit the amount of work that can be performed.
- Multiple uses of the data for engineering surveys, asset management, and other applications is enormous.
- Speed. Collecting 20 miles of data on a four lane freeway is achievable in a day. Traditional surveys over that same area could take months.
- The ability to capture detail on highway corridors that cannot be surveyed any other way.
- Combining with airborne LiDAR, photogrammetry, traditional surveys, and stationary scanning for faster corridor mapping.

Some of the challenges of mobile scanning are:

- Bad GPS environments in narrow canyons, long bridges, forested areas, and cities.
- Vertical accuracies based on GPS. GPS derived elevations do not meet our design specifications.
- Processing the massive amounts of point cloud data.
- Storing the data.
- The technological savvy, skills of potential users, and the demand for scan data have not been fully developed yet. Personnel need to be trained, beefy computers purchased, databases created, applications created, and products defined.

(Source: FHWA Research Advisory Committee Survey, 2009)

From the California experience, it appears that champions at the mid-management level are again important to the initiation of use of new technology. However, past the pilot phases, it is important that the researcher or vendor provide detailed cost information (such as the $100 per bridge estimate) and provides information on data storage, processing or software capabilities. It is also important that the researcher or vendor continue to highlight the advantages such as improved safety of workers past the pilot stage and also highlight the future possibilities (such as time lapse comparisons) to improve the possibility of full implementation.

<u>Kentucky Transportation Cabinet</u>

The Kentucky Transportation Cabinet (KYTC) also sent representatives from their bridge evaluation and maintenance offices to the Midwest Bridge Preservation Partnership meeting held in the Fall of 2010. During this meeting, Mr. David Steele discussed Kentucky's efforts of piloting the use of LiDAR technology. Mr. Steele directed questions to Mr. Dan Farrell, the

State Survey Coordinator. A phone interview was held in February 2011 with Mr. Farrell. Information on KYTC's organization was provided. Kentucky is a mostly centralized DOT with 12 District Offices. KYTC is responsible for approximately 13,500 bridges throughout the state. Most bridge inspection is done using typical hands on, visual inspection.

The initial pilot project for KYTC involved a partnering with the Kentucky Division of Water. The division of Water instigated the project and funding was provided through FEMA. The partnership resulted in and overall documenting of vertical clearance accuracy for some routes throughout the state using fly over LiDAR and aerial photography. During the interview, Mr. Farrell named the firm GRW Engineers, Incorporated as the main survey consultant. He further described how after the Division of Water project, GRW was again contracted for bridge pilot studies first for New Circle Road in Lexington Kentucky and then a 10 miles stretch of road in District 4 (south central Kentucky). These two projects then became "showcase" projects and were presented at conferences and to staff throughout the state to highlight uses of LiDAR. Although many state surveyors and inspectors were interested in the technology, Mr. Farrell expressed concern that there was an issue that the staff were "resistant to change" and that they didn't want to "test anything new". Mr. Farrell's main concern was that the new technology was going to take extensive training both on how to use equipment, as well as how to use the resulting data, and that this may hinder any full implementation efforts.

A follow-up interview with Mr. Ben Fister, Vice President of GRW, and Mr. Jeremy Mullins, GRW LiDAR Manager, was scheduled. The interview took place in March 2011 and a presentation was given of UNCC model. Discussions with Mr. Fister and Mr. Mullins revealed that GRW Engineers had been presenting the technology to KYTC for over three years hoping to spark interest in the advantages of using LiDAR. GRW had given presentations at the KYTC Partnering Conference (and annual conference where state and consultant designers and contractors come together to discuss topics). They had also provided presentations at local technical conferences (such as American Society of Civil Engineers meetings) and at the Kentucky Professional Surveyors conference. Mr. Farrell had attended many of these presentations and became the "internal champion" at KYTC for the technology.

One advantage to using LiDAR that GRW sited is that LiDAR is a proven technology that has been used for many years. Therefore, GRW did not have to prove that the technology worked, they just had to show the advantages to the correct people to instigate buy-in. One hindrance that GRW did find is that the technology is competing with conventional costs of surveying or inspecting. That being said, the conventional types of processes can take several months to provide only a few data points, while LiDAR technology can give millions of points in much less time. To market to KYTC, GRW presented LiDAR as "another tool in the toolbox", not necessarily a replacement for all situations.

For the pilot projects that were done for KYTC, the biggest issue GRW ran into was that "people are scared by the amount of data generated". One way that GRW mitigated this was to be clear about actual deliverables, which for KYTC were mostly CADD files. The pilot project took two hours to drive the route (car mounted LiDAR) and produced 650 million points. Because of this, GRW felt that processing the data HAS to be part of the total package marketed to States. For

KYTC, as mentioned above, the resistance to providing training on the technology forced GRW to package the final results in a recognizable way (through CADD files). For future projects, GRW is looking at using scans to document overall bridge inventory, vertical clearance data, horizontal clearance data, long term / time-lapse data on the life of bridges and bridge deflections.

In Kentucky, the consultant ended up being the ultimate champion of the technology. A firm with significant experience using LiDAR (GRW) continued to market to KYTC until they agreed to a pilot project. The consultant also contacted an internal champion, Mr. Farrell, to instigate continued projects in the future. Also playing a part in the initial use of the technology was the partnering opportunity with the Division of Water. Having alternate funding resources may play an integral role in initial use of a new technology.

1.4.3 Survey of State DOTs on the Use of LiDAR

After completing interviews with Minnesota, Kentucky and California about their LiDAR technology use and implementation, it became even clearer that even more states were using LiDAR as a tool in their surveying toolbox. It seemed reasonable that states that were already using LiDAR as a surveying tool or for bridge related tasks would be more open to trying LiDAR technology for bridge inspection as well. A survey of the state DOTs could provide more information on what states are using the technology and how it is being utilized.
In March of 2011, a survey was sent to all the members of the AASHTO Subcommittee on Bridges and Structures with the following questions:

- Agency and office within the organization
- Does your state use LiDAR Technology for surveying or inspection for roadways or bridges?
- If yes, please provide information for the contact person within your agency.
- Does your state agency use LiDAR technology for (choose all that apply): Bridge Clearances, Bridge Inspection, Bridge Survey, Roadway Survey, Other?
- If “other” was chosen, please explain.
- Does your state agency use consultant contracts for LiDAR applications, have equipment and staff in-house, or both?

Overall, 40 State DOT’s and the US Army Corps of Engineers responded to the survey. Figure 9 shows the state responses.

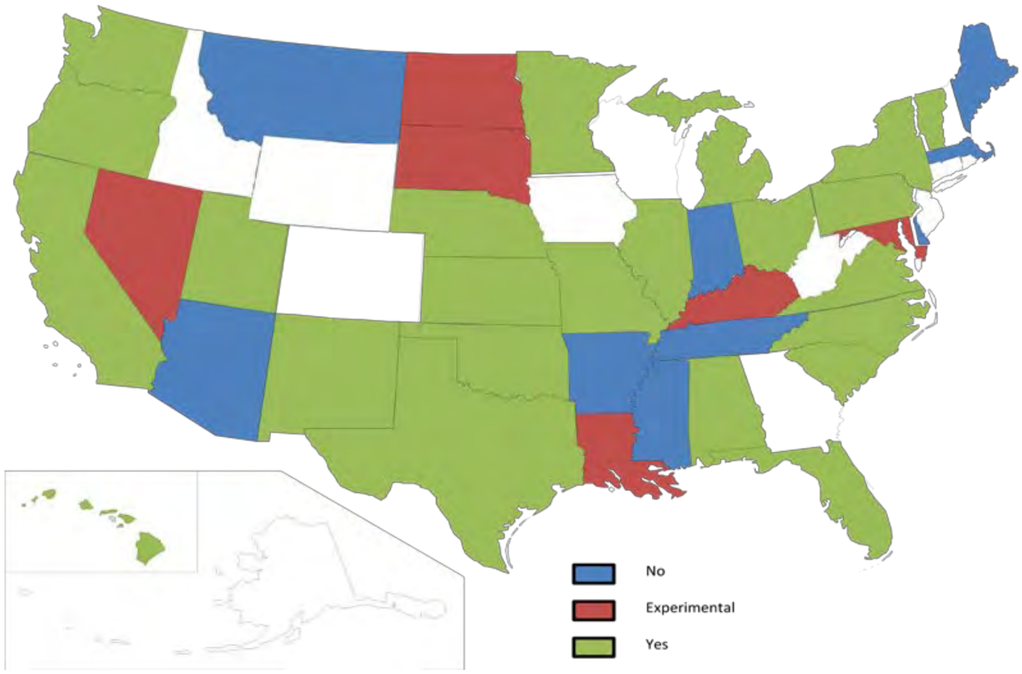


Figure 9. State Responses to LiDAR Uses

Of the 41 responses, nine states responded that they did not use LiDAR technology; six states responded that they did not use it on a regular basis, but provided comments on experimental or early stage use of the technology, and 26 agencies responded that they did use LiDAR on a regular basis. This is an encouraging finding; since it shows that 62% of the states have at least some experimental use of the technology already and at least half of all state DOT's are using LiDAR on a regular basis for some purpose.

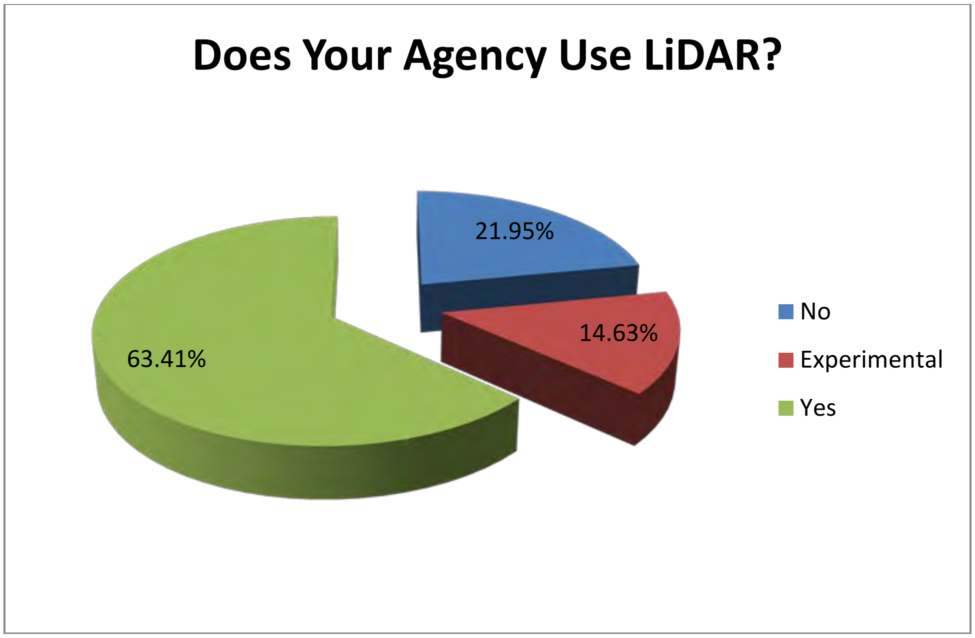


Figure 10. Percent of Responding Agencies Using LiDAR

Of the responses, three states, Michigan, Pennsylvania and Washington State responded that they are using LiDAR for bridge inspection purposes. Pennsylvania commented that they have used LiDAR to do surveys of bridge beams impacted by over-height vehicles and have also used the technology for survey of MSE walls and slope stability.

Responders to the survey also reported use of LiDAR for Bridge Clearances, Roadway Survey and Bridge Survey. Seventeen states reported that they use LiDAR to record bridge clearances, 18 states reported use for roadway survey and 13 states reported use of LiDAR for bridge survey. Fifteen states and the Corps of Engineers reported using LiDAR for “other” uses. These uses included a wide range of applications including power line clearances, measurement of salt stockpile volume, intersection survey, accident analysis, rock cut monitoring, Lock and Dam monitoring, fiber-optic utility installation, corridor planning, cut and fill investigation and hydraulic analysis.

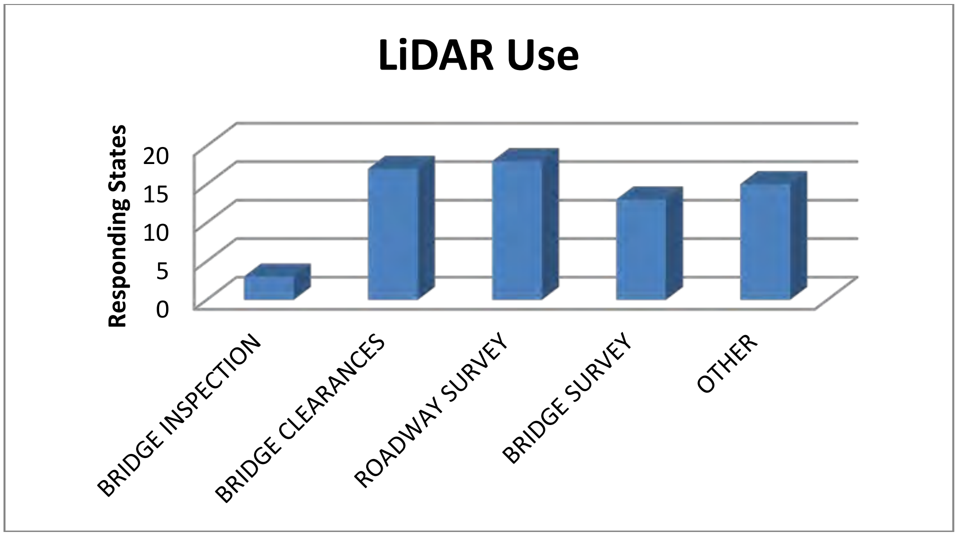


Figure 11. LiDAR Uses among Responders

Many states even responded that they had LiDAR equipment and experienced staff in-house, while the majority of states still contracted out most of their LiDAR work. Thirteen responders stated that they contracted out all LiDAR uses, while 15 states responded that while they have in-house equipment and staff, they still contract out some of the LiDAR work. Only three states responded that they do all LiDAR work with in-house equipment and staff.

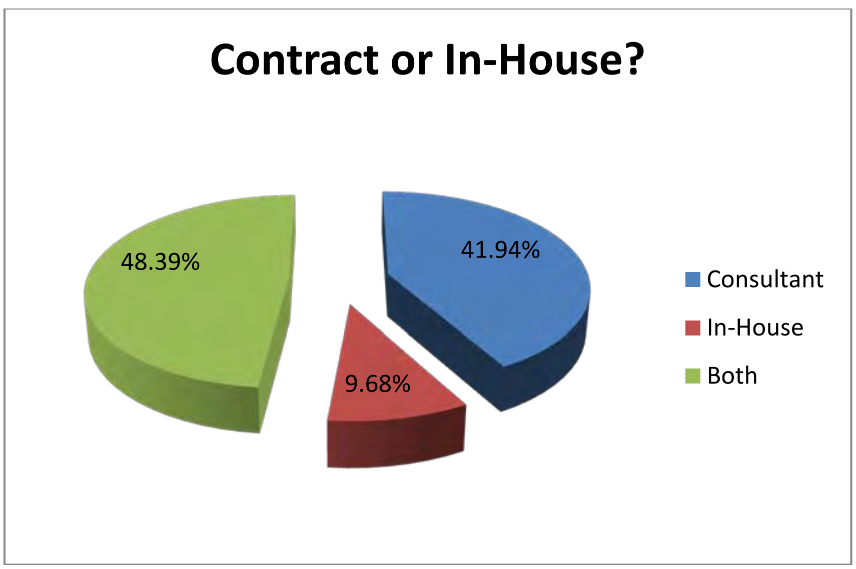


Figure 12. Percentage of Responders that Contract LiDAR Work

From the survey responses provided, it was determined that many states are in a prime position to begin incorporating LiDAR technology into their bridge inspection programs. With many states already having trained staff and equipment in-house, and many more states having relationship with LiDAR contractors, the overall environment for acceptance is a good one. Twenty-five states and the US Army Corps of Engineers provided contact information for those directly responsible for LiDAR implementation within their agencies. This information could be used to reach out to these agencies to learn more about their programs and determine how the UNCC research on Remote Sensing Technology for Bridge Inspection could benefit these agencies.

When analyzing the interviews and survey results, some recommendations for actions became apparent. Recommended steps in developing the model are highlighted below. The first step of the model is the P*reparation for Transfer*. One of the main actions the vendor or researcher can take is to prepare clear instructions for the technology. In this case, a handbook that details the type of uses remote sensing tools can be best used for, as well as the type of data output to expect and how to interpret that data would be an ideal action. This would help to dispel some of the fears of organizations of like KYTC, who fear the data will be overwhelming or fear that the training efforts may be too extensive.

In the second phase or step of the model, the *Marketing* actions take the forefront. The most mentioned key to success of implementation of new technology is the identification of the most effective champion. In the case of KYTC, GRW became an external champion of a technology and an overall marketer. They then identified an internal champion that helped to further their cause. The marketing of the technology fell solely on the consultant in this case, who publicized the technology through showcases at local conferences and technical workshops.

Preparation for Transfer

- **Clear Instruction**
- **Tech Support**
- **Adaptability**

After a pilot program was initiated, the showcasing of the technology became easier following the same local channels used before. In Minnesota, the internal champion was the one that identified the technology and brought several different vendors to the staff to showcase its advantages. California also had an internal champion that showcased the technology by finding funding for a pilot project. Remote sensing technologies may already have champions within each state and these survey results may help to identify those that are more open to innovative technology and pilot studies.

Marketing

- **Identify Champion**
- **Identify Users**
- **Promote**

The next step in technology transfer falls more with the agency. Once champions are identified and “convincing” has been done, it is time for a start-up project in the *Perform* stage. Initiating activity takes funding, however, so often alternate funding sources must be identified. With KYTC, a partnership with the Water Division helped to fund the pilot project, and with Minnesota, the division offices all agreed to spare some of their equipment budget for the start up. A researcher or vendor may be able to initiate pilot projects by providing discounted services or even doing initial projects or trials for free.

All three states interviewed were into the *Manage* phase. Minnesota was the furthest along with purchase of equipment and training of staff already complete. Although Minnesota has done all of their work with LiDAR in-house, they do have a software and equipment support company to help develop processes.

Perform
- **Champion Driving Start-up**
- **Initiate Activity**

Manage
- **Develop Processes**
- **Train Staff**

Researchers or vendors can help new technologies through the manage stage by developing efficient and cost-effective training programs and provide assistance to the agencies to develop processes to help projects past the experimental or pilot phase.

The last two stages that ensure that a new technology will be fully implemented within a government agency are the *Integrate* and the *Optimize* stages. Minnesota has already developed processes and documented them within their system, as well as developed a budget item to maintain their equipment and full time staff. The next steps for the agency will be to determine performance measures and develop a plan for improvement to continue innovative use of the technology in the future.

Integrate
- **Document Processes**
- **Measure Performance and Decide on Success**
- **Budget Program**

California and Kentucky are also on the way to the integrate phase, having moved past the initial pilot projects and continuing to fund further projects. During these phases, the researcher or vendor can continue to have active involvement by helping the agency to develop their performance measures and helping to report the level of performance and suggest improvements.

Optimize
- **Formal Program**
- **Performance-Based Improvement**

Further research is needed to determine if the steps in the presented model will encourage more implementation of new technology. A first step may be to look at the states that have said that they have implemented LiDAR technology and see to what extent and how they are using it. From that information, it may be easier to determine which states are the “innovators” and “early adopters” of remote sensing technology.

Other remote sensing tools such as small format aerial photography should also be investigated in the same way this research has looked at LiDAR use. States may also be implementing aerial photography in innovative ways. Those states may be contacted to market these technologies for use in bridge inspection.

1.5 Implementation Priorities of IRSV Components - LiDAR and SFAP

When the IRSV Project was initiated in the fall of 2007, there were very few highway agencies across the country that was utilizing LiDAR for ANY purpose, much less applications in bridge management and preservation. As the project team started making contacts with various potential users (state and local highway agencies), there have apparently been parallel efforts underway from technology providers, with a time-honored procedure over the past decades that vendors are the most likely source of initiating the use of advanced technologies. The experience of the UNC Charlotte Team was no different from most new technology applications. Once an agency begins adding new technology to its operating units, other states follow suit. This chapter identifies several potential uses of LiDAR primarily, with a brief introduction to SI-SFAP. Spatially Integrated, Small Format Aerial Photography (SI-SFAP) technology will be provided more information to as near as possible identify potential applications of SI-SFAP.

Laser based scanning is an optical remote sensing technique that measures scattered light to identify the shape of a distant object. Several terminologies have been applied to similar technologies including LiDAR and Radar. The key difference between LiDAR and Radar is that shorter wavelengths (such as ultraviolet and near-infrared) are used. Recent advances in LiDAR scanning techniques have made it more attractive and cost-effective for bridge damage assessment and overall bridge management. LiDAR scans provide high resolution, 3D optical images that can be used to quantify bridge component conditions including collision damage, large permanent deformations, overload cracking and different kinds of surface erosion.

Different practical applications of the remote sensing technique for bridge heath monitoring are presented to demonstrate the potential in enhancing the bridge management decision-making process at the state, local or regional level. "Remote sensing" in the context of this research project applied to any method that does not come in contact with, or be imbedded in a bridge member. Although these methods will never substitute for traditional bridge inspection methods, the combination of these remote sensing techniques could yield a better understanding of bridge health condition in a simple yet comprehensive way.

LiDAR is the optical remote sensing technology developed for range detection. The images produced by LiDAR result in millimeter resolution. A typical LiDAR system is formed by a transmitter, a receiver and a signal processing unit. The transmitter emits a series of light to the object. The receiver receives the reflected energy and the time cost of the reflected energy traveled back from the object is measured in the signal processing unit. Then the two-way distance between the scanner and the object can be calculated by multiplying the speed of light with its travel time.

One cycle of a measuring process can only collect the range information of an object in its direction of view. To obtain the surrounding information instead of a single point, a reflection mirror with an oblique surface is placed opposite to the scanner transmitter, rotating 360 degree vertically. The laser head itself also rotates 360 degrees horizontally. After the scanner head rotates 360 degree horizontally, a full scan can be finished. The scanner head and mirror direction as well as the collected range information forms the 3D position of each point relative to the scanner. A point "cloud" of the target surface is formed by the combination of these 3D points.

A LiDAR-based automated bridge structure evaluation system, called LiBE (LiDAR Bridge Evaluation), was developed over the course of this project with the functions of a) defect detection and quantification, b) clearance measurement, and c) displacement measurement for bridge static load testing. The following descriptions will introduce the potentials of LiBE for bridge health monitoring.

Bridge defect detection and quantification

The LiBE protocol developed for this project for damage detection and quantification uses a second-order analysis technique to detect structural problems and to quantify surface defects. By recording the surface topology of any component of the bridge deck and superstructure, the laser radar can detect different levels of damage on the structure and differentiate damage types by contrasting surface flatness and smoothness. LiBE detected bridge defects based on its surface roughness and bias to the surface plane. The target area is first divided into small grids. In this case, using a 10 X 10 point grid results in a 0.01m X 0.01m resolution.

The gradient of each point and the distance between the point and the surface plane are calculated in each grid. A grid is determined to be defective depending on the number of irregular points within the grid. An omni-directional search reveals defective grid connectivity. The area and volume of each defective area can be calculated based on the area of each defective grid. The rate of irregularity in each grid determines the severity of the problem. The benefit of using the LiDAR scans becomes clearer when data are collected for the defective area over a period of time, yielding the rate of mass loss in the bridge element.

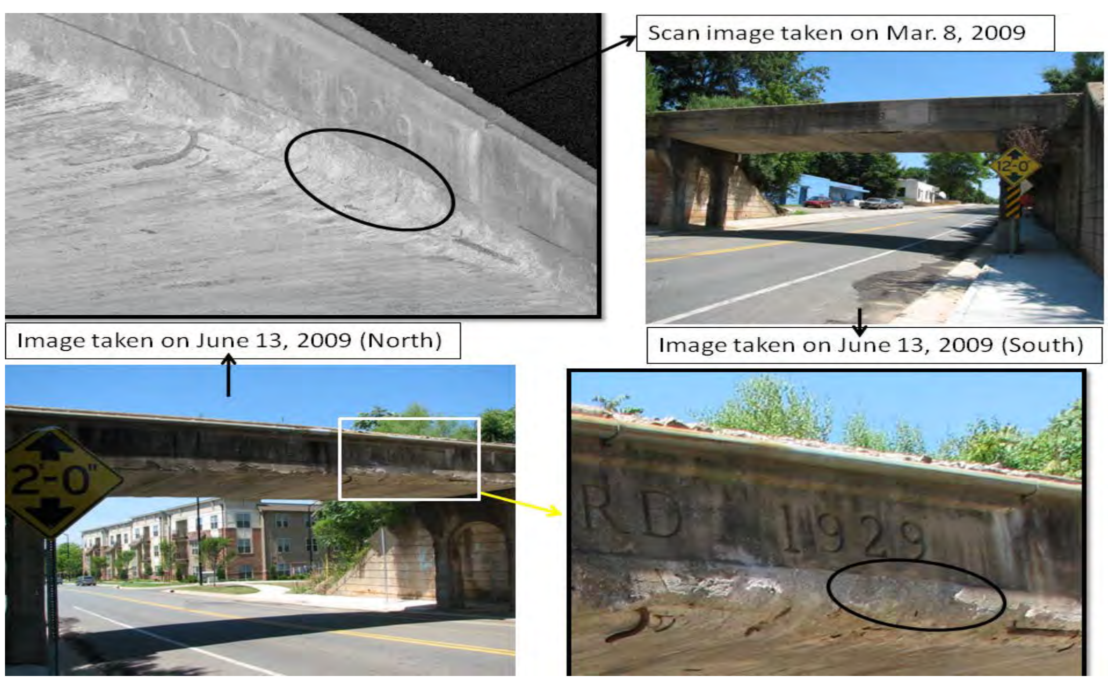


Figure 13. Collision damage comparison of Bridge 590704

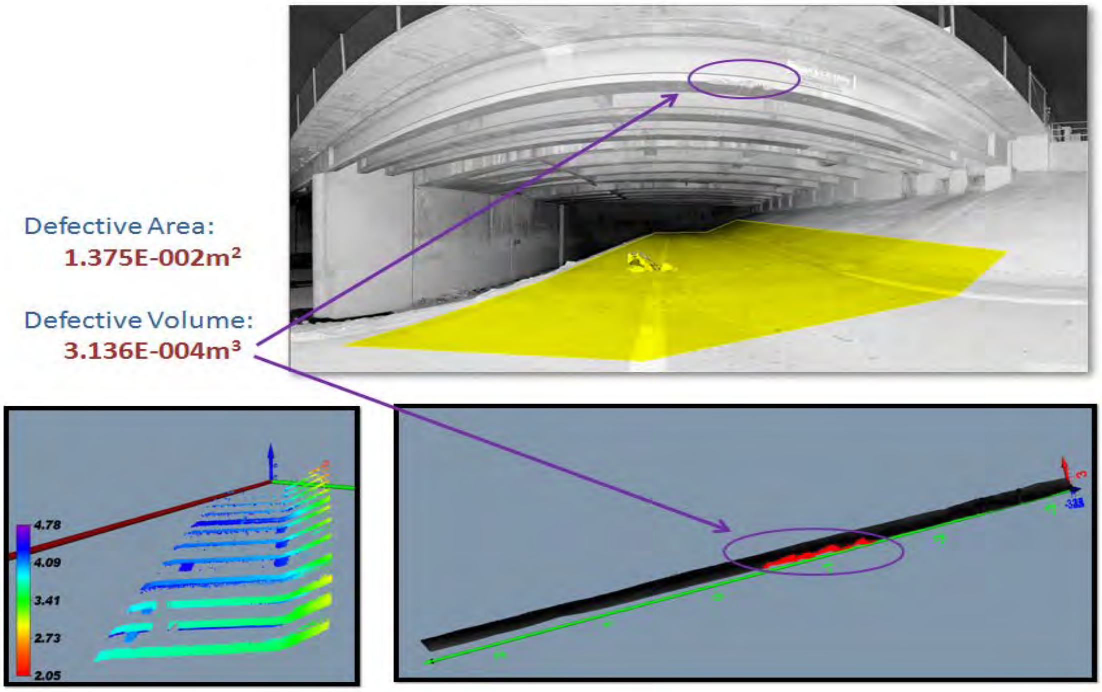


Figure 14. LiBE results from Imperial Highway (CA) bridge study

Bridge Clearance Measurements

Another application of LiDAR bridge data to the bridge is clearance measurement. Bridges with low clearance are vulnerable to vehicle collision damage. Clearance height changing over time can reflect vertical structural movement, ground settlement, or pavement overlays. Clearance measurement by LiBE indicated that the bridge clearance is increasing from the front side to the backside. At the damage location, the clearance was measured as 3.6m, which is 0.6m longer than the posted limit of 3.0m.

The minimum vertical clearance area is located in around the center of the deck on the north side. The clearance of the bridge is increasing from that location to all around. Therefore, the south side of the bridge has higher clearance than the north side and corners of the south side have the highest clearance among all the locations. It can be concluded that clearance here is the main factor that determines the damage level of the bridge. Proper pavement treatment can be proposed to increase the minimum vertical clearance of the bridge and this clearance measurement method can be used to guide the treatment.

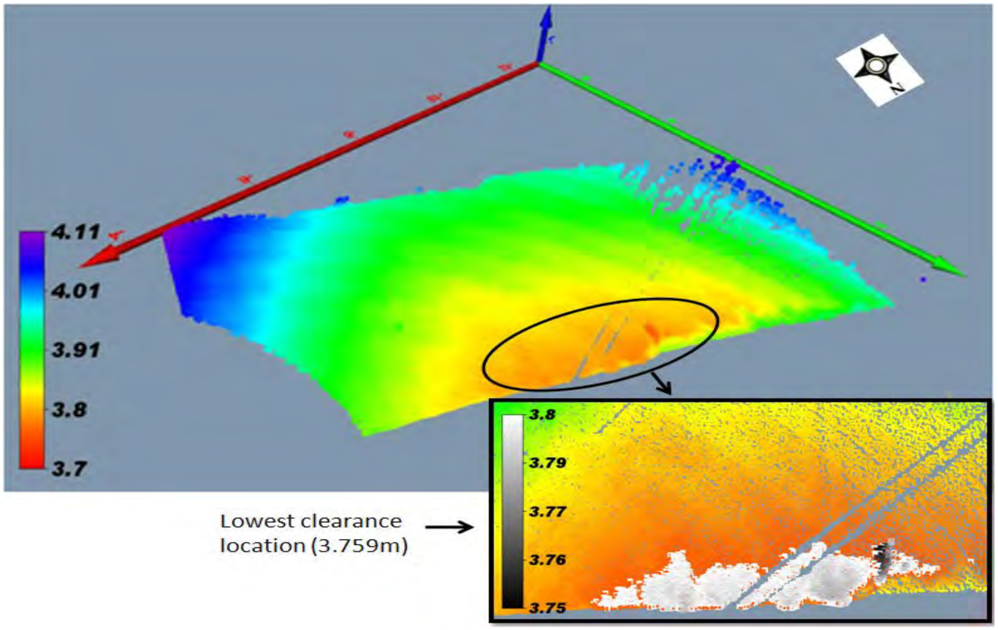


Figure 15. Vertical clearance plot of Bridge 590704

The 3-D laser scan technique has also been used for load testing of a bridge on Langtree Road over Interstate I-77 near Charlotte**.** This recently constructed bridge has three spans, with nine steel girders under the reinforced concrete deck. For load testing, two heavy-duty dump trucks were used to provide the static loading at fixed locations on the bridge. Truck A weighed 55,640 pounds, and Truck B weighed 54,820 pounds.

Two trucks parked side by side with girder seven (counting from right to left) passing through their center during loading. The bottom image renders the displacements of sample points on the bridge girders, which were generated by LiBE based on the LiDAR data. From the displacements display it can be seen that parts of the three girders, which were near the truck location, have relative larger displacements than other locations.

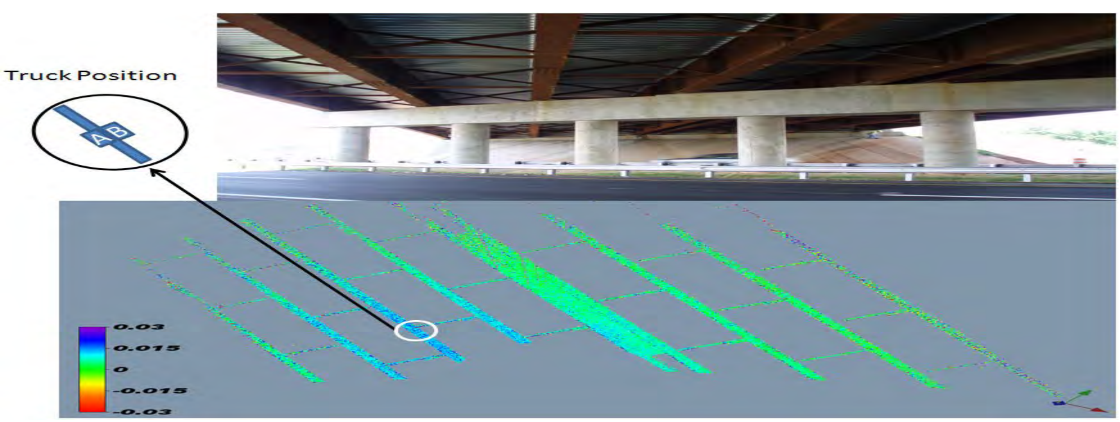
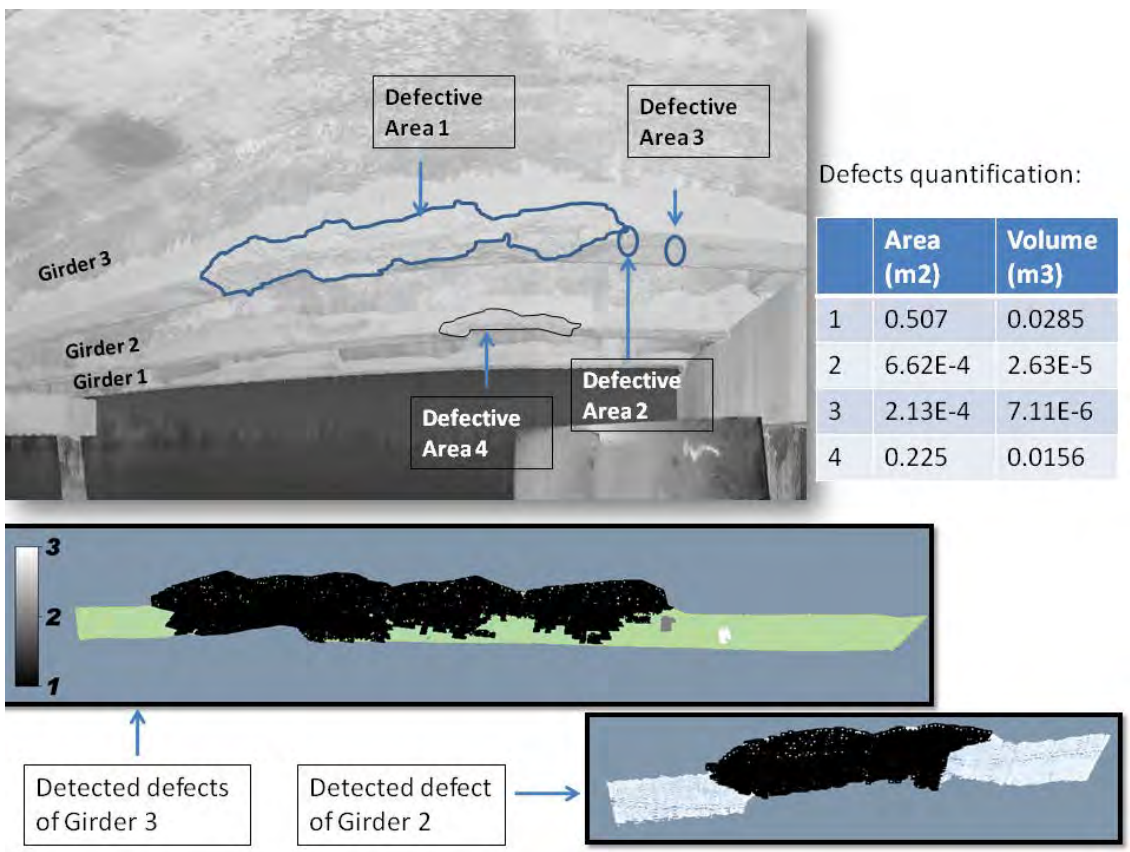


Figure 16. Load testing using LiDAR scan

One of the most difficult challenges in conducting a LiDAR scan of bridge superstructure is where bridges traverse a waterway. The research team worked with the Division Bridge Engineer in the Wilmington area (New Hanover County) to test out the capability of providing a steady platform and keep it level in order to run a LiDAR scan. In this particular case, a boat that is used by NCDOT personnel for inspection and light maintenance work was provided to provide a platform on a bridge span on US 74 connect Wilmington with Wrightsville Beach (NCDOT Bridge # 640024). The experiment worked better than anticipated, with very little unsteadiness in the 22 ft. “Boston Whaler,” which was secured to bridge piers on both ends of the boat to provide a steady platform for the LiDAR. However, one of the factors that made this test successful was a relatively moderate current on the inland waterway on the day the test was run.



	Area (m2)	Volume (m3)
1	0.507	0.0285
2	6.62E-4	2.63E-5
3	2.13E-4	7.11E-6
4	0.225	0.0156

Figure 17. Damage detection and quantification of NCDOT Bridge # 640024

<u>Clearance measurement</u>

Bridges with low clearance are vulnerable to being struck by over height trucks and other high loads. North Carolina DOT sets the design requirement for bridges over interstates and freeways at 5.0m; over other roads, bridge clearance must be 4.6m. Several older roadway bridges that were built prior to 2000 in Mecklenburg County have a minimum vertical clearance lower than

4.6m. Most of these bridges have experienced collision damage, which can increase deterioration and reduce their service life.

In the ideal case, with accurate calibration before a scan, the z value of each scan point equals to the vertical distance between the point and the scanner head. By matching the point on the deck with each point on the ground, the clearance above each ground point is measured by calculating the z value difference between the ground point and the matching point.

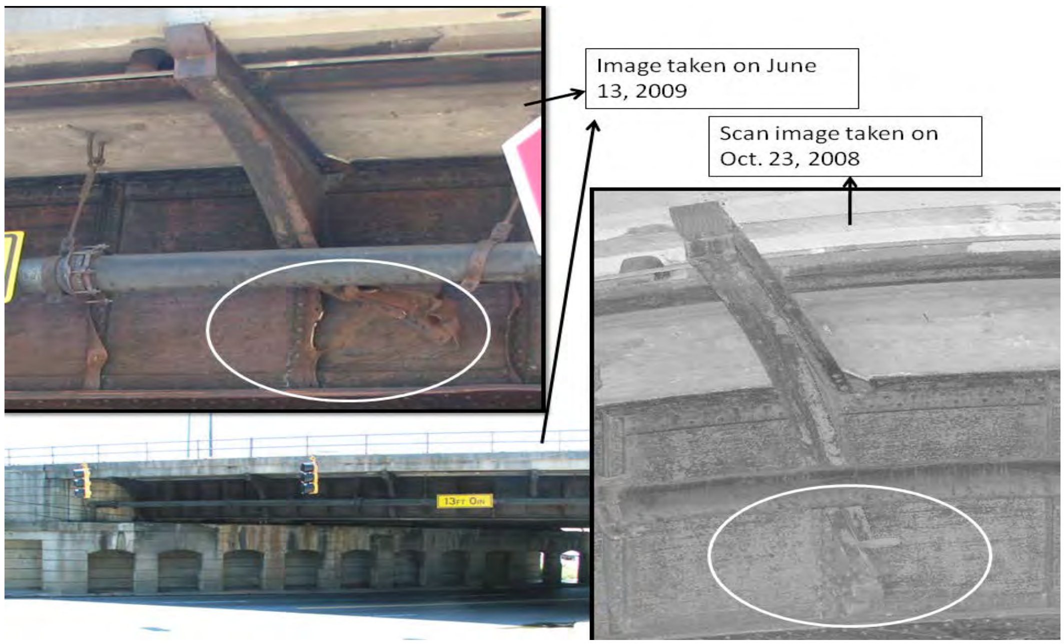


Figure 18. Collision damage comparison of Bridge # 590700

Displacement measurement for load testing

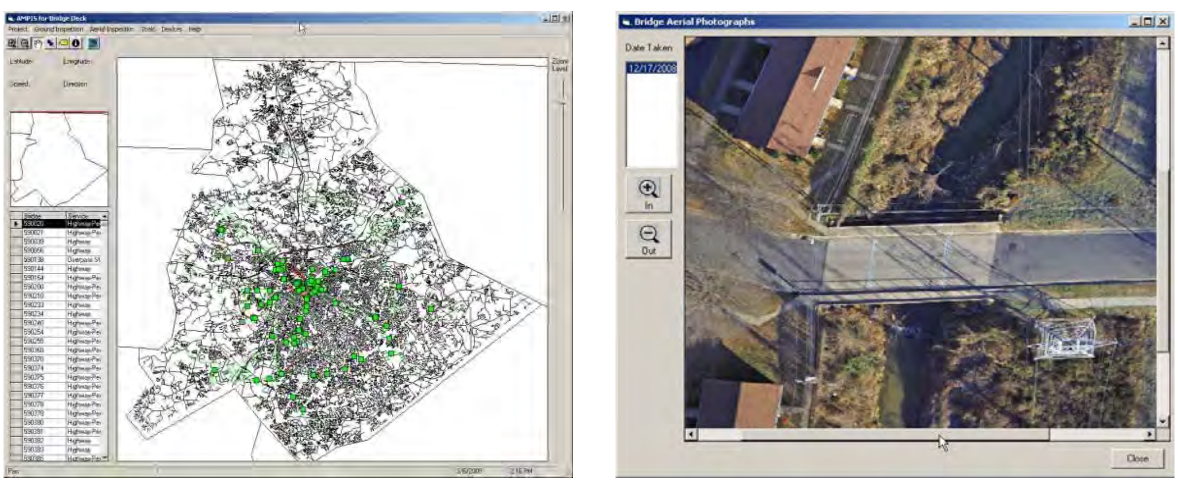
By comparing the deck surface position before and after loading, LiDAR scan can be used for displacement measurement during bridge load testing. The accuracy of the measurement is in millimeters. Strain gauge and displacement transducer have been widely used in bridge load testing to measure strain and displacement. Both of these two methods need to contact the surface of the bridge components and the measuring is restricted only to the sensor installation locations. LiDAR scan is a noncontact method and can provide the displacement of the entire scanned surface simultaneously. This information is useful for bridge structure computer model updating and structure performance monitoring.

The scanned records of the bridge can provide bridge managers direct information on current conditions of the bridge. The LiDAR-based bridge measurements and evaluations are repeatable. With the utilization of LiDAR technology and an automated data processing system, bridge inspection accuracies can be improved significantly. More accurate bridge inspections and damage evaluations can lead to better maintenance decisions.

Integration of IRSV with AMBIS software

In the IRSV Phase One project, the primary sub-contractor/ partner in the initial research tasks was ImageCat, Inc., a consulting firm based in Long Beach, CA. In this project, ImageCat collaborated with UNCC's Software and Information Systems (SIS) group to create a database link between the IRSV data model and the Automated Management of Bridge Information System (AMBIS). Common elements of the bridge database are now shared between IRSV and AMBIS. The AMBIS workflow was revised so that when a user defines a project to collect and import data, all the data is linked by the unique bridge identifier. This effectively allows a very tight integration between the two systems without sacrificing the flexibility and modularity of AMBIS. While running the program, IRSV requested analysis results for a specific bridge from AMBIS, the results are returned, and IRSV posts the results to users.

These results are imported into the IRSV system and are accessed through the IRSV inference engine, in a similar manner that data from the bi-annual on-site visual inspection is imported into the IRSV visual images. The relationship among the remote sensing databases (such as high-resolution aerial photography), the analysis components (AMBIS and Ground Truth Analysis), NBIS Database, and the IRSV Rating for each bridge is shown below. As the result from the AMBIS analysis program, and the on-site "ground truth" inspections and resultant proof of concept index, a comparison can be made with the calculated IRSV Bridge Rating. This rating is assumed to be on a scale of 1 to 9, in order to give it the same range of ratings that is commonly (but not universally) provided by bridge management engineers based on NBIS (National Bridge Inspection System) inspection data.

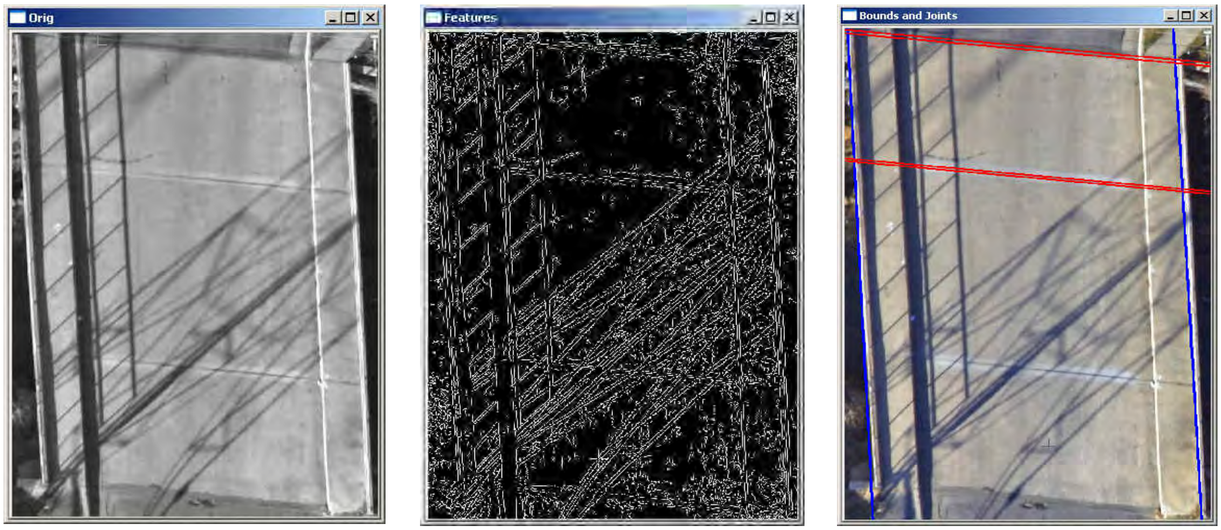


a) A new map-centric interface

b) Integration of very-high resolution aerial photography

Figure 19. Innovations using AMBIS

ImageCat explored different alternatives for processing aerial photographs. The challenge was to recognize joints, but ignore shadows, which often had a very similar pattern to the joints or may interrupt the pattern of the joints.



a) Raw image b) Results of edge detection and filtering c) Results of joint detection algorithm

Figure 20. Images resulting from AMBIS algorithm

Preliminary results of the joint detection algorithm in AMBIS

Following is an example of LiBE application, with data obtained at a bridge on the Imperial Highway crossing the Long Beach Freeway, Route 710 in Los Angeles, California. The lower right image illustrates the detection and quantity of the damage on the front girder that is typical of losses caused by vehicle collisions with a bridge girder. LiDAR scan provides precise quantities of material loss. The bridge managers recognized the benefits derived and the potential applications of remote sensing technologies in helping quantify bridge damage that cannot be accomplished using visual inspection only.

High Resolution Photography

Aerial photography is the original form of remote sensing and remains the most widely used method. Typical applications include geographical mapping, military reconnaissance, environmental studies, and geological explorations (5). These photos are generally taken at high altitudes, i.e. 5,000 ft. and higher, providing general spatial information such as coordinates, orientations and colors. For a tool to aid in bridge inspections, higher resolution images are needed. As a result, the aerial photographs used in this study are taken from a much lower altitude (approx. 1000 ft.) such that higher resolution digital images can be captured. This technique is called Small-Format Aerial Photography (SFAP). Since these photos are from a lower altitude, the orthogonal rectification of the imagery was not performed. The photographic scale of the photo can be determined using Equation 1.

$$Scale = \frac{L}{H} \quad (1)$$

Where, L is the lens focal length, and H is the camera or flight height (Figure 1.12).

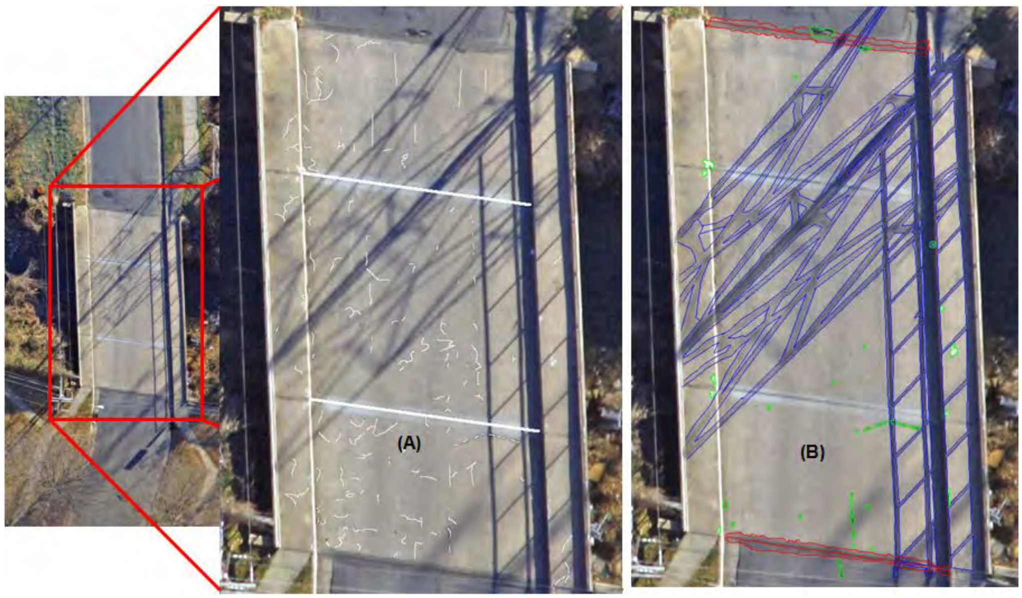


Figure 21. Aerial photo processing: (A) crack analysis (B) noise analysis

1.6 Commercialization Process - Extended Focus on SI-SFAP

1.6.1. Overview of Phase One Commercialization and Partnering

As we concluded Phase I, we had tested and validated this approach on 21 different bridges in the Charlotte area in collaboration with NCDOT and Charlotte DOT (16 and 5 bridges, respectively). The tests present a glimpse to the potentials of the two proposed CRS technologies for bridge monitoring. Several data are not readily available to include in the database at this point in time because of limited bridge types.

The summary results of bridges studied in this project were shown in Chapter 1.1 with an overall count of 79 bridges (total) scanned using aerial photography in six states. The data for all bridges scanned were taken from the most recent NBIS database for each bridge (times over a two-year period that are identified as either 2004 or 2006 in the NCDOT and CDOT databases). Note that the “status” of the bridge (the metrics that receive much attention in the press - functionally obsolete or structurally deficient) is not available for all bridges in our sample. Several bridge condition ratings computed from CRS data. The different condition ratings are also identified with the specific problem types that are associated with the AASHTO CoRe element types. Hence, the CRS-based condition ratings are not a bridge-level rating, hence, no attempt is made to compare the condition ratings with the NBIS rating. The condition ratings that were calculated from the three technologies used in the IRSV system – Aerial Photos, AMBIS bridge deck analysis, and LiDAR results. These results are presented as a demonstration of the potential condition indicators that can be adopted for bridge monitoring. Although only three bridges (all three are bridges over roadways or water) are completed at this time. The existing NBIS Sufficiency Rating is presented along with all three CRS-based condition ratings: BSCI Aerial Photo Rating, AMBIS-DDI Rating and LiDAR Damage Rating. Each of the measurements taken has been "normalized" into a numerical scale.

1.6.2. Overview of Phase Two Commercialization and Partnering

The UNCC Research and Prototype Development Team was enhanced during Phase Two of the IRSV Project by adding an engineering consulting firm (Boyle), specializing in environmental assessment, geotechnical engineering, construction quality assurance/ materials testing, geospatial technologies, and high resolution aerial photography. As a partner in the IRSV project, Boyle collected high resolution, *georeferenced, manually rectified* vertical aerial images of bridge decks in the states of North Carolina, Alabama, and Florida, utilizing the Boyle Cessna C210L airplane and a small-format, Digital Single Lens Reflex (DSLR) camera (Canon 5D).

To test the commercial viability of the technique, the data was also obtained using members of the Professional Aerial Photographers Association (PAPA) the predominant trade association associated with aerial specialists using the DSLR camera type. See the following website: (www.papainternational.org). The Boyle team consisted of members of PAPA, and their services were used for collection of aerial photos of bridge decks that were included in this project. There are approximately a dozen members of PAPA around the country that are certified in use of Small Format Aerial Photography (SFAP). For this IRSV project, the following professional photographers were used.

Table 4. Networking of Professional Aerial Photographers Association

Jurisdiction Surveyed	Aerial Photographer
City of Charlotte DOT	BOYLE
NC DOT, Div 10, Div 12, HQ	BOYLE
City of Los Angeles DPW	Dave Byrnes
Florida DOT, Div 5	BOYLE
Osceola County, Florida	BOYLE
Alabama DOT, Division 4	BOYLE
Shelby County and Alabama DOT	BOYLE
Iowa DOT	Don Voland
New York State DOT	John Majoris

For this research, Boyle and PAPA members used readily available, inexpensive, commercial off-the-shelf technology, to demonstrate the viability and cost effectiveness of the technique for improved bridge management in the United States. There are over 600,000 bridges in the United

States and limited budgets are available to inspect and maintain them. The objective of the "flyovers" is to obtain cost effective, color digital photography and data, of sufficient resolution and accuracy, in order to view meaningful and measurable bridge deck condition factors. Visualization and measurement of condition and environmental factors such as cracks, spalls, joint separations, water staining/ drainage, etc. in bridge decks can be used to assess pre-curser conditions related to bridge structural performance, deterioration, movement, and failure, as well assist in more effective and objective decision making in bridge preservation practices. This has been accomplished by obtaining high resolution digital color photography with pixel sizes less than 1 inch.

Table 5. Capabilities of PAPA members used in this project

Photographer	**Chuck Boyle**	**Dave Byrne**	**John Majoris**	**Don Voland**
RW/ FW	FW	FW	FW	RW
Aircraft	C210	M20J	C177B	SchweizerT33
Airspeed	90 KIAS	90 KIAS	100 mph	30 MPH
Altitude (Feet AGL)	1,000	1,000	1,500+	300
Time of Day	Late AM	Noon	Early PM	Late AM
DSLR Camera	Canon 5D	Canon 5D MkII	NikonD3X	Canon 1DS Mk III
Camera Settings	Aperture, ISO 400 F4.5 1/x	Manual, ISO 400 F5.0 1/4000	Aperture, ISO 400 F4.0 1/x	Shutter, ISO 200 FX.0 1/1000
Lens	135mm	135mm	200 mm	46 mm
Geography	Piedmont NC and AL, Coastal FL	Los Angeles	Hudson River Valley	Iowa
GSD	0.7 inch	0.6 inch	0.7 inch	0.49 inch
Airspace Access	Class B, E No delays	Class C,D,E No delays	No delays	Controlled & Uncontrolled
Terrain Maneuvering	No issues	No issues Longer lens would be required for mountainous areas	Needed longer lens for higher maneuvering altitude	No issues
Excessive Ground Reflectance	No issues	Bridges over water require sun angle < 45 degrees	No issues	No issues

KIAS=Knots Indicate Airspeed
AGL=Above Ground Level
MPH=Miles Per Hour
FW=Fixed Wing (Airplane)
RW=Rotary Wing (Helicopter)

1.6.3 DSLR Technology

The Digital Single Lens Reflex (DSLR) camera (such as the Canon 5D or equivalent Nikon, etc.) has recently demonstrated potential for widespread remote sensing asset management applications, particularly if integrated with geographic information systems (Spatial Integrated-Small Format Aerial Photography, SI-SFAP). Its primary advantages at the time of this writing include:

- Full frame sensors (35 mm) with high electrostatic recharge rates allowing rapid firing (4-5 frames per second) at maximum pixel sensor utilization.
- Large selection of optics allowing for flexible altitude planning in the National Airspace System as well as very high resolutions at the altitudes employed (Ground Sample Distances of less than one inch).
- Significant utilization by professional aerial photographers utilizing General Aviation assets across the United States.
- Extremely high shutter speeds, negating the need for Forward Motion Compensation (FMC) typically used in "aerial cameras"
- Low cost and fast turnaround, particularly for temporal (time sensitive) analysis applications.
- Sensor attributes, specifically high shutter speed, that allow the effective use, without image blur, on stable, fast-moving fixed wing aircraft or UAV, negating the current requirement of utilizing larger sensors on slower, and more expensive, rotary-wing aircraft.

Camera Equipment, Optics, and Preparation

The camera is prepared by ensuring adequate battery charge and a functional, cleared internal data memory card capable of storing the total number of images identified during the Photo Mission Planning phase of work. With some variation of camera settings based on time of year (season) and time of day for the mission, the camera is prepared as follows:

Camera: Canon 5D w/ 35 mm CMOS sensor
Lens: 135mm Prime (Canon "L" series)
Exposure Setting: Aperture Priority
Shutter Speed: Minimum 1/2000
Aperture, FStop: f4.5
ISO Setting: 400
Focus: AF/ Auto-focus
Image Stabilization (IS): Off

Note: Deviation from proper camera settings (for available light) will not change the "image capture resolution" (pixel size) but may cause less clarity in the aerial photo (excessive noise, slow shutter, large aperture, etc.) which makes crack and joint feature interpretation and measurement more difficult/ less accurate. It is imperative that the aerial photographer consider all pertinent factors related to proper exposure including the presence of clouds over the bridge site, time of year (sun angle to the ground), time of overflight during the day, presence of water under the bridge, shadows, bridge deck reflectance, etc. The general approach to correct exposure setting is as follows:

1. Adjust aperture setting to focus light on the highest quality part of the lens, typically 1.5 stops from wide open.
2. Set light metering to average-weighted; this may vary depending on the orientation of the camera in the aircraft and other geographic/ lighting considerations.
3. Set ISO to the most sensitive (400+) to ensure extremely high shutter speed while minimizing noise in the data collected.

Actual technique employed varied (as expected, but minimally) among photographers.

Planning Image Capture Resolution and Ground Coverage

The first items to consider in planning the aerial photo mission for the project is to understand what "image capture resolution", ground area coverage, and deliverables are required. For this project, it was necessary to obtain imagery with a pixel size less than 1 inch and sufficient ground area coverage to accommodate the targeted bridge within the center third of the photo. The one inch pixel size, when accurately georeferenced, would allow for measurement within a GIS (geographic Information System) of very small features identifiable in the image; therefore, the digital format of the final files need to be in "geotiff" or similar file type.

The pixel size is determined as follows:

N/F=C/H and Pixel Size=C x 12/long dimension pixels

Where: N=Size of long dimension sensor (mm) (perpendicular to flight line)
F=Focal length of lens (mm)
C=Ground coverage long dimension (ft.) (perpendicular to flight line)
H=Altitude of camera above the ground in feet (ft.)

Example:

Given: Canon 5D w/ sensor length of 4368 pixels across 35 mm
N=35 mm
F=135 mm
H=1,000 ft. above ground, minimum safe operating altitude for fixed-wing aircraft in congested area (see Federal Aviation Regulations)
C=HN/F=259 feet (width of coverage)

Pixel Size= 259 feet x 12/4368 pixels= .7 inch pixel size

Pixel Size Calculation Considerations

Focal length: In order to increase the accuracy of the pixel size calculation, the lens focal length should be determined. A prime lens that is produced and delivered from the factory, and advertised to be 125 mm, may actually be 125.55 mm. The actual focal length may be determined through testing or by obtaining a lens calibration record from an approved independent testing facility such as the USGS. In all cases, a "prime" lens of fixed length should be used, rather than a variable focal length lens ("zoom" lens) to ensure focal accuracy and lens optical quality associated with the "prime" lens.

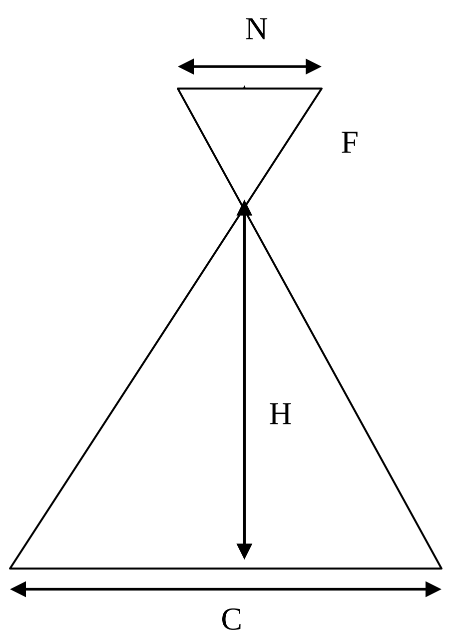


Figure 22. Dimensions of SFAP Set-up

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Sensor Size: The camera sensor dimension should be the "effective" sensor dimension listed in the camera technical specifications.

Aircraft Altitude: There are two types of altimeters used in aircraft to determine the aircraft altitude: 1) Barometric altimeters and 2) Radar altimeters. Radar altimeters are generally much more precise than barometric altimeters but not generally used on light general aviation aircraft. The barometric altimeter can be set prior to takeoff by adjusting the device to match the known field elevation located at the departure end of the runway. Alternatively, if an AWOS (Automated Weather Observation Service) or ATIS (Automated Terminal Information Service) is available at the departure airport, an altimeter setting is provided and used, prior to takeoff. The altimeter instrument should be set periodically in flight, especially if weather patterns of low/high pressure are moving through the flight area.

In any case, the aircraft altitude, altimeter setting, and time of day should be recorded during flight and supplied with the final imagery for quality control purposes. A deviation of 10% from the assigned altitude will have a 10% deviation in planned pixel size.

1.6.4 Flight Track Planning and Photo Exposure Planning

Once the mission altitude (height above ground level), camera, optics, and camera field of view (ground coverage) have been determined based on requisite image capture pixel size (typically less than 1 inch), then the mapping of the flight track, ground coverage area, and camera on/off waypoints may be conducted. All photo mission and flight track planning should be reviewed and approved by the FAA-licensed Commercial Pilot-in-Command (PIC) prior to takeoff, to ensure that photo requirements do not present a safety hazard to flight.

For this research, BOYLE utilized a Cessna C210L. It is recommended by the Cessna 210 Pilots Association that a flight in the C210L be conducted no more than 4.0 hours at cruise power setting (approx. 160 mph at 17 gph-gallons per hour). This gives the aircraft a range of about 640 miles without refueling.

When conducting overflights of bridges, a more practical range will restrict the distance to about 300 miles at the overflight speed of 100 mph, to avoid excessive pilot fatigue and subsequent poor aircraft handling which affects image quality. If the bridges are well spaced and limited time is spent flying from one bridge to the next, each flight may afford photographing approx. 30 bridges, or approx. one bridge for every 10 miles of track flown (typical).

If bridge locations are more closely spaced, more bridges cannot necessarily be photographed in the same time period, since the maneuvering required becomes excessive and pilot fatigue increases rapidly. If bridge locations are more widely spaced, then too much time is used to travel between bridges to meet cost control objectives.

Software

Garmin Mapsource software, in conjunction with a Google Earth interface, is used to perform the flight track and photo exposure planning tasks. This software is ideal for bridge mapping because it is 1) affordable, 2) allows detailed planning of flight tracks over readily available (and free) orthoimagery datasets that cache to your desktop from the internet, 3) affords viewing of aeronautical maps and other feature datasets for flight planning, 4) affords viewing of any other GIS feature attributes such as political boundaries, transportation system divisions, and 4) integrates easily with portable aeronautical GPS devices such as the Garmin 296/396/496 commonly used in General Aviation aircraft. Alternative, and more conventional, Aerial Survey Flight Management Systems (FMS) may be used (such as Track ‘Air etc.), however, these FMS are typically used for higher altitude, larger area, low resolution mapping projects, are not generally integrated with small-format DSLR cameras, and do not have ready access to needed geospatial data.

The following steps are used for flight track and photo exposure planning:

Step 1-Gather Information and Spatial Understanding

Planning begins with collecting bridge location information, Lat/Long, address, cross street, water features, etc. from the client or available from FHWA as NBI GIS files, .shp. Bridge locations are then identified and plotted in ArcMap and exported as .gpx (GPS Exchange format) files that can be read in Mapsource with a visual interface to Google Earth, which contains geo-referenced VFR Sectional Charts and Terminal Area Charts for Uncontrolled and Controlled Airspace flight path planning.

Step 2-Map Flight Waypoints for Each Bridge in Garmin Mapsource

Each bridge is given three waypoints. "Camera Approach" point, "Camera On" point, and "Camera Off" Point. The "Camera On" point is placed first at a distance of approximately 200-300 feet before the beginning of the bridge and in alignment with the center of the longitudinal axis of the bridge. The "Camera Off" point is placed at a distance of approximately 200-300 feet beyond the end of the bridge. The "Camera Approach" point is then placed approximately 10,000 feet before the "Camera On" point and in alignment with the track created by the "Camera On" and "Camera Off" points. The intent is to create a VFR flight track that is safe and easy to fly.

Photo Exposure Planning: After the flight track and Camera On/Off exposure waypoints have been determined, subsequent mid-track exposure waypoints may be mapped if desired. The exposure waypoints are based on a 30-50% forward lap of each image. Alternatively, for short bridges of relatively short overflight, the camera may be preset to fire continuously.

Figure 23. Waypoints and Direction of Flight Path

Factors to consider when determining waypoints and direction of flight run:

- relationship to air space restrictions and other aircraft traffic
- relationship to other bridge locations and overall flight route
- relationships to other obstructions/dangers .i.e. radio/cell towers, stadiums, airports, buildings, etc.

Step 3-Create Flight Route in Portable Aeronautical GPS

Using the Route tool in Mapsource, a Route is completed from Airport of Departure to Camera Approach point of the first site, Camera On and then Camera Off to the next Camera Approach point (of the next bridge) until the last Camera OFF point, before returning to the Airport. The route and waypoints are saved and the .gdb file is exported to the GPS device.

1.6.5 Mission Execution

The actual execution of the flight track is dependent on many factors to consider:

- Weather and available light, especially at the bridge site
- Airspace flight restrictions, especially at the bridge site
- Estimated time of arrival (ETA) at the bridge site

The goal is to minimize shadows on the bridge deck and achieve the correct camera exposure at the time of the bridge overflight. Camera settings may need to be adjusted during progress of the flight, to adjust for changes in sun position. For bridges over water, the flight should not be conducted with a sun angle greater than 45 degrees above the horizon.

BOYLE utilizes a C210L (Centurion) aircraft to conduct the flyovers. This aircraft is ideal for small area, high resolution imaging, because of its relatively high airspeed (160 mph) to move from site to site over large geographic areas in a DOT jurisdiction, its ability to slow down for photo missions (100 mph), and its ability to fly safely at the lowest altitudes over congested areas (1,000' agl-above ground level) with a crew of 2 people. The high-wing configuration for potential oblique photography and its relatively low operating cost (approx. $150/ hr.) also make it attractive compared with other aircraft that are more typical in the aerial mapping industry (light twin engine aircraft, for example). Other aircraft such as the C150, C172, C177, and C206 may be used effectively as well. Aircraft that may not be well-suited include low-wing models which limit oblique photography (if needed) or particularly slow aircraft (such as helos) which are less stable, subject to gusty conditions, especially at low altitudes.

Figure 24. C210L with Portable GPS

After being prepared, the camera is mounted in a non-gyro-stabilized, non-articulating, pitch and yaw-adjustable camera mounts with vibration dampeners such as the one depicted here:

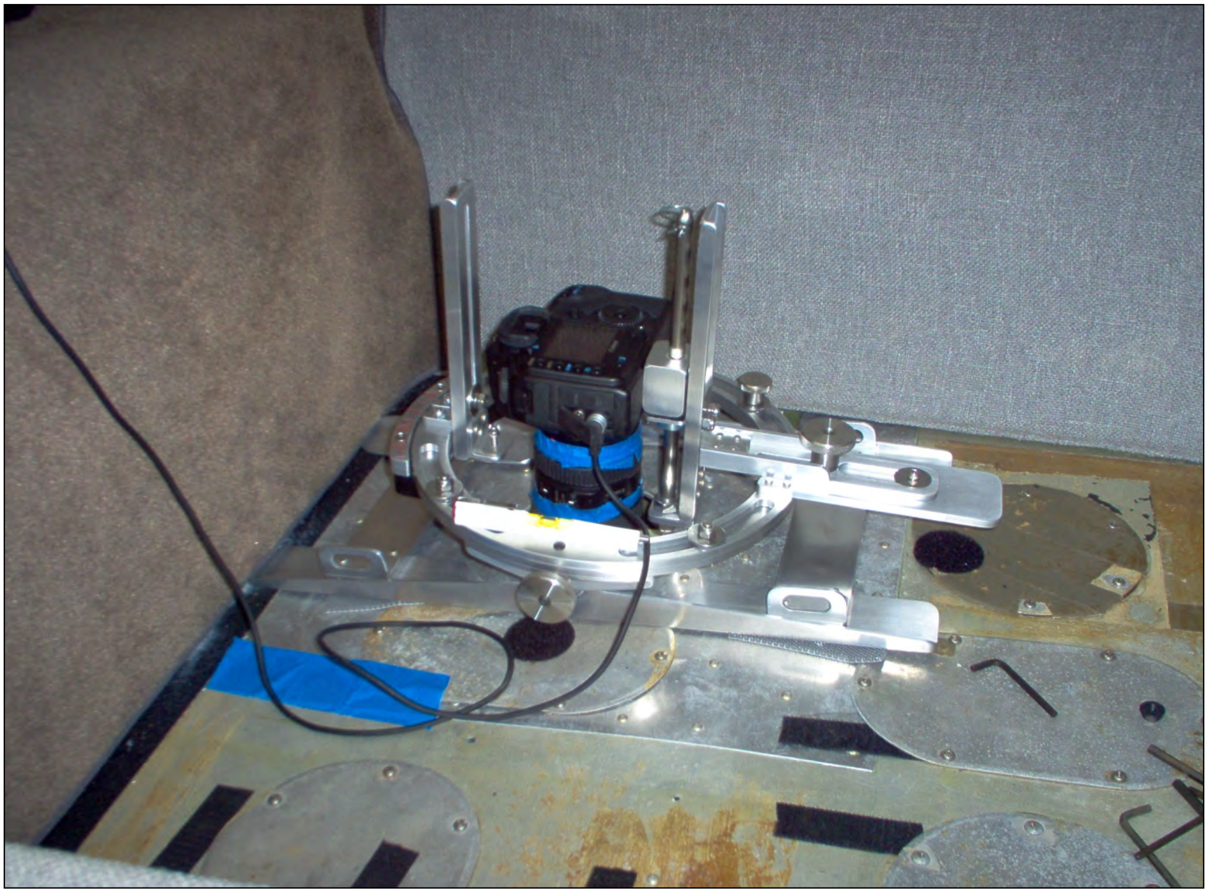

Figure 25. Canon 5D Mounted in C210L Baggage Hold Compartment

The camera and mount are configured so that the camera is oriented in the vertical ("nadir") position utilizing a level and adjusted in flight to match the aircraft pitch axis at 100 mph and 10 degrees flap setting (or as appropriate for the aircraft). The assembly is "Velcroed" to the bottom of the aircraft baggage compartment to meet FAA requirements ("non-permanent" attachment). The camera portal was installed under a "Field Approved" airframe modification (STC337) by the FAA FSDO located in Raleigh, NC.

The camera is remotely activated from the cockpit of the Cessna 210L aircraft utilizing a 20 feet long remote shutter cord. The portable Garmin 296 GPS is mounted on the aircraft instrument panel in a "heads up position" for maximum effectiveness to the pilot during the flight. It is imperative that cockpit duties, including radio communications, visual scanning for air traffic, and monitoring of aircraft engine and navigational instrumentation be well coordinated between the pilot and camera operator/ crewmember for safe operations.

Figure 26. C210L Cockpit

Aircraft Navigation and Airspace Considerations

All flights are conducted in strict accordance with the Federal Aviation Regulations (FARs). This includes all regulation related to Visual Flight Rules (VFR) including, but not limited to, 1) operations in controlled airspace, 2) altitude restrictions (no lower than 1,000 feet above the ground in congested areas for fixed wing aircraft), 3) obstacle avoidance requirements, 4) communications, 5) aircraft equipment, and 6) airspace restrictions.

Flight into controlled airspace, such as the Charlotte Class B airspace and the Greensboro Class C airspace, may require faxing a mission sheet and map to the TRACON prior to takeoff, to assist with proper air traffic coordination. An experienced instrument-rated commercial-type rated pilot is recommended for all data collects.

In-Flight Operations

Once airborne and flying to the prescribed Camera Approach waypoints for each bridge, the aircrew must function as a team. Accurate communication in the cockpit and with air traffic control personnel is imperative, especially in Class B, C, and D airspace, to accomplish the job safely and efficiently, and to arrive at the prescribed waypoint at the correct airspeed and altitude, ready for camera activation.

It is also important that the camera operator and the pilot help each other with the assigned tasks of aircraft maneuvering and camera shutter activation during each bridge overflight. A system of verbal communication between the aircrew members to verify that the aircraft is positioned correctly and that the camera is firing correctly is very important.

Accurate tracking over the bridge is accomplished through strong piloting and use of the portable GPS unit, viewed at the correct scale as required. It is important for the pilot to remember that the WAAS-enabled portable GPS is accurate to 10 feet, has a delayed update period, and that precise tracking over the bridge is needed. Alternatively, a remote miniature video camera w/ cockpit viewing screen can be installed at the belly camera portal, to facilitate visual acquisition of the bridge under the nose of the aircraft.

Both crewmembers must remain vigilant during the bridge overflights to ensure adequate scanning for other aircraft is accomplished. Additional measures of safety are available from the ATC (Air Traffic Controller) when operating in Class B, C, and D airspace and when "VFR Flight Advisories" are requested by the pilot. Other proprietary flight maneuvering and data capture is performed to assist in data processing.

1.6.6 Image Processing

Upon landing, the camera is retrieved from the aircraft and all images are downloaded and placed in electronic folders corresponding to each site flown. Exposure issues are corrected en masse by lightening or darkening the exposure of the individual photos to improve contrast, saturation, and color. Other proprietary methods are used to remove deck obstructions such as moving cars.

Individual images for each bridge are geo-processed for viewing in a Geographic Information System, ArcGIS. The technique used is manual feature matching to available orthoimagery datasets available from ESRI within the ArcGIS Desktop framework. Ground control reference points may be utilized but are not required unless the bridge to be photographed is not present in available ortho-datasets.

The procedures described herein are utilized to establish and verify an accurate image scale for measurement purposes across the image, and not precise geo-position. The accuracy of the scaling, therefore, is primarily a function of the geo-positional and resolution quality of the orthoimagery dataset used for feature matching. In addition, the points used for feature matching should coincide with joint locations to assure the highest degree of scale accuracy for joint locations if joint monitoring is being conducted.

Figure 27. High Resolution Aerial Photo using Small Format Technology

Bridge Distress Feature Extraction

After the imagery is geo-processed, deck distresses including spalls, cracks, and other selected anomalies are extracted from the image data using proprietary techniques that involve a rastor to vector conversion algorithm described below.

Original Image: Geo-processed image of FDOT5 bridge taken from 1,000 feet above ground and aircraft at 100 mph. Note the clear identification of cracks, spalls, sensor embeds, joints, oil deposition, etc.

Figure 28. Image with vector file overlay used to quantify cracks, spalls, etc.

Using proprietary computer image processing techniques, vector data is produced, filtered, sorted, quantified, and converted to numerical values. These values can be used for trending and comparative analysis of bridge deck condition for individual bridge or network-centric decision-making. For example, the following numerical values were converted from GIS data extracted from imagery using proprietary algorithms:

Span ID	Span Area-SF	Spalls-SF	%	Total Spalls	<6" Dia	>6" Dia	% > 6" Dia	Cracks-In	% of Total	Efflorescence
1A	5,475	16	0.29%	37	31	6	16%	640	18%	Yes
1B	5,764	73	1.27%	43	36	7	16%	1,192	34%	None
2A	5,702	14	0.25%	29	27	2	7%	0	0%	None
2B	6,041	36	0.60%	56	47	9	16%	235	7%	None
3A	5,673	8	0.14%	22	21	1	5%	100	3%	None
3B	5,941	13	0.22%	34	28	6	18%	420	12%	None
4A	6,289	10	0.16%	28	25	3	11%	570	16%	None
4B	6,264	38	0.61%	33	24	9	27%	359	10%	None
Total	47,149	208	0.44%	282	239	43	15%	3,516	100%	None

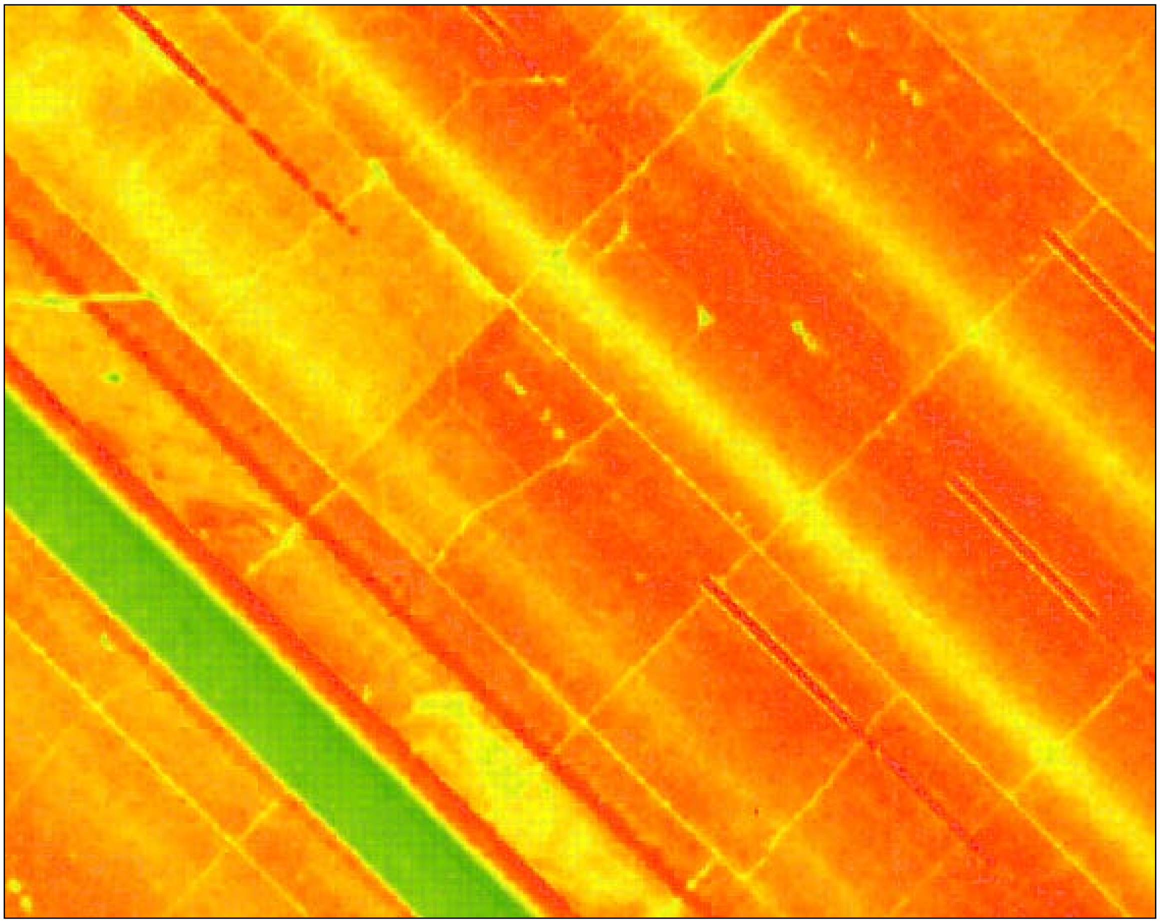

Figure 29. SI-SFAP Data Consumption and Commercial Product Examples

All visual and numerical data generated by the SI-SFAP technique can be consumed by users at any level of the transportation or consulting organization by maintaining the data as common file types in a centralized Bridge Management System (BMS) database, Bridge Inspection System database, or any other proprietary application database such as ESRI ArcGIS, WIGINS etc.

Visual Data File Types (rastor and vector):	Numerical Data File Types:
.shp .kml .jpg .pdf .tiff .tiff w/ auxillary files	.xls .dbf .dbm .dba

Examples include the following, in order by level of sophistication, in the available information technology architecture:

JPEG: One of the simplest forms of data dissemination is a JPEG image containing the patterns of spalls and cracks, etc. Although not depicted below, the numerical data can be furnished in a table format on the image. This method provides a simple visual for information distribution using license-free photo visualization software available on modern desktops, laptops, tablets, and mobile devices such as ipod, ipad, and smart phones. High-resolution images can be made as small as 8 mb.

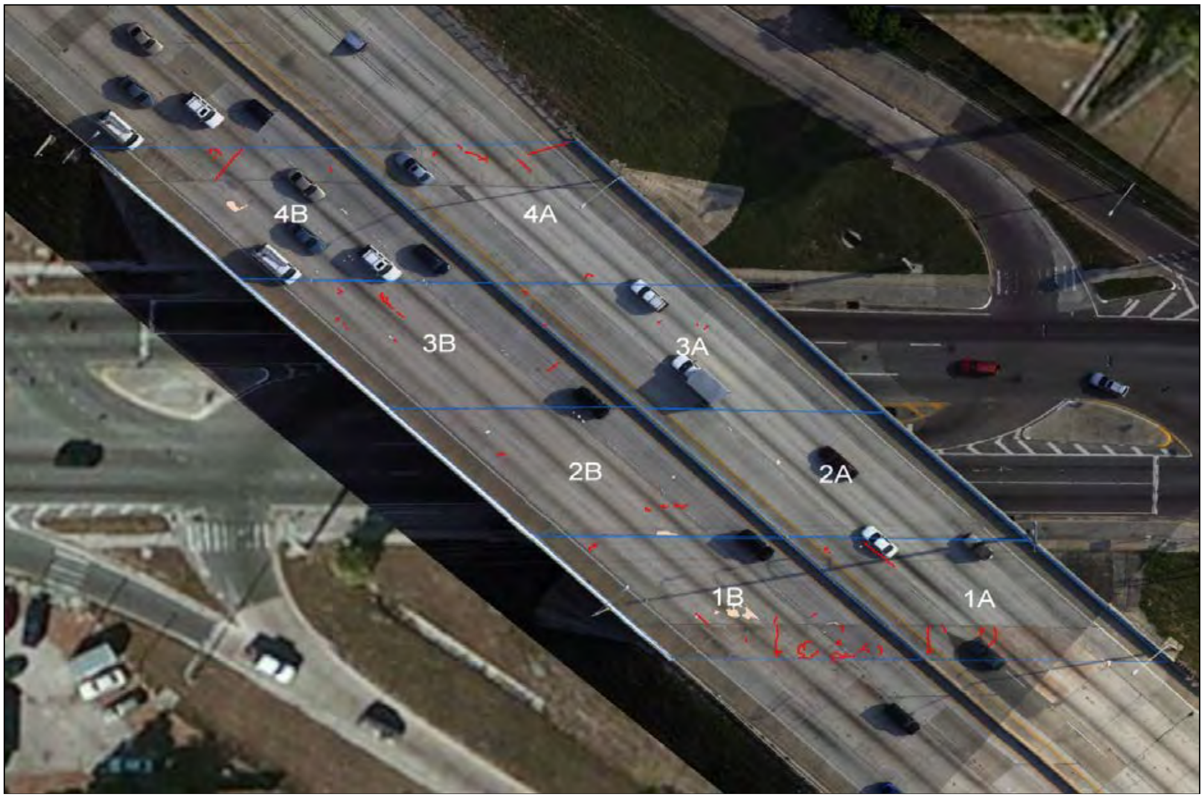

Figure 30. Image created in JPEG file

Adobe Acrobat Reader:

In a license-free .pdf viewer, visual data is furnished in a raster format that can be viewed by image/ data layer, measured, and shared, w/ editorial notes, in a common .pdf format. Although in just a .pdf format, the “geopdf” can be viewed dynamically by “zooming in” and manipulating layer data in new ways to visualize the deck performance.

This method provides a simple visual for information distribution using common pdf software available on modern desktops, laptops, and tablets. PDF files can be made available in a network database or intranet. High resolution images can be made as small as 8 mb.

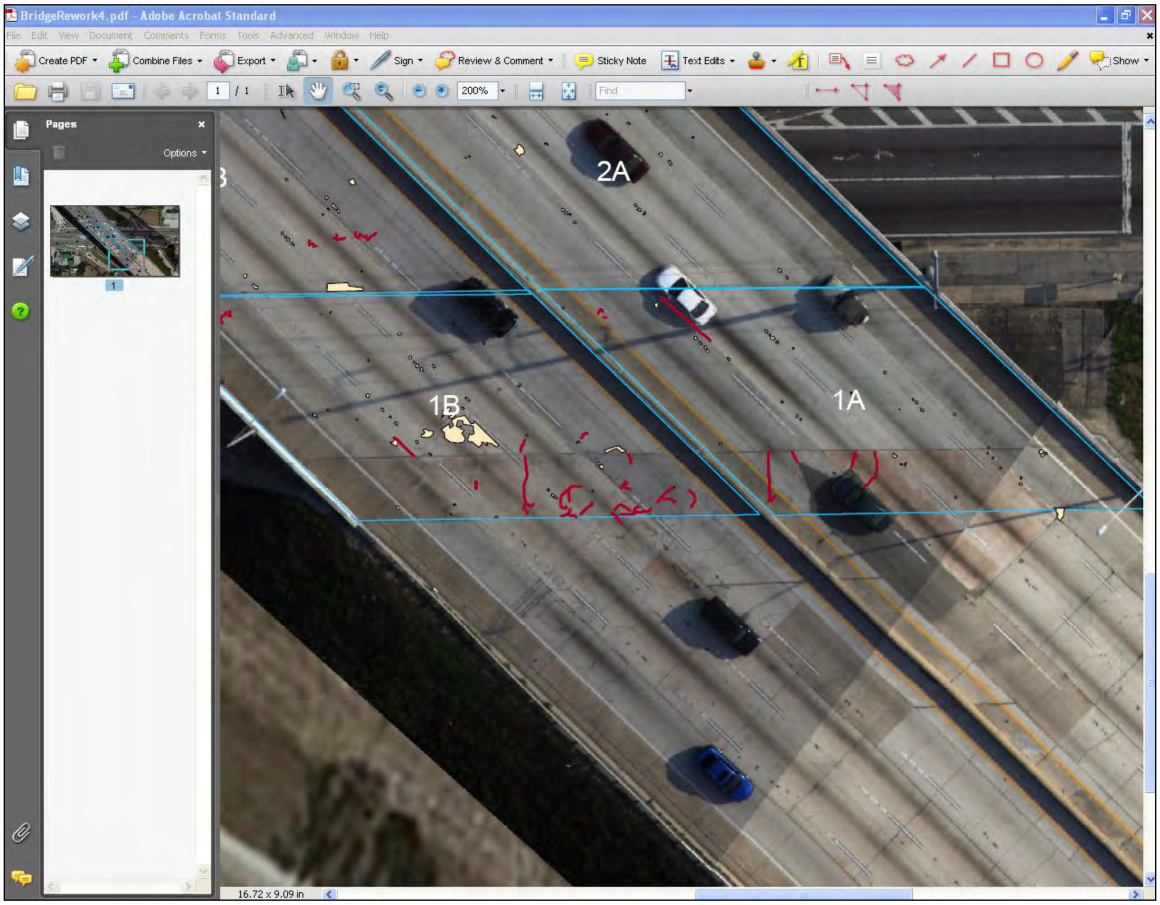

Figure 31. Image created in Adobe File

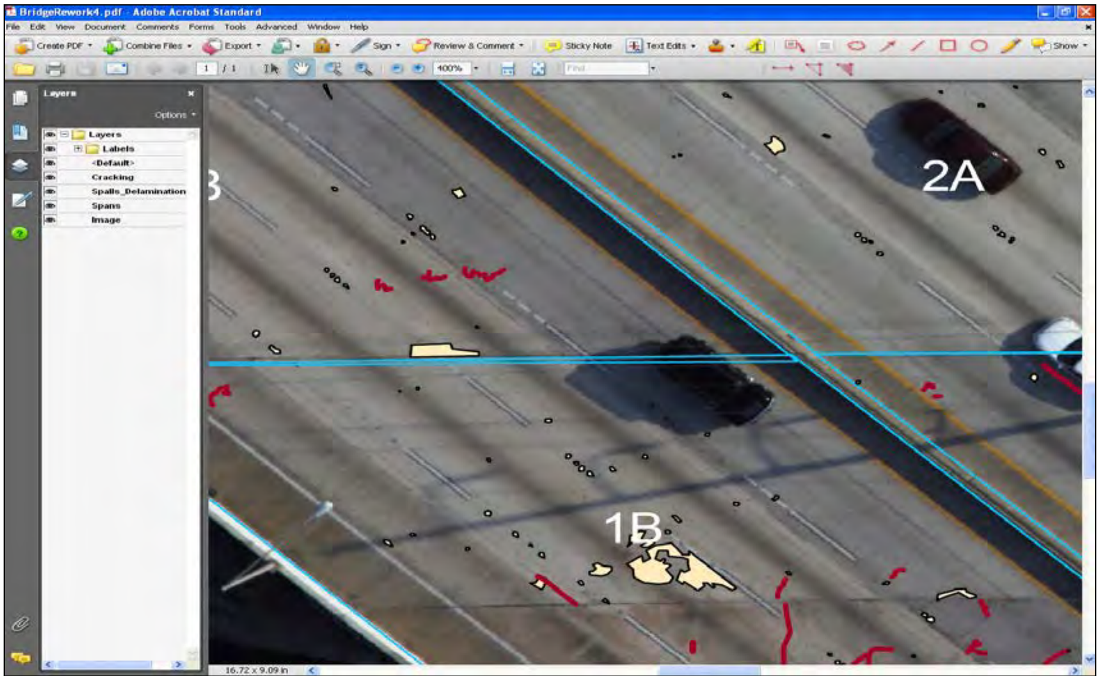

Figure 32. Adobe Reader Functionality by zooming

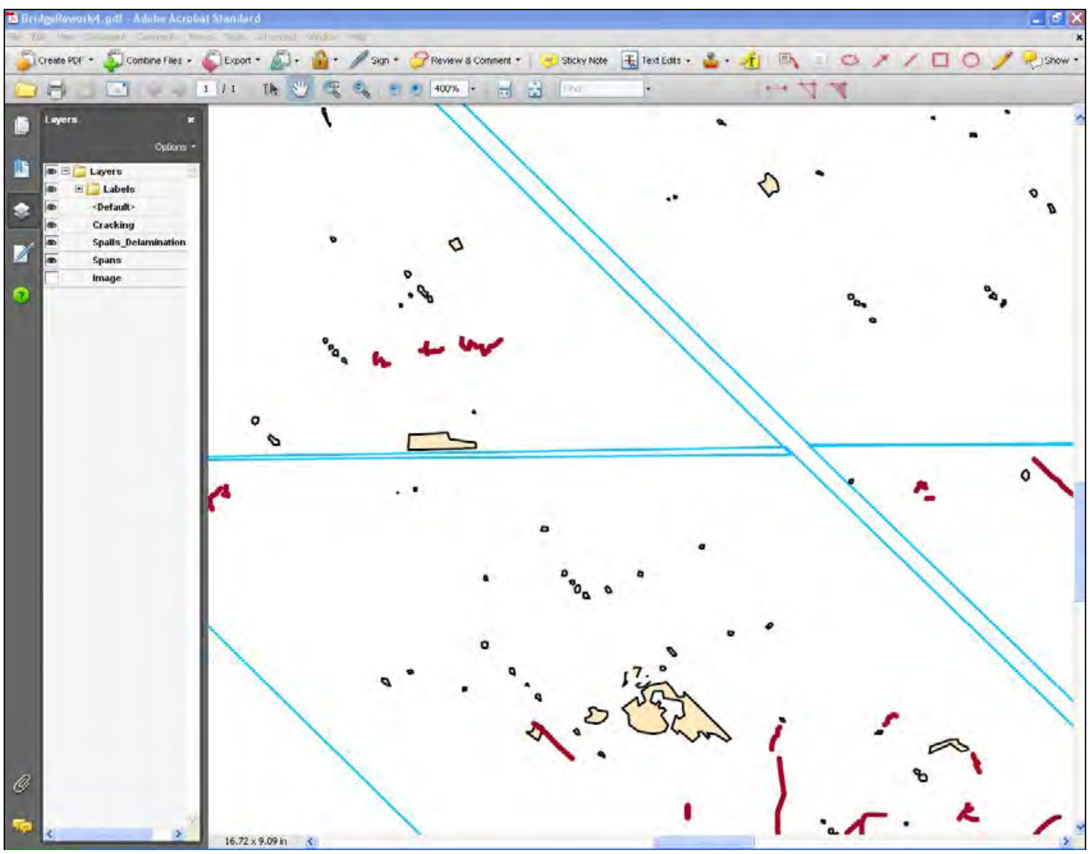

Figure 33. Adobe Reader Functionality by layer manipulation

ESRI ArcGIS Explorer Geobrowser

Similar to Google Earth, this license-free geo-browser is effective for non-GIS trained individuals to view, analyze and share information of disparate file types such as raster images, data overlays, spreadsheets, and ground photos ("GIS for Everyone"). Most GIS functionality is available such as measuring, panning, zooming, and layer manipulation to include image change detection analysis. Added benefits include links to files, websites, and other data sources.

ArcGIS Explorer can be used in a connected or disconnected environment. Connection to the internet allows streaming of base mapping from ESRI servers in many formats including orthoimagery, street maps, and topographical maps. Data can be made available from a network database or intranet on a desktop.

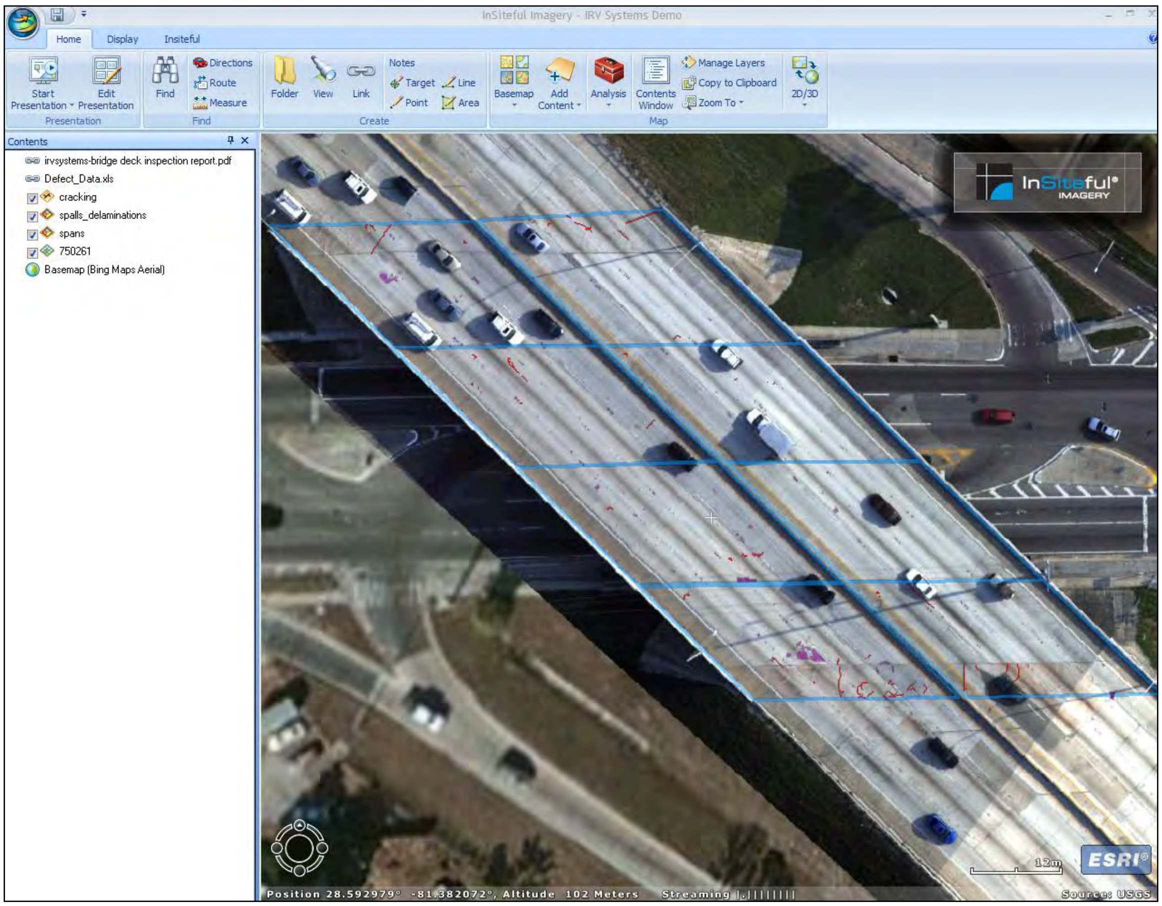

Figure 34. ARC GIS Explorer Image

Compare the clarity of the first image, Figure 35 (developed using SI-SFAP, resolution 1 inch) to the second image, from streaming orthoimagery, Figure 36 (resolution 1 meter).

Figure 35. SI-SFAP Image

Figure 36. Streaming Orthoimagery Image, Same Bridge, Same flyover

Desktop Geographic Information System (GIS)

These systems are complex, proprietary, geographic processing and database software systems that consume a wide variety of GIS data types that require management by trained GIS professionals. These systems are available for detailed and complex geographic analysis, layer manipulation and change detection analysis on a desktop. (Note: Winter photo peeled back to reveal Spring joint damage in ArcMap).

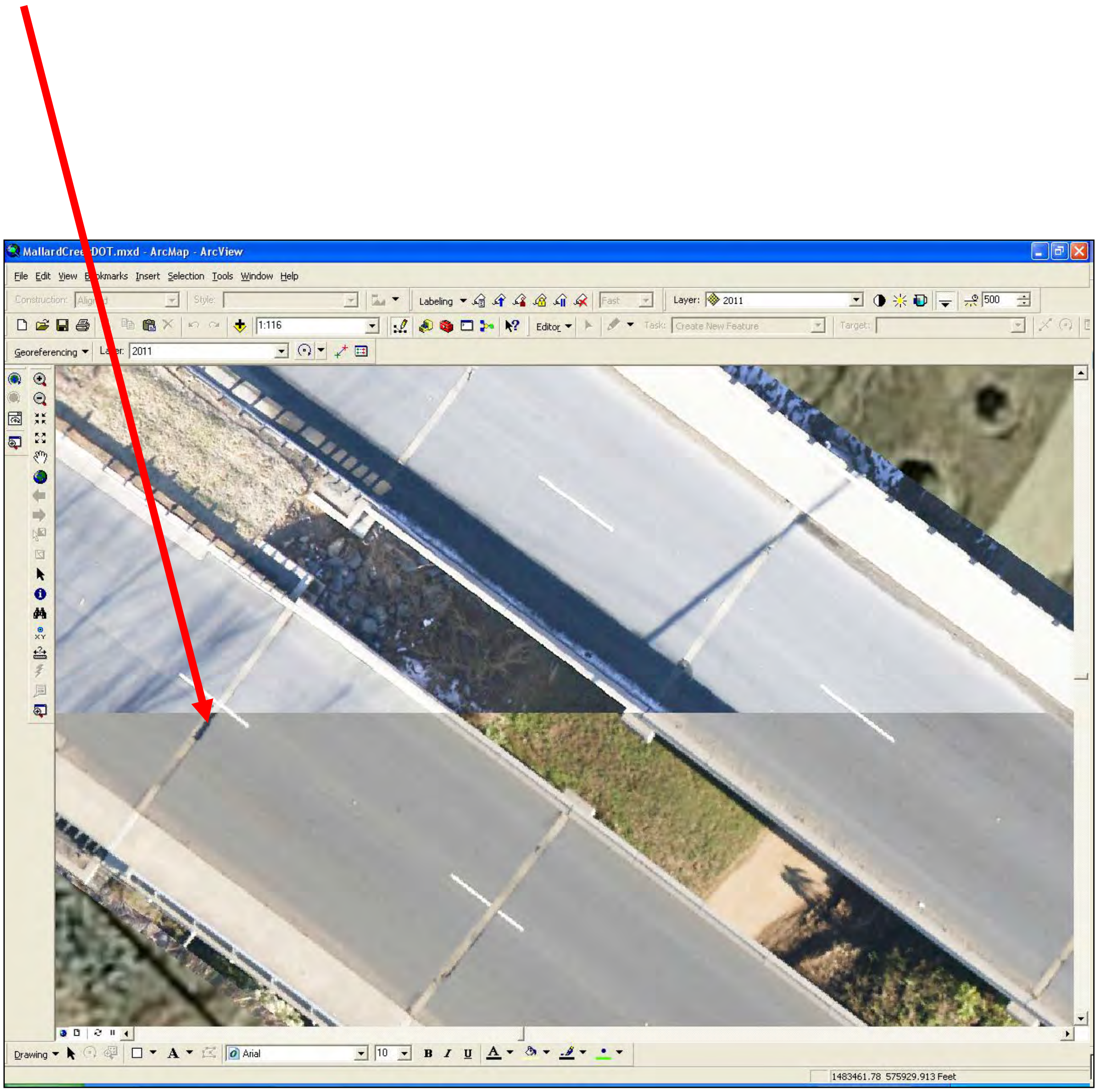

Figure 37. Desktop GIS Image

Web Map Servers

Server-based web mapping allows wide dissemination of centralized information over the internet in an easy to use service that often requires no specialized software for users. Examples of these types of servers include GIS servers used by governments to publish real estate information, flood potential maps, etc. SI-SFAP data can be published, with visual data overlays, and used by internet users located anywhere. The ability to query visual data is not available.

These systems require host server software licensing and a staff of GIS professionals, making web publishing expensive. However, a complete web map service can be streamed to modern desktops, laptops, tablets, and mobile devices such as iPod, iPad, and smart phones. Alternatively, the map data alone can be streamed to other map applications on these mobile devices. Web Map applications can be developed through popular platforms such as ArcGIS Server, Google Earth, and Microsoft Virtual Earth to meet specific client requirements.

BOYLE provides a web map application that was used to monitor the progress of 20 schools under construction in the Charlotte-Mecklenburg School System, Charlotte, North Carolina (www.insitefulimagery.com). The web map service illustrated here provides GIS functionality, change detection analysis, draw tools and full map production in jpeg, pdf, and png formats:

1.6.7 Benefits of SI-SFAP Technology over Competing Technology

SI - SFAP compared to LiDAR

The SI-SFAP technology is effective at rapidly, and cost effectively, collecting, processing, and disseminating sub-inch resolution color digital imagery showing and quantifying detailed visible bridge deck surface anomalies (such as 1/8" cracks) as x-y information in both visual and numerical formats. File sizes for each bridge depends on bridge size but can be on the order of 100-200 MB, lowering data storage requirements. In many applications, data can be consumed by the client using commercial off the shelf (COTS) license- free software or easily integrated with existing IT systems. The data accuracy is limited to the constraints of the image processing procedure that is dependent on the resolution of base orthoimagery that is used in geo-processing the SFAP. There is no investment in aircraft, cameras, software, nor training for the customer.

LIDAR (Light Detection and Ranging) technology produces a vast amount of high accuracy x-y-z gray-scale point cloud data that requires a significant investment in equipment, vehicles, software, and training. Further investment in data extraction technique would be required by a vendor to furnish bridge defect data but could be provided in x-y-z form which would better quantify volume of surface spalls, as well as provide a point cloud for every part of the bridge, including deck, superstructure, and substructure. Data management and storage requirements would be quite significant, even for one bridge.

SI – SFAP compared to LAMP

Low-altitude Mapping Photography (LAMP) can achieve sub-inch resolutions utilizing medium and large format film or digital aerial mapping sensors; however, the sensor must be employed on a helicopter to fly much lower and slower, in order to stay within the operating envelope of the sensors (to achieve clear, sub-inch imagery with no pixel smear). Helicopters also have the disadvantage of higher operating costs and slower transit airspeeds than light fixed-wing aircraft, increasing the labor costs of piloting them. Also, the medium and large format sensors employed in conventional LAMP data collection are more expensive to purchase, maintain, and incur a significant opportunity cost by employing them in a bridge deck condition assessment role rather than the large area mapping role for which they were designed. The SI-SFAP technique leverages the parameters of a commercial off the shelf (COTS) camera type, optics, and readily available, low-cost general aviation aircraft available at nearly every airport in the country.

Technology Trends

The DSLR camera continues to improve with a general trend to higher shutter speeds, higher firing rates, higher pixel density sensors w/ improved CMOS technology, less noise, and improved optics. These trends will radically improve the detail obtainable through remote aerial sensing for other infrastructure asset management applications. In addition, although not specifically utilized in this project, high definition video, and aerial thermography are becoming more capable and cost-effective to spatially-integrate for widespread commercial usage.

Point cloud computing will also offer significant advantages to process data and deliver results with minimum human effort. The conversion of 2D datasets collected with high-resolution DSLR imagery to 3D high resolution colorized visualization will provide high quality accurate information that can be rapidly disseminated to internet users requiring no investment or expense to maintain massive datasets. Many of these technologies utilizing 3D image sensors, computer clusters, and 3D algorithms have been developed by defense contractors; they will be integrated domestically over the next few years..

Figure 38. 3-D Image Extraction, Multiple Views (Source: Urban Robotics)

1.6.8 Potential for Commercialization of SI-SFAP

Currently there are a limited number of qualified SI-SFAP aerial photographers nationwide to provide this service. Among nearly 400 members of PAPA, there are perhaps 15-20 aerial photographers nationwide that could collect this data using techniques described herein. The innovative patent-pending technique is attractive because of the attributes of cost, quality, responsiveness, and generally license-free consumption of data by customers with no requirements to invest in equipment, training or software.

Current barriers to successful commercialization of SI-SFAP nationwide include:

1. Need to establish data collection standards
2. Need to establish vendor training to assure consistent quality
3. Limited number of qualified vendors
4. Limited history of use-emerging technology
5. Potential product licensing requirements

The Professional Aerial Photographers Association-International (PAPA) is the predominant trade organization in the United States for aerial photographers using the DSLR camera. Its "goal is that of an educational group, dedicated to the promotion of high business ethics, helping our members to provide quality service and products through shared experience". The organization has shown interest in establishing a certification program for mapping photographers using the DSLR camera type and small aircraft. During this project, a number of PAPA members have been used to collect imagery and to compete in project-sponsored photo competitions to demonstrate, with favorable results, the capability across the country. Over time, the vendor pool will grow and the data extraction components of the technique can be licensed to engineering firms, technology vendors, and Departments of Transportation.

1.7 Intellectual Property Protection

The University has proactively identified and protected valuable intellectual property created under this award. The different forms of intellectual property protection available are copyrights, which protect the expression of an idea as well as software patents, which protect novel methods and machinery, and trademarks which are used to protect an identifying mark of a product, or service. The UNCC Project Team has identified the following types of intellectual property created under this award:

- **Patentable Inventions** covering a novel method of bridge and structure inspection, the method including; capturing high resolution, small format digital images using a fixed-wing aircraft, compiling the images using a computer, and marking defects and attributes of the structure using software and a computer.
- **Copyrightable Software** covering novel high-resolution image processing steps to identify important aspects of a structure.

The University has filed the following patent applications covering the novel inventions created under this award:

Patent Application Title	Patent App. Filing Date	Patent App. Serial No.	Inventors
Spatially Integrated Small Format Aerial Photography for Bridge Monitoring	April 22, 2010	61/326,828	Shen-En Chen Edd Hauser
Spatially Integrated Small Format Aerial Photography for Bridge Monitoring	April 22, 2011	13/092,452	Shen-En Chen Edd Hauser Charles Boyle

By leveraging its intellectual property rights, the University plans to actively commercialize the technology developed under this award. The University has already entered into preliminary agreements with a commercial entity to rapidly introduce the technology to the marketplace. Officially, the SI-SFAP for Bridge Monitoring is now among the list of technologies that are identified as "Patent Pending."

1.8 Testing the Business Model

As discussed in Chapter 1.6, private sector engineering firms have seen value in the technology of aerial photography for bridge inspection applications, their primary role in bridge management nationwide. The SI-SFAP product is seen as a supplemental tool to bridge inspections but would not replace the trained eye of an inspector. However, significant advantages could be realized by utilizing the aerial photography on particularly large bridges or where traffic was extremely dangerous to the inspector and actual observation of the deck is impossible. It would also enable the inspection firm to provide deck distress feature quantities to Departments of Transportation and the FHWA. The following uses of the SFAP protocol have helped to identify the market potential for this technology.

Bridge Scan interest by Connecticut DOT (Sep 2011): On September 8, 2011, Mr. Chuck Boyle contacted Mr. Bob Zaffetti PE, Manager of Bridge Safety and Evaluation for CTDOT. Mr. Zaffetti was contacted as a result of his expressed interest in the technology shared by Ms. Kelly Rehm PE, Bridge and Structures Program Manager for AASHTO at a regional bridge preservation meeting. Mr. Zaffetti expressed interest in the capability of the technology to efficiently monitor joint movements on highly trafficked urban bridges in Hartford, CT.

Bridge Scan for NCDOT Division 12 (Jan 2012): In October 2010, BOYLE collected SI - SFAP of 10 bridges in NCDOT12. The images were delivered to Mr. Mike Holder PE Division Manager. On January 10, 2012 BOYLE personnel met with Mr. Rubin Chandler PE, Division 12 Maintenance Engineer and Mr. Steve Rackley PE, Division Bridge Project Manager. After our SI-SFAP presentation, these individuals indicated that the technique could be used as a tool to more objectively set priorities (and more efficiently spend money) for state funded bridge deck resurfacing projects as part of the bridge preservation practices being implemented in North Carolina.

Data Collection Flight on two bridges in NCDOT Division 9 (Feb 2012): On February 1, 2012, BOYLE collected imagery on two additional bridges located in Greensboro, North Carolina. Both bridges were selected due to their bridge deck rating (4) and their location within NCDOT Division 9. The bridges flown were:

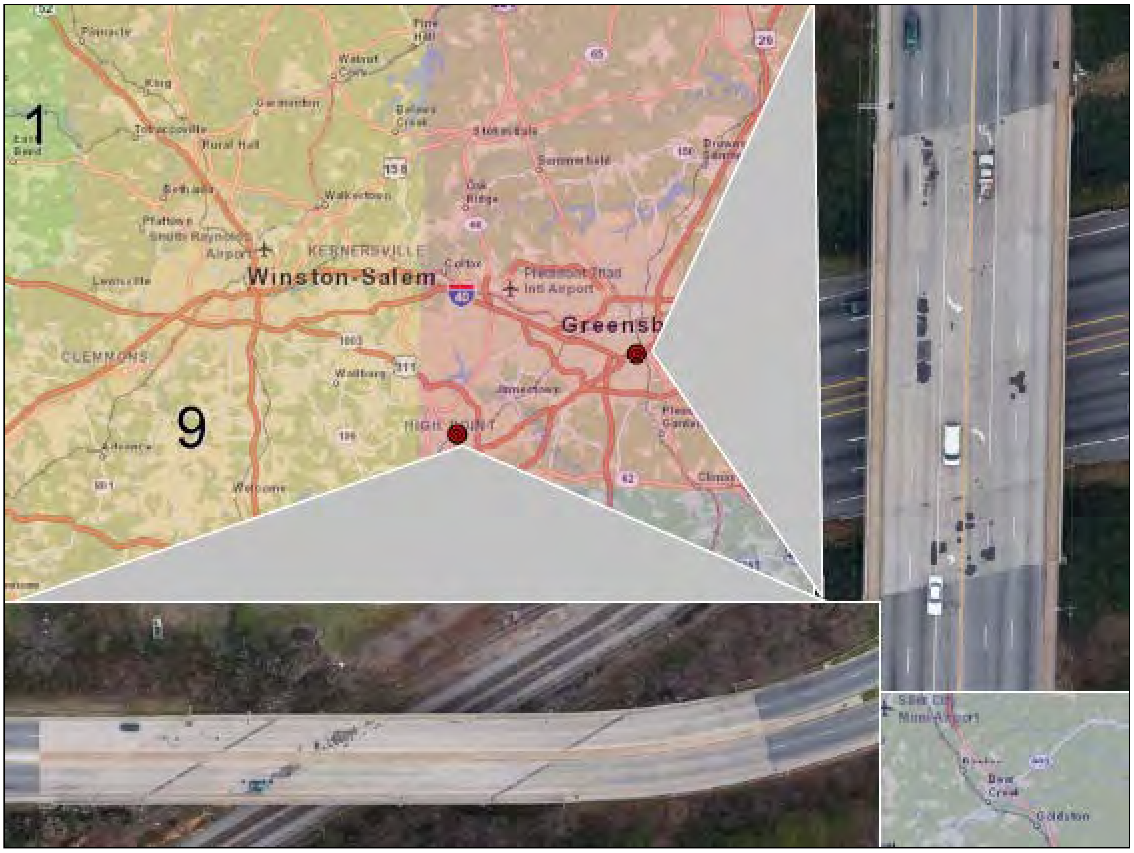

Figure 39. Bridge # 810309 Image and Data

NCDOT (Feb 2012): On February 22, 2012, a presentation of the SI-SFAP technology was made by Mr. Chuck Boyle and Ms. Kelley Rehm, AASHTO Bridge Program Manager to Mr. Rick Nelson PE and the NCDOT Bridge Inspection and Maintenance Unit. The results of our image processing work from the February 1 flyover was also shared. The following comments were made by NCDOT personnel:

Deck Inspection: At the inspector level, use of the SI-SFAP technology, coupled with Mobile Ground Penetrating Radar (GPR), with chloride testing, and would provide sufficient information for a quality deck inspection along the interstates, in lieu of shutting down traffic and performing timely chain dragging.

At the manager level, use of the technology was also seen as beneficial for these same stated reasons, but to a lesser extent, depending on available state manpower and bridge type/ location. With reductions in force and more pressure being applied to do more work, with less, the techniques seemed very attractive.

Detailed Deck Evaluation for Rehabilitation: At the manager level, SI-SFAP, coupled with GPR, was seen as beneficial to use, especially for federally funded bridge deck rehab projects. The NCDOT currently spends approximately 10% of rehab budgets to develop rehab specifications; it is desired to reduce this evaluation expenditure to 5% of rehab project budgets. NCDOT encouraged BOYLE to contact other specified local engineering firms that provide detailed deck evaluations to consider using the technologies.

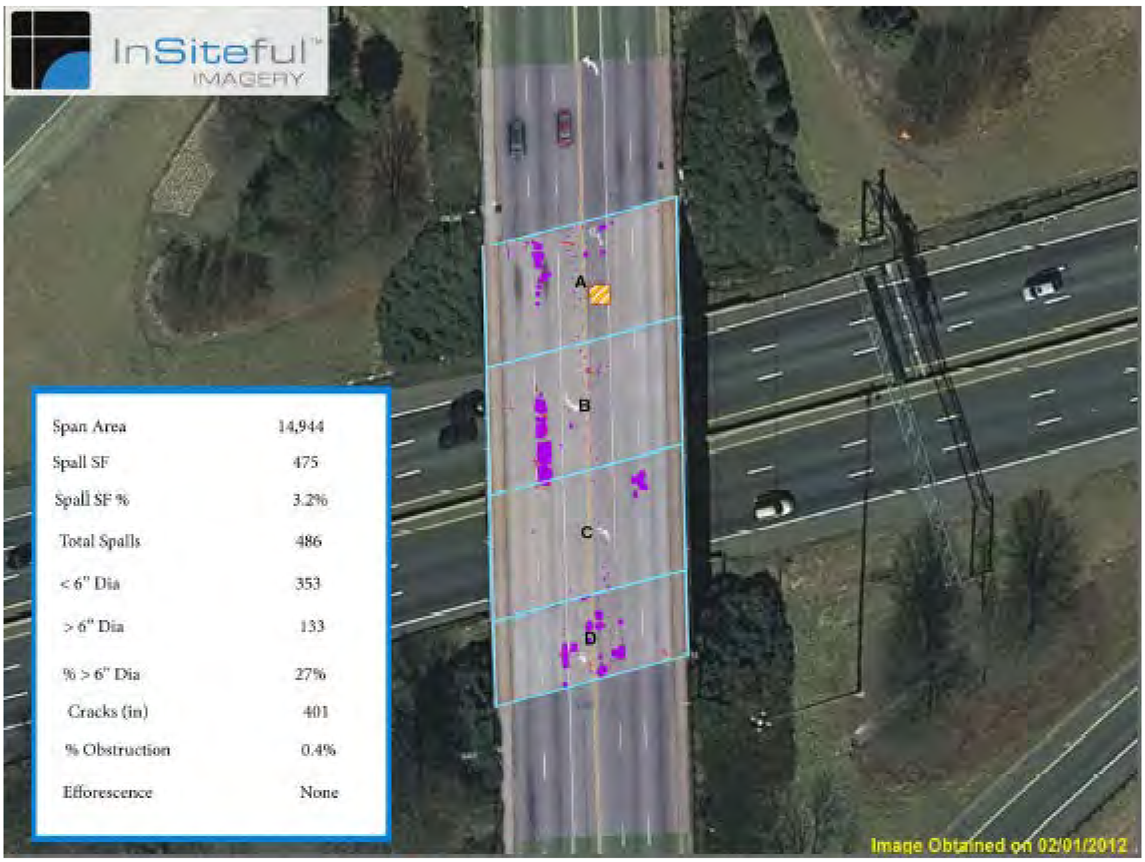

Figure 40. Image with Captured Data using Insightful Imagery

1.9 Summary and Conclusions

There are over 600,000 bridges in the United States. Of these, there are approximately 25,000 bridges with deck condition ratings less than 5 which is considered deficient. In North Carolina alone, there are 440 bridges with bridge deck condition ratings less than 5. In all of these cases, a bridge deck rating has been assigned using visual and auditory methods, not quantitative methods.

For new technology to be successfully and fully implemented in government bridge agencies, it is clear that researchers and vendors must stay engaged in the process from the initiation phase to the optimization phase. The following are suggestions that may make the implementation of remote sensing tools such as small format aerial photography into bridge inspection and management programs.

- Develop marketing tools including cost estimate information and clear outlines of deliverables and advantages of the technology
- Highlight states that have successful programs with the technology
- Identify states that are innovators or early adopters of technology through surveys or interviews
- Identify champions within states that may already be using the technology and develop relationships.
- Develop a “showcase” type of presentation and present at local workshops and conferences or at the agencies of those states that are innovators or early adopters or have a champion in place.
- Identify other vendors or consultants that are already marketing technologies to government agencies and look for partnering opportunities.
- Look for funding partnerships
- Develop a comprehensive handbook on the technology choices, uses and data interpretation
- Develop a comprehensive training manual for agencies that want to train their staff or use collected data.
- Develop information outlining data storage requirements, equipment accuracy needs, and suggestions for software.

The two surveys of the states conducted as part of the IRSV Project shows that the climate is right at this time to start introducing new technologies that will lower costs, save time and provide for safer employee environments. In recent months, partnering opportunities have been explored to determine how small format aerial photography may be paired with other more established technology such as Ground Penetrating Radar (GPR) or Thermographic technology.

Based on information collected during the project, implementation of SI-SFAP will produce a very cost-effective procedure in bridge inspection and management practices nationwide will:

- Improve safety during bridge inspections (probably the most important result of implementing SI-SFAP).
- Quantify visible surface and subsurface defects which leads to more accurate bridge deck ratings.
- Provide the data needed to more efficiently spend bridge preservation dollars.
- Provide quantitative bridge deck information required by PONTIS and other Bridge Management Systems such as AgileAssets and other consultants.
- Provide an undisputable photographic record of deck condition.
- Provide a means of network-centric bridge deck preservation decision making capability within, or outside of, any BMS.
- SI-SFAP will allow bridge deck assessment that requires no traffic control, nor lane closures.

The results of our cursory surveys at two different time periods – near the beginning and near the end of the project - indicate that state bridge management units have in general began to focus on the use and successful implementation of LIDAR in many states. We also conclude that, for other remote sensing technologies, a similar outreach effort could be used by researchers, and vendors, working and engaged in an implementation from initiation to full technology integration. That strategy is currently being followed taking a private sector consulting approach to demonstrating the effectiveness of SI-SFAP technology and marketing the capabilities (and constraints) of the system in various professional forums, particularly TRB, AASHTO, and SPIE.

In closing, on a very general level of documenting conclusions and "lessons learned," it should be pointed out that this study, documentation, and prototype development of an Integrated Remote Sensing and Visualization (IRSV) system has been fortunate to obtain considerable review, comment, and collaboration involving a large number of partners, from both the public and private sectors. Several case studies were conducted with a number of state and local highway agencies, plus an extensive outreach to technology developers and vendors who have been through similar projects that have attempted to introduce new technologies to highway agencies.

A number of important keys to success of partnerships that would introduce new technology and applications can be summarized as follows:

- Use some type of formal or informal Partnering Process for technology planning, design, implementation and operations.

- Find a "comfort level" in public organizations that recognize the status of the private sector to take risks in developing and marketing new technologies.

- Develop a “culture” of establishing and preserving open and honest communications among partners.

- Taking advantage of specific strengths and technical capabilities of each member of a partnership.

- Develop a willingness and ability to compromise and adapt varying organizational cultures into an effective team for testing and implementing new technologies**.**

- Maintain continuity of participation among organizations, as well as among representatives from each organization involved.

- Provide an effective decision-making process within partnerships, such as the creation and effective use of a small core group, each member with well defined responsibilities within the partnership.

A final, but very important key to effectively developing and maintaining partnerships is the need to assure that a strong, unbiased leader is the facilitator of the partnership. This is a necessary feature that is often overlooked in the formative stages of partnerships. In addition, the importance of a **neutral** facilitator is often underestimated. A number of such partnerships among various organizations from the public and private sector have fortunately demonstrated this characteristic over the course of the past four or five years.

This research and prototype development of the IRSV System has shown that those partnerships that understand and follow a partnering process have a higher degree of success in introducing new technologies. Where a partnering process uses an outside facilitator to manage the partnering process, an even higher degree of success is achieved.

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Appendix B. List of Acronyms and Definitions

(NOTE: Highlighted acronyms are considered as key descriptive elements of this research and development project.)

AADT – Average Annual Daily Traffic
AASHTO - American Association of State Highway Transportation Officials
ACE – Army Corps of Engineers
ACI - American Concrete Institute
ADT – Average Daily Traffic
AGL – Above Ground Level
AISAA - Aerial Image Shape-file Automation and Analysis
ALT – Altitude
AMBIS – Assisted Management Bridge Information System
AMPIS – Automated Management of Pavement Inspection System
ASCE – American Society of Civil Engineers
ASTM – American Society of Testing and Materials
ATIS – Automated Terminal Information Service
AWOS – Automated Weather Observation Service

BHI – Bridge Health Index
BHM – Bridge Health Monitoring
BMS - Bridge Management System (more accurately called a process)
BSCI – Bridge Surface Condition Index

CBA – Cost Benefit Analysis
CBR – Cost Benefit Ratio
CCD -
CDOT – City of Charlotte Department of Transportation
CFID - Cognitive Fused Imaging of Damages

CMAS -

COTS – Commercial off the shelf Software
CR – Condition Rating
CRS – Commercial Remote Sensing
CRS-SI – Commercial Remote Sensing and Spatial Information
CTPS – Center for Transportation Policy Studies at UNCC
CoRe – Commonly Recognized Structural Elements

DBIR - Dual-Band Infrared Thermography
DDI - Digital Damage Index
DEM – Digital Elevation Model
DI - Digital Imaging
DLF - Dynamic Load Factor

FEA – Finite Element Analysis
FEM - Finite Element Method
FHWA – Federal Highway Administration
FO – Functionally Obsolete

GenOM – Generic Object Model
GIS – Geographical Information System
GPR – Ground Penetrating Radar
GPS - Geographical Positioning Satellite
GSM – Global System for Mobile communications
GVW – Gross Vehicle Weight (loaded total weight)

HBRRP – Highway Bridge Replacement and Rehabilitation Program
HPS – High Performance Steel
HTF – Highway Trust Fund

IDE – Integrated Development Environment
IF - Image Fusion
ImageCat – a private sector partner in the IRSV Project
IRSV – Integrated Remote Sensing and Visualization
IRV – Integrated Remote Views (for Infrastructure Monitoring)
ISTEA – Intermodal Surface Transportation Efficiency Act
KIAS – Knots Indicating Air Speed

LCCA – Life Cycle Cost Analysis
LiBE – LiDAR Bridge Evaluation
LaDAR – Laser Detection And Ranging
LiDAR – Light Distancing And Ranging
LOS – Level of Service
LTBPP – Long Term Bridge Performance Project

MR&R – Maintenance, Repair and Rehabilitation
MSVE – Microsoft Virtual Earth
NBI – National Bridge Inventory
NBIP – National Bridge Inventory Program
NBIS – National Bridge Inspection Standards
NCDOT – North Carolina Department of Transportation
NCRS-T - National Consortium for Remote Sensing in Transportation
NCSBEDC – North Carolina Small Business and Economic Development Center
NDE - Non-Destructive Evaluation
NDI – Non-Destructive Inspection
NDT – Non-Destructive Testing
NEVC – Nondestructive Evaluation Validation Center
NHS – National Highway System

NIST – National Institute for Standards and Technology
NPV – Net Present Value
NSTIFC – National Surface Transportation Infrastructure Financing Commission

OAM – Office of Asset Management, FHWA
Ontology - Synonym meaning Knowledge Modeling
PAPA – Professional Aerial Photographers Association
PC – Prestressed Concrete
PCView – Parallel Coordinate View
PDI – Pavement Distress Index
PDO – Problem Domain Ontology
PMS – Pavement Management System
Point Cloud – A display of 3-D surface points in a laser scanned image
PONTIS – A "Bridgeware" software suite of programs developed through AASHTO that is used by many states as part of their Bridge Management System
RC – Reinforced Concrete
RITA – Research and Innovative Technology Administration

SAR – Synthetic Aperture Radar
SBRP – Special Bridge Replacement Program
SD – Structurally Deficient
SDOF - Single-Degree-Of-Freedom
SFAP - Small Format Aerial Photography
SHM - Structural Health Monitoring
SHRP2 – Strategic Highway Research Program, phase 2
SI – Spatial Integration
SI – SFAP - Spatially Integrated Small Format Aerial Photography

SIS – Software and Information Systems Department at UNC Charlotte
SMO – Semantic Matching Operation
SOA – Service Oriented Architecture
SPIE – an acronym identified as the International Society for Optics and Photonics
SPView – Scatter Plot View
SQL - Standard Query Language
STIP – State Transportation Improvement Program

TRB – Transportation Research Board, a part of the NAS/NAE
UNCC – University of North Carolina at Charlotte
USDOT – United States Department of Transportation
VBA - VBA program
VIS – Visualization
VisCenter – Charlotte Visualization Center at UNCC

Appendix C. Papers Submitted by the IRSV Research Team

Lidar -Based Bridge Structure Defect Detection; Wanqiu Liu, Shen-en Chen and Edd Hauser; submitted for publication in *Experimental Techniques*.

Integrating visual analysis with ontological knowledge structure; Xiaoyu Wang , Wenwen Dou, Seok-won Lee, William Ribarsky, Remco Chang; Presented at the *Knowledge Assisted Visualization Workshop*, held on October 19, 2008 in Columbus Ohio.

Remote sensing for bridge health monitoring; Wanqiu Liu, Shen-En Chen and Edd Hauser; Presented at the *Optical Engineering and Applications Conference,* August 2, 2009, San Diego, California.

Knowledge Integrated Visual Analysis of Bridge Security and Maintenance; Xiaoyu Wang, Rashna Vatcha, Wenwen Dou, Wanqiu Liu, Shen-En Chen, Seok-won Lee, Remco Chang, and William Ribarsky; Presented at the April, 2009 *SPIE Visual Analytics for Homeland Defense and Security Conference.*

*Visualization and Data Integration for Bridge Management***;** Xiaoyu Wang, Remco Chang, William Ribarsky, Shen-En Chen, Garland Haywood, Jimmy Rhyne, Edd Hauser; Submitted to the *ASCE Journal of Performance of Constructed Facilities.*

Towards Sustainable Infrastructure Management: Knowledge-based Service-oriented Computing Framework for Visual Analytics; Seok-won Lee, W.J. Tolone, A. Murty, R. Vatcha, X. Wang, R. Chang, W. Ribarsky, W. Liu, S. Chen, and E. Hauser; Presented at the *SPIE Defense, Security and Remote Sensing Conference,* April, 2009.

Review paper: Remote Sensing Applications to Health Monitoring of Civil Infrastructure; Wanqiu Liu, Shen-en Chen, Kaoshan Dai and Edd Hauser; Submitted for publication in the *Journal of Structural Health Monitoring*.

Establishment of Bridge Management Decision Ontology for State Highway Bridges; Rashna Vatcha, Seok-Won Lee, William Tolone, Shen-En Chen and Garland Haywood; Submitted to the *ASCE Journal of Bridge Engineering.*

Visualization as Integration of Heterogeneous Processes; Xiaoyu Wang, Wenwen Dou, William Ribarsky, Remco Chang; Presented at the April 2009 *SPIE Conference on Visual Analytics for Homeland Defense and Security*.

*An Interactive Visual Analytics System for In-Depth Bridge Management; X*iaoyu Wang, Wenwen Dou, Shen-en Chen, William Ribarsky, Remco Chang, Edd Hauser; submitted for publication in *ASCE Journal of Bridge Engineering.*

Integrated LiDAR Applications in Enhanced Bridge Management; E. Hauser, W. Liu, S.E. Chen, B. Ribarsky, S.K. Lee and B. Tolone; Presented at the *American Society of Non-destructive Testing (ASNT) Fall Conference*, October 19-23, 2009, Columbus, OH.

Bridge Health Monitoring Using Commercial Remote Sensing, S. Chen, E. Hauser, R. Eguchi, W. Liu, C. Rice, Z. Hu, C. Boyle, and H. Chung, Presented at the *7th International Workshop on Structural Health Monitoring* at Stanford University, Palo Alto, CA, Sept 9-11, 2009.

Enhanced Bridge Management via Integrated Remote Sensing ; S. Chen, E. Hauser, K. Dai, W. Liu, B. Ribarsky, S.K. Lee, B. Tolone and C. Boyle, Presented at the *Fifth International Conference on Bridge Maintenance, Safety and Management, Philadelphia, PA, July 2010.*

*Bridge Low Clearance Detection Using LiBE***,** W. Liu, S.Chen, and E. Hauser, Journal Paper, submitted for publication in the *ASCE Journal of Bridge Engineering.*
Defining and Applying Knowledge Conversion Processes to a Visual Analytics System; Xiaoyu, Wang, Dong Hyun Jeong, Wenwen Dou, Seok-won Lee, William Ribarsky, and Remco Chang., accepted for publication by *Elsevier Journal of Computers & Graphics*.

Validation of Bridge Girder Deflection and Strain Measurements Using LiDAR Scan;
K. Dai, C. Watson, S. Chen, E. Hauser, University of North Carolina Charlotte; W. Liu, Dalian University of Technology, China, Presented at the *NDE/NDT for Highways and Bridges: Structural Materials Technology,* Aug. 16 – 20, 2010; New York LaGuardia Airport Marriott, New York City.

LiDAR Scan Applications during Construction for Bridge Condition Validation; Y. Tong, H. Bian, C. Watson, K. Dai, S. Chen, UNC Charlotte; W. Liu, Dalian University of Technology, China, (Ibid.).

Spatial Information - Small Format Aerial Photography (SI-SFAP) Applications for Bridge Condition Validation Post-Blast Load and New Construction; S. Chen, C. Rice, B. Philbrick, E. Hauser, UNC Charlotte; C. Boyle, Boyle Consulting LLC; R. Eguchi, ImageCat, Inc.; H. Chung, Accelent Technologies, Inc. (Internal Technical Memorandum submitted to the City of Charlotte DOT.)

Enhanced bridge management via integrated remote sensing; S. Chen, E. Hauser, K. Dai, W. Liu, B. Ribarsky, S. Lee, B. Tolone, University of North Charlotte at Charlotte, Charlotte, NC, USA; and C. Boyle, Boyle Consulting Inc., Charlotte, NC, Presented at the *ASCE Bridge Maintenance, Safety and Management Conference,* Philadelphia, PA, July 12 – 16, 2010.

FINI!

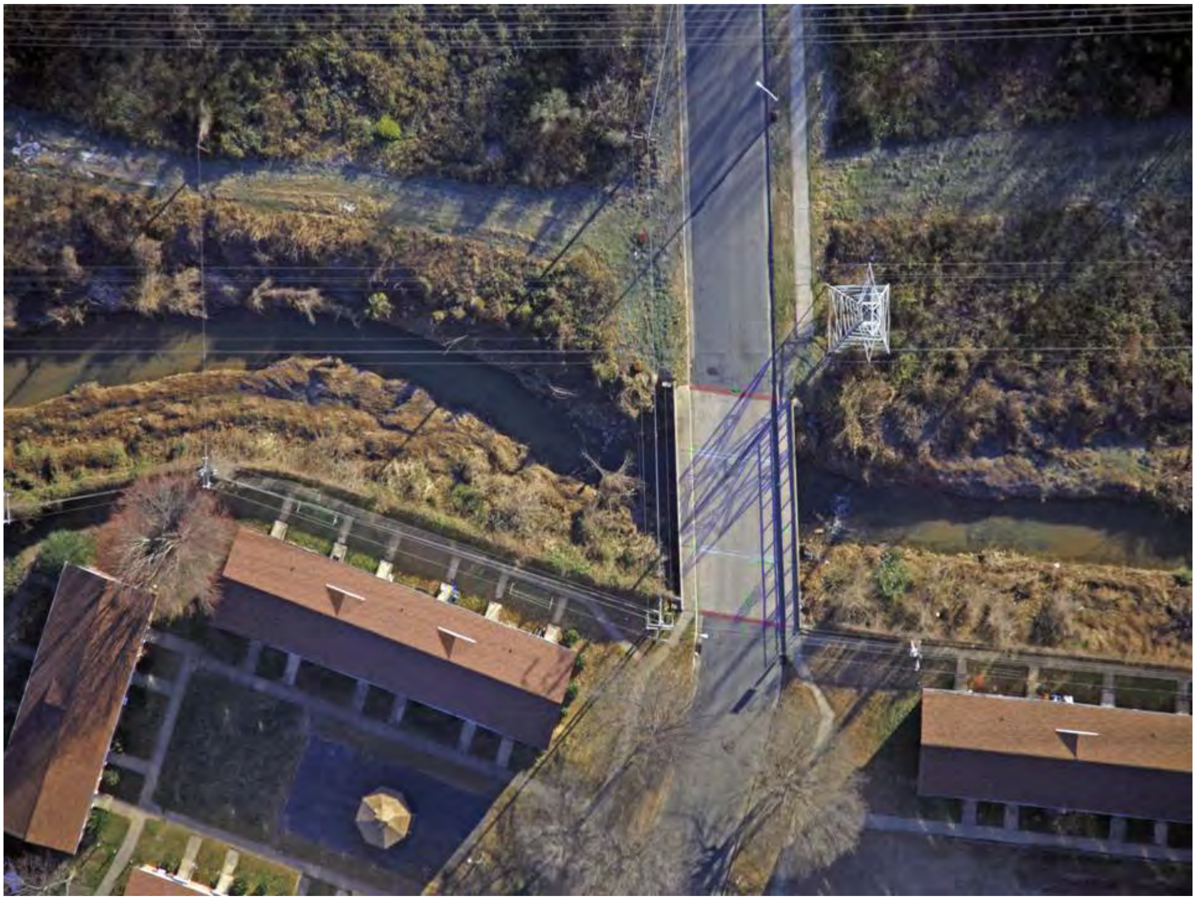

Figure 41. Your moment of zen