Michigan Tech

CAR
CENTER FOR AUTOMOTIVE RESEARCH

Memo

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Number: 22

Subject: Task 6 – Technical Assessment and Economic Valuation Update

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Michigan Technological University (MTU) currently is leading an investigation of the utility of using remote-sensing technology for bridge condition assessment. This project, under contract to the USDOT, includes the field testing of several technologies for bridge condition assessment. As part of Task 6 of the study, Michigan Tech Research Institute (MTRI, part of MTU) will perform a technical assessment and evaluation of the bridge condition Decision Support System (DSS) tools and its software and sensor components. The Center for Automotive Research (CAR), a subcontractor to MTU, has the task of conducting an economic evaluation of the cost-effectiveness of a broad deployment of remote sensing techniques for bridge condition assessment. This assessment is designed to provide insights into which techniques tested are good candidates for adoption into standard bridge management practice by state and potentially other department of transportation (DOT). This memo provides an update on the status of DSS tools, software, and sensor components, as well as a description of the team’s research findings pertaining to bridge inspection cost data and analysis and a discussion of future activities planned to complete Task 6.

DSS TOOLS, SOFTWARE, AND SENSOR COMPONENTS UPDATE

> *TM-22 is to include the DSS in "discussing technical and economic approach for evaluation of commercial remote sensors for bridge condition assessment".*

The DSS is being developed as a user-friendly, on-line web mapping tool focused on the needs of the bridge assessment community. It has been designed to be able to integrate existing historical bridge condition data typically collected and used by DOTs, as well as integrate the analyzed remote sensing results from the technology assessments that have been underway to this point. A next focus is to integrate these existing and new data sources into one or more overall bridge health signatures using the DSS. Also upcoming is a version of the DSS that displays clearly in mobile table-computers such as the Apple iPad and others running the Android operating system to make the DSS readily available to bridge inspectors and engineers in the field.

Figure 1 shows an example of the current version of the DSS displaying existing Pontis-style bridge condition data, as shared by the Michigan Department of Transportation (MDOT). In this example, the user has zoomed to an area of interest, drawn a polygon around the area for which they wish to see bridge condition data, and then clicked on a bridge of interest to see its existing bridge data. This capability is new for our primary DOT partner, MDOT. The user can also get directions to the bridge by using the DSS (using the "Get Directions" link seen below), which is a requested feature by MDOT, as bridges can be difficult to navigate to in the field by bridge inspection crews because they do not have traditional street addresses that work in tools such as Google Maps. However, these types of data displays are not the only major focus points of the DSS. Integrating the remote sensing results into the DSS is the next major focus of the DSS development.

Various technologies are described below in the economic evaluation, including 3D Optics, Thermal Infrared, Digital Image Correlation, Radar (including SAR and InSAR), Street View-style Photography in the form of the Bridge Viewer Remote Camera System, GigaPan System, LiDAR, and various forms of satellite imagery and aerial photography analysis. Most of these systems were tested during an intensive summer 2011 field demonstration period, and the data from these field tests are now being analyzed to produce indicators of bridge condition.

Once the analysis of these data is complete, the DSS will be able to display both the remote sensing results and their integration into an overall bridge health signature or set of signatures. It is this integration that will help provide the necessary environment for helping Departments of Transportation understand if the remote sensing technologies can provide the information needed to help advance bridge condition assessment in a cost-effective economic manner. Full use of the DSS to help with technical and economic assessment of the results will be possible once the remote sensing data and interpreted results have been integrated into the DSS, which is a major focus for the next part of the study.

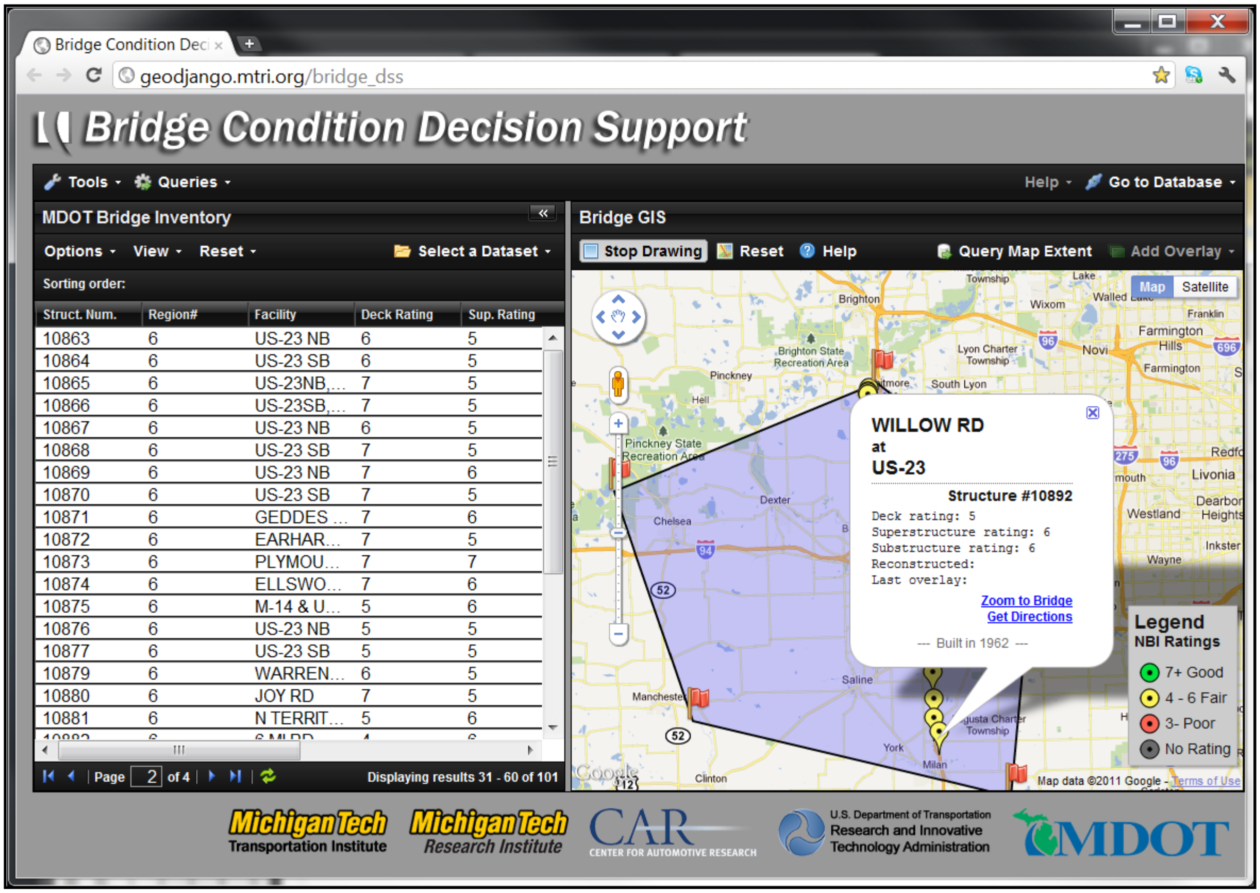

Figure 1: An example screenshot of the current version of the DSS that will be able to display existing Pontis-type bridge condition data (shown) and newer remote sensing-based bridge condition indicators (under development).

ECONOMIC VALUATION OF BRIDGE CONDITION ASSESSMENT USING REMOTE SENSING TECHNOLOGIES

The quality and performance of transportation infrastructure, including highway bridges, are vital to the nation's economy and social well-being. Federal investment in the Highway Bridge Program (HBP) totaled $4.95 billion in 2009, representing 15% of total expenditures of federal funds administered by the Federal Highway Administration (FHWA).[1] Over the past three decades, the HBP (previously the Highway Bridge Replacement & Rehabilitation Program or HBRRP) received more than $81 billion federal funds and the funding level is moving higher (see Figure 2).

[1] USDOT Federal Highway Administration. Highway Statistics 2009, Table FA-3. http://www.fhwa.dot.gov/policyinformation/statistics/2009/

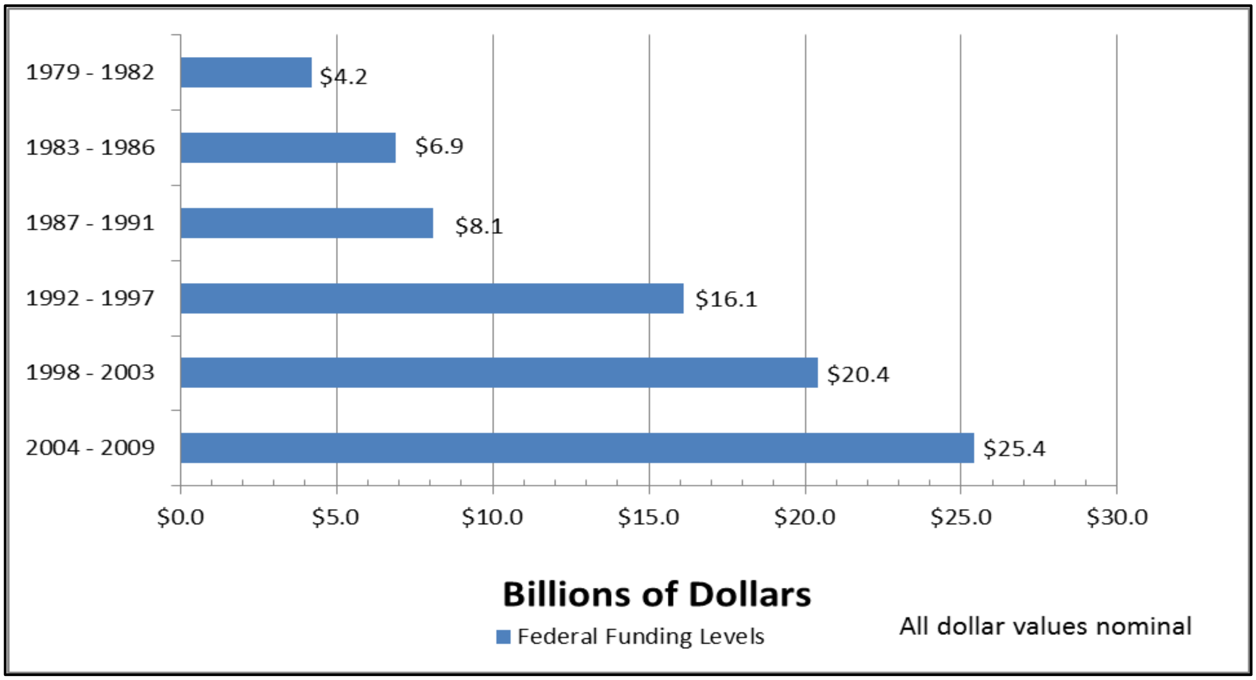

Figure 2: Funding levels of the HBP (1979-2009). Data source: 1979 - 2003 data from Bridge Inspector's Manual; 2004-2009 data from USDOT Office of Highway Policy Information website <http://www.fhwa.dot.gov/policyinformation/statistics.cfm>.

Fiscal sustainability of a national HBP remains a challenge as the Highway Trust Fund (HTF), which funds the HBP and other highway programs, is projected to incur significant deficits in the years ahead. Further, the purchasing power of funding currently available for bridge maintenance, rehabilitation, and replacement is also declining (GAO, 2010).

Addressing the scope of deficient bridges will be a bigger challenge as larger numbers of bridges built after 1950 reach the age at which they are increasingly likely to need to be rehabilitated or replaced; as shown in Figure 3, the correlation between bridge age and condition is strong. About 21% of nation's bridges were built before 1950 or are more than 60 years of age, and more than 40% of these "old" bridges were either structurally deficient or functionally obsolete (see Figure 4). Bridge repair and replacement needs soon will exceed available funding from federal and state sources.

An increasing pressure to increase economic efficiency of expenditures has created the necessity of bridge management systems (BMSs) and effective life-cycle cost management. National Cooperative Highway Research Program (NCHRP) recently conducted a domestic scan focusing on practices among DOTs for identification, prioritization, and execution of programs for management of highway bridges. One of the scan team's key recommendations for bridge management decision-making is to adopt element-level bridge inspection programs and establish standard condition states, quantities, and recommended actions (i.e., maintenance, preservation, rehabilitation, and replacement) to match the operational characteristics of the agency maintenance and preservation program (TRB, 2009).

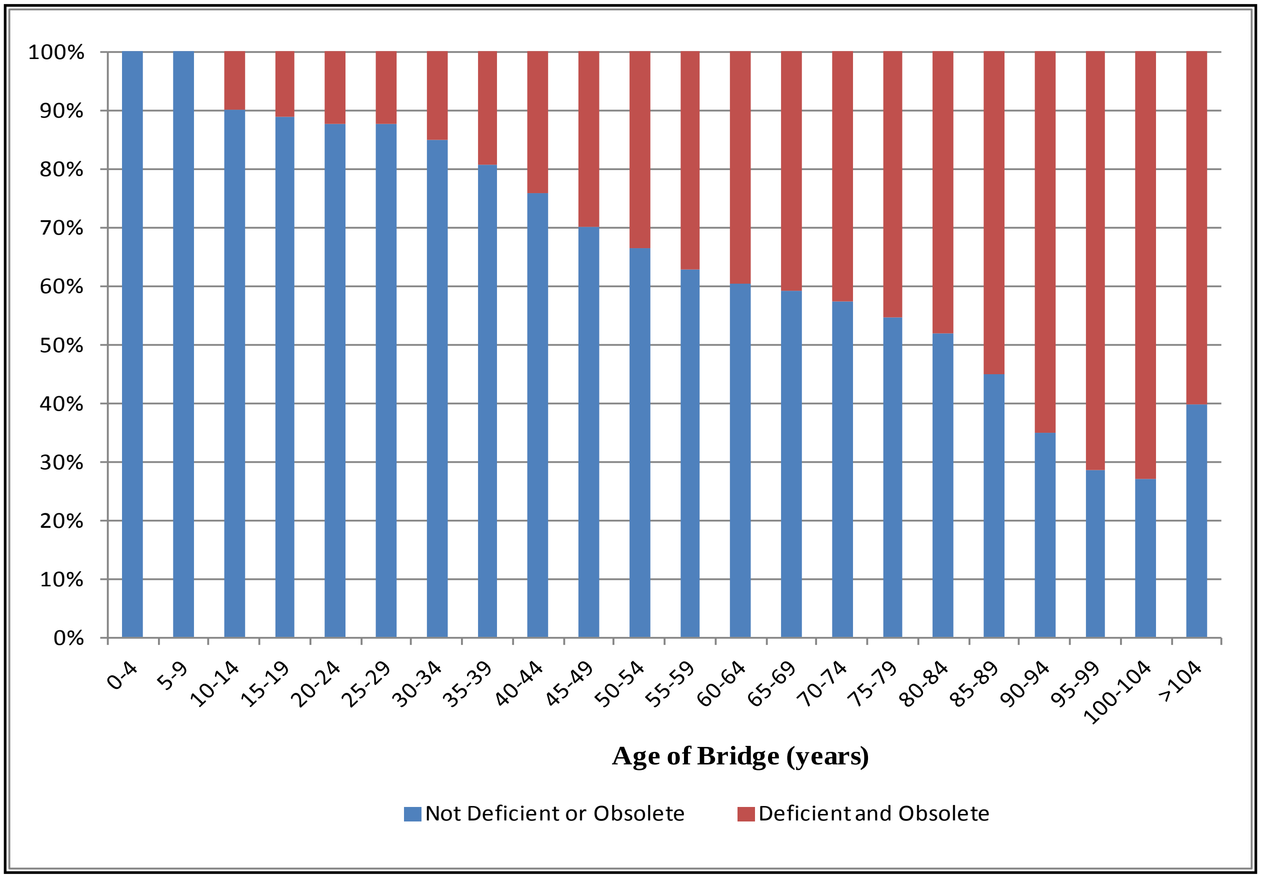

Figure 3: Age of bridge strongly correlated with condition (deficient or not). Data source: 2010 National Bridge Inventory (NBI) data.

Bridge management systems are data-driven and based on a strategic, systematic, and balanced approach to managing bridge preservation and replacement needs. The main components of bridge management are condition assessment, planning, life-cycle analysis, and maintenance management. Bridge inspection data and condition rankings are essential to BMSs to in order optimize the use of available funds and help local, state, and federal agencies make smart maintenance and rehabilitation decisions. Research suggests that preventive maintenance (PM) is a cost-effective way of extending the service of highway bridges. For every dollar spent on the PM program, $4 to $10 was saved in the rehabilitation program (Adams, 2008).

The team's DSS has the goal to take traditional BMS data and making it more valuable and user-friendly through a geospatial web interface that integrates newer remote sensing data. This is intended to enhance the usability of BMS data and advance the technologies that can be displayed through BMS-related decision support interfaces.

Furthermore, a new bridge safety initiative was introduced recently by FHWA to improve bridge inspection and management practices. The new process is based on objective, statistical data, providing for greater consistency in bridge inspections and more strategic approaches to identifying problem areas by using defined criteria for 23 key metrics.[2] Such strategy is in align with the process and basics of a bridge management systems and will improve bridge investment decisions at all levels.

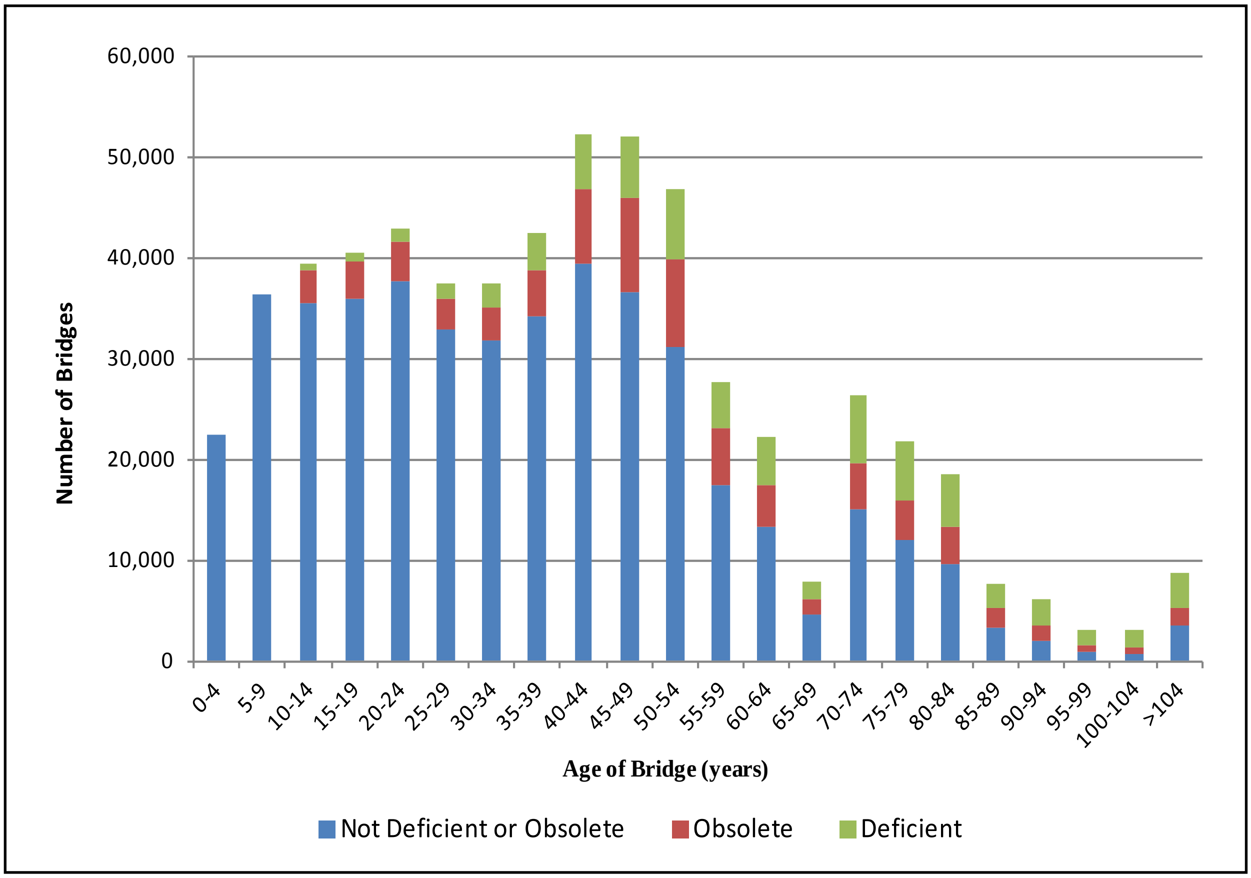

Figure 4: High percentage of older bridges are obsolete or deficient. Data source: 2010 National Bridge Inventory (NBI) data.

[2] USDOT Federal Highway Administration. *FOCUS*. August 2011. Retrieved from http://www.fhwa.dot.gov/publications/focus/index.cfm

OVERVIEW OF CURRENT BRIDGE INSPECTION PRACTICES

U.S. federal regulations define eight types of bridge inspections (routine, fracture-critical, underwater, damage, hands-on, in-depth, initial, and special). Three of these, routine, fracture-critical, and underwater inspection occur at intervals set by regulation (TRB, 2007). In most cases, the National Bridge Inspection Standards (NBIS) suggests a 24-month interval for routine inspections. Some states, such as Minnesota and Ohio, require routine inspection at 12-month intervals. Bridges with condition problems can be inspected on 6-month or even 3-month intervals. The current state of the practice was also reviewed in the team's Deliverable 2-A, available on the project website can be found at <http://www.mtri.org/bridgecondition/doc/State-of-PracticeSHMforBridges(July2010).pdf> (see "Bridge Evaluation Process" section).

Routine inspection is described as “regularly scheduled inspection consisting of observations and/or measurements needed to determine the physical and functional condition of the bridge, to identify any changes from initial or previously recorded conditions, and to ensure that the structure continues to satisfy present service requirements” (see TRB NCHRP SYNTHESIS 375).

All routine bridge inspections, by federal mandate, require rating five major bridge components, including bridge deck, superstructure, substructure, channel and channel protection, and culvert condition. Most transportation agencies and owners go beyond the NBIS and federal mandates to collect more information to support their bridge management program (Alampalli, 2010).

Currently most inspections are visual based, even though non-destructive evaluation (NDE) methods are becoming popular in augmenting the visual inspections and subsequent evaluations advocated. Traditional structural health monitoring techniques include:

- Strain gauges.
- Deflectometers.
- Accelerometers.
- Live load vehicles.
- Hammer-sounding.
- Chain-drag.

U.S. federal regulations identify four staff positions for bridge inspection programs:

- *Program manager:* The individual in charge of bridge inspection, reporting, and inventory.
- *Team leader:* The individual in charge of an inspection team and responsible for planning, performing, and reporting field inspections.
- *Load rater:* The individual with the overall responsibility for bridge load rating.
- *Underwater bridge inspection diver:* Individual(s) performing inspections, by diving, of submerged components of bridges.

State DOTs may use different staff titles for each of the above four positions. For example, Michigan has one state bridge inspection manager, 7 region bridge engineer, 15 bridge inspectors, and 15 inspection assistants.

U.S. federal regulations require training for program managers and inspection team leaders in an FHWA-approved comprehensive course in bridge inspection. Federal regulations do not establish qualifications for inspection team members working under the direction of an inspection team leader (TRB, 2007). In Michigan, professional engineers must complete the National Highway Institute (NHI) two week training class. A non-professional engineer needs 2 years of training in addition to the two week training class. After obtaining 5 years of inspection experience, non-technical inspectors can become an inspection team leader.

Most state DOTs use two-person inspection team, including Michigan. Local agencies and consultants often use single-person teams.

COST ESTIMATES OF CURRENT BRIDGE INSPECTION TECHNIQUES

Estimating bridge inspection costs is a very complicate issue since the data is not readily available in most cases. Agency experience or budgets are the only practical source for costs estimates. As previously discussed, state DOTs are required by federal law to inspect all bridges owned and maintained by the states at least once every 24 months. Most DOTs include regularly scheduled inspections costs in their “normal” or “preventive” maintenance budget since bridge inspection is often part of a DOT’s overall highway maintenance, repair, and traffic operations program (TRB, 2003). The CAR research team used a combined approach, namely through extensive literature review and face-to-face interview with MDOT partners, to establish realistic agency cost estimates of current bridge inspections. The initial findings of the research are presented below.

Inspection Costs by State, County, and City

The average inspection cost per bridge varies significantly from place to place. For example, Connecticut's DOT oversees inspection of about 5,300 highway bridges and 330 railway spans in the state, and spent around $22.9 million on private bridge inspection services and in-house inspection for FY 2010[3]. On average, this translates into an annual inspection cost of $8,135 per bridge in Connecticut (assuming 50% or 2,815 bridges were inspected each year).

In 2008, Wisconsin Legislative Audit Bureau conducted a limited-scope review of WisDOT's bridge inspection program that included FY 2006-07 bridge inspection expenditures by state staff and consultants ($1.31 million and $1.01 million, respectively). There are 5,188 state-owned bridges in Wisconsin and the on-time inspection rate is 98% or 2,542 bridges were actually inspected. As a result, the average inspection cost is $917 per bridge for FY2006 - 07.[4]

State/County/City	Bridge Inspection Cost	# of Bridges Inspected Annually	Period	Annual Inspection Cost Per Bridge	Type of Inspection Services
Connecticut	$22.9 million	2,815	FY2010	$8,135	$15.8M for contractors; $7.1M for in-house
Wisconsin	$2.32 million	2,542	FY 2006-07	$917	$1.01M for contractors; $1.31M for in-house
Armstrong County, Penn	$482,172	34	2010 to 2015	$2,398	Contract service with PennDOT
City of Tulsa, Oklahoma	$98,000	256	2007 - 2008	$383	Contract service
City of Tulsa, Oklahoma	$130,000	256	2005 - 2006	$508	Contract service
Tulsa County, Oklahoma	$70,000	195	2007 - 2008	$359	Contract service
City of Sapulpa, Oklahoma	$4,500	11	2009 - 2010	$409	Contract service
Coal County, Oklahoma	$18,300	52	2009 - 2010	$352	Contract service
Garvin County, Oklahoma	$73,200	272	2009 - 2010	$269	Contract service
Logan County, Oklahoma	$88,000	231	2007 - 2008	$381	Contract service
Oklahoma Turnpike	$150,000	399	Since 1998	$376	Contract service

Table 3: Bridge inspection costs by state, county, and city.

Armstrong County in Pennsylvania recently signed bridge inspection contract with PennDOT from 2010 through 2015. The average inspection cost is $2,398 per bridge.

A long-time bridge inspection service provider in Oklahoma charged from $269 to $508 per bridge for state, county, and city-owned bridges.[5] The inspections are for the NBIS inspection program, and include updating the Pontis database, reviewing the load ratings and updating

[3] http://www.ct.gov/scsb/lib/scsb/Cost_Benefit_Analysis_attachments.pdf
[4] Wisconsin Legislative Audit Bureau. Bridge Inspection Program. February 2008. http://legis.wisconsin.gov/lab/reports/08-bridgeinspectionprogram_ltr.pdf. (accessed August 15, 2011)
[5] http://www.okladot.state.ok.us/projmgmt/off_system_bridge_inspection_consultants/EC-1321%20-%20The%20Benham%20Companies%20LLC.pdf. (accessed August 15, 2011)

where necessary, preparing reports with Pontis data and work candidates, and coordinating load postings and overhead clearance signage. These bridge inspection cost information is summarized in Table 3.

Time Spent on Inspections

While the time required for a bridge inspection varies according to the type and design of the bridge, the Inspection Manual published by Ontario Ministry of Transportation (MTO) states that an inspector should plan to spend at least two to three hours at a typical bridge site to adequately assess the condition of all elements. Insufficient time spent on inspections increases the risk that serious deficiencies will be missed, especially in older structures and bridges that have a history of problems. On average, inspectors conducted three to five inspections in a single day. Larger bridges take longer to inspect.[6]

In Wisconsin, most routine inspections take less than one day to complete, and some take less than an hour, although inspections of bridges with complex designs or structural problems can last several days. [7]

Another study points out that visual inspections rely upon the inspector having access to all components of a bridge and, therefore, methods of gaining access to an elevated bridge are critical to inspection times. The two primary access methods are access equipment and vehicular (aerial) lifts. Access equipment includes ladders, rigging and scaffolds. Typical vehicular lifts are Manlifts, bucket trucks, and under-bridge inspection vehicles. Usually, employing a vehicular lift will be less time-consuming than deploying access equipment; however, the time savings will be offset by the higher costs associated with operating vehicular lifts.[8]

Findings from Interview with Bridge Inspection and Management Experts

A preliminary discussion on the assessment task of the project was initiated at the MDOT partner meeting and the TAC meeting in February 2011. The discussion focused primarily on the challenges associated with the assessment and the inputs required from project partners to allow for a realistic assessment. Therefore, follow-up interviews with bridge inspection and

[6] Ministry of Transportation, Ontario. Bridge Inspection and Maintenance. 2009. http://www.auditor.on.ca/en/reports_en/en09/302en09.pdf. Accessed in August 2011.
[7] Wisconsin Legislative Audit Bureau. Bridge Inspection Program. February 2008. http://legis.wisconsin.gov/lab/reports/08-bridgeinspectionprogram_ltr.pdf. Accessed in August 2011.
[8] Brian Leshko. Access Methods for Bridge Inspections. Structure Magazine, October 2008.

management experts, including MDOT partners, were conducted in August and September, 2011.

The purpose of the interviews is to quantify costs of traditional bridge inspection methods, such as time and labor requirements for bridge inspection, equipment needs, costs of special bridge inspection, and overall annual budget for bridge inspection program in Michigan. Another round of interviews are necessary in order to measure the benefits of new bridge inspection technologies, as well as incentives or barriers to their implementation, after the field demonstration data and analytical results become available. Following is a summary of the interviews.

Michigan has 4,465 state-owned bridges. For routine bridge inspections, almost 100% are done by MDOT inspectors. MDOT also owns about 200 over-water bridges that often require consultants help in inspection. On-time inspection rate at MDOT is 99.8%. Only a few bridges may be delayed due to their special conditions. Meantime, special needs bridges may be inspected more frequently, at less than 24-month intervals. Annually inspected bridges include:

- Moveable Bridges.
- Fracture Critical and Fatigue Sensitive Bridges.
- Special Needs Bridges.
- Complex and/or Large Bridges.
- Underwater Bridge Inspections.

Michigan's annual budget for bridge operations is $185 million, increased from $28 million since one cent per gallon gas tax increase goes directly to MDOT to fix seriously deficient bridges on the state road system in 1997. The annual budget for in-house and contract service is about $2 million, which includes inspection, the bridge asset management program, and contract services. This translates into an inspection cost of $896 per bridge.

Typically, preparation for inspection (e.g., review historical inspection reports) requires about 10-20% of total inspection time. The actual field inspection requires about 70-80% of the total inspection time. Data entry requires the remaining 10% of bridge inspection time.

A typical 3-5 span bridge will require 4-6 hours inspection time. The deck, superstructure, and substructure will each take about 30% of the total inspection time. The remaining 10% of time is spent on approaches. All routine inspections can be done without interrupting the traffic.

For list of interviewees, interview questions, and MDOT partners' responses, see **Appendix A**.

COST ESTIMATES AND DATA COLLECTION OF USING REMOTE SENSING TECHNOLOGIES

While cost-benefit analysis can be straightforward in cases with known or measurable costs and benefits, analysis of remote sensing technologies is complex because neither the true benefits nor true costs can be measured with certainty. Additionally, the current technologies are being assessed as part of an applied research project. Once implemented on a commercial basis, the cost of these technologies is likely to fall significantly. One important approach used for this study is to collect and analyze cost data through field demonstration and associated technical assessment of these technologies.

Three MDOT bridges were selected for field demonstration in August 2011. The bridges provides a variety of conditions from poor to good and are the same type (pre-stressed concrete I-beam with concrete deck) to provide comparability between remote sensing results but under different condition ratings. The 2011 field demonstration bridges, their location, and dates are:

- MDOT structure nº 10940 – Freer Road over I-94, Washtenaw County, August 1-3.
- MDOT structure nº 10892 – Willow Road over US-23, Washtenaw County, August 3-5.
- MDOT structure nº 1713 – Mannsiding Road over US-127, Clare County, August 8-10.

The remote sensing technologies and the specific systems used to deploy these technologies on the three selected bridges include:

- 3D Optics (3DO), in the form of a 3D Optical Bridge-evaluation System (3DOBS).
- Street View Style Photography (SVSP), in the form a Bridge Viewer Remote Camera System (BVRCS).
- Thermal Infrared (ThIR) Imaging.
- Digital Image Correlation (DIC).
- Light Detecting and Ranging (LiDAR).

- Synthetic Aperture Radar (SAR) in the form of an Ultra Wide Band Imaging Radar System (UWBIRDS).

- GigaPan (gigapixel panoramic photograpy).

A field demonstration cost data collection form was developed with a purpose of documenting detailed inspection activities on the bridge, including types of technology and equipment use, personnel, set-up time, running time, traffic closure etc.

The use and quantitative analysis of the cost data collected through field demonstration will be conducted in combination with ongoing data processing steps, software needs, and final technical assessment and performance of remote sensing technologies, which will be available to CAR research team at a later stage of the study. The detailed field demonstration activities and notes (from day one through day eight) are presented in **Appendix B**.

NEXT STEPS

CAR researchers will continue to work closely with MTTI and MTRI teams to complete a thorough and comprehensive economic valuation and assessment of the cost-effectiveness of the new technologies and bridge monitoring system, including signatures and the DSS. Specifically, CAR researchers will next focus on following areas:

- Quantify costs of using remote sensing technologies (labor, equipment, software etc.) into monetary values and link the costs to the performance and detection capability of the technologies. Careful analysis will need to be performed to estimate the cost of these technologies once at a commercially available stage, as research costs are not typically representative of implemented technology costs.

- Collect user costs data. Current routine bridge inspections usually do not require traffic lane closures. Several remote sensing technologies, however, will need to close the traffic. User costs will be included in final analysis, such as traffic delay and accidents rates.

- Benefit estimates of DSS. In general, inspection costs are not that significant comparing to bridge investment since they represent less than 4% of bridge life-cycle costs (construction, maintenance, and rehabilitation etc.)[9] The greater value of remote sensing technologies is likely the benefits of a more efficient bridge management system and DSS that will lead to timelier detection of problems,

[9] Hank Bonstedt. Life Cycle Cost Analysis for Bridges. http://caba-bridges.org/Presentations/files/LCCA.ppt. (accessed September 28, 2011)

resulting in substantial cost savings and longer asset life – if these technologies become practical and cost-effective. The Bridge Condition DSS described above, and technical memorandum nº 21 in greater detail, will be used to understand and evaluate this value.

- Conduct scenario analyses and prepare final report. This will include considerations of alternative scenarios, time period, scale of implementation, and valuing outcomes. Because each of the remote sensing technologies has its own advantages and disadvantages, combining several methods may yield better results and take advantage of the unique strengths of each individual technology. As a result, development of scenarios to a large extent will rely on the outcomes of technical assessment of the technologies.

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APPENDIX A: INTERVIEW WITH BRIDGE INSPECTION AND MANAGEMENT EXPERTS

Interview dates: August 31 and September 2, 2011

Interviewees: Amy Trahey, Great Lakes Engineering Group

Rich Kathrens, MDOT

Dave Juntunen, MDOT

Steve Cook, MDOT

Jason DeRuyver, MDOT

Purpose: 1) To quantify the costs of traditional bridge inspection methods, such as time and labor requirements, equipment needs, cost of special bridge inspections, and develop an estimate of the overall annual budget for bridge inspection programs in Michigan.

2) To measure the benefits of new bridge inspection technologies, as well as incentives or barriers to their implementation (we will schedule a separate interview on this topic after field demonstration data becomes available in October);

3) To obtain results that will be in the white paper "Economic Valuation of Commercial Remote Sensing and Spatial Information for Bridge Health Monitoring."

General Questions About MDOT Bridge Inspection Program

1. How many people are on the bridge inspection team at MDOT? How many years of experience does a typical bridge inspector have? What are the qualifications for bridge inspection?

The type of inspection drives the need for and number of inspectors. For MDOT, there are always two inspectors in each inspecting team. Local agencies vary and a lot time there is only one inspector.

There are seven regions that have 2-3 dedicated bridge inspectors per region, making a total of 21-24 inspectors in MDOT. There is also an 8th group of inspectors based in Lansing that are called in when bridge inspections require special services. They are responsible for following bridges:

- Fracture Critical Bridges
- Complex Large Deck and Large Superstructure
- Underwater Fatigue Sensitive and Removable

Qualifications: There are several different ways to become a Qualified Team Leader. Professional engineers must complete the National Highway Institute (NHI) two week training class. A non-professional engineer needs 2 years of training in addition to the two week training class. After obtaining 5 years of inspection experience, non-technical inspectors can become an inspection team leader. Also the Federal Highway Administration (FHWA) has guidelines for bridge inspector's qualifications.

2. Of the 4,465 state-owned bridges, how many of them require specialized inspection services by private consultants? What are the determining factors for hiring a private consultant (e.g., special equipment, expertise, in-house staff shortage etc.)?

For routine bridge inspections, almost 100% are done by MDOT inspectors. By contrast, about 90% of local bridges are contracted out to consultants. For scoping inspections, about half are done in-house and the other half by consultants. There are about 260 total scoping inspections done by MDOT each year. MODT also owns about 200 under water bridges that often require consultants help in inspection. Almost 100% of underwater bridge inspections are hired out.

Most scoping in the University Region is hired out, with an average cost of about $10,000 per bridge.

3. What is the percentage of state-owned bridges that are inspected at least once every 24 months? What factors cause this to be less than 100%?

On-time inspection rate at MDOT is 99.8%. Only a few bridges may be delayed due to their special conditions. Meantime, special needs bridges may be inspected more frequently, at less than 24-month intervals. Annually inspected bridges include:

- Moveable Bridges.
- Fracture Critical and Fatigue Sensitive Bridges.
- Special Needs Bridges.
- Complex and/or Large Bridges.
- Underwater Bridge Inspections.

4. What is the breakdown of bridgework funding at MDOT (e.g., capital scheduled maintenance, capital preventive maintenance, bridge rehabilitation, and bridge replacement)? How much is provided by federal and state governments, respectively?

Michigan's annual budget for bridge operations is $185 million. This increased from $28 million due to the gas tax increase.

- $163 million is distributed to DOT regions for replacements (48%), rehabilitations (32%), and preventive maintenance (20%).
- $16 million is allocated to the Big Bridge Program.
- $3 million is allocated to special needs, such as emergency maintenance.
- $3 million is allocated to Michigan's emerging technology program for trial applications of new materials and methods.

U.S. Federal Highway Bridge Program (HBP) funds make up $110 million of Michigan's bridge operations budget, about 60% of total. Other federal programs, such as interstate maintenance, surface transportation, and national highway system funds, are also used to fund bridge preservation projects.

Funds are distributed across state regions based on their proportion of statewide bridge inventory in each work category. For each region, the inventory of bridges in each work category (i.e., prevention, rehabilitation, and replacement) is computed. The work categories have significantly different costs. The average cost of a bridge preventive maintenance project is $450,000. Replacing a bridge deck will cost $1.7 million for a 5-lane deck. The average cost of bridge replacement is $2.2 million. In 2009, Michigan will execute 118 preventive maintenance projects, 87 rehabilitation projects, and 51 replacement projects.

5. Over the next ten years, how important are each of the followings to MDOT's bridge inspection program?

- *Funding limitations for bridge inspection programs*

Funding is always an issue, but as long as the inspection is completed on-time, the cost will be reimbursed from the Federal Government. In that sense, funding is not an issue.

- *Not enough qualified bridge inspectors*

It's not an issue since MDOT has a lot engineers with potential to become bridge inspectors after training. But on the other hand, some specific regions (e.g. metro region) may have a hard time to fill a vacancy.

- *Applying new technologies*

New technologies are the future, and they are a potential solution to many challenges. If a new technology saves time, saves money long term, helps makes bridge inspectors safer, or interrupts traffic less, then it could be a good and attractive investment.

New technologies will have more impact on bridge construction and management than on bridge inspection itself. Examples of new tools:

- Optimize bridge data management system
- Hand-held tablets
- Uploading photos when on-site
- Online system that can track real-time maintenance records
- Consolidating/streamlining various paper files
- Fit in MDOT overall IT strategies

- *Increasing maintenance and improvements costs*
- *Optimizing bridge inspection and repair programs*
- *Meeting federal regulations and inspection guidelines*

This is a critical component of bridge inspection policy. We have to comply with Federal requirements.

Costs of Current Inspection Techniques

6. What are the annual budgets for in-house and contract service of bridge inspections at MDOT?

The annual budget for in-house and contract service is about $1.5 – $2.1 million, which includes inspection, the bridge asset management program, and contract services.
(Metro and University Regions spend about 1.5 million on scoping each year.)

7. What are the current inspection techniques and related equipment requirements for a typical bridge? Is there any way to examine the inspection accuracy of these techniques?

The accuracy of current methods used in the bridge inspection process is reliant on the skills of the bridge inspector. Interpreting the results from the inspection methods is subjective, so it takes a keen sense to accomplish the inspection process with a good degree of accuracy.

8. On average, what is the percent share of annual hours a bridge inspector spends on preparation for inspection, conducting field inspection, data entry and reporting, training, and other activities (such as providing local support)?

Preparation for inspection requires about 20% of total inspection time.
The actual field inspection requires about 70% of the total inspection time.
Data entry requires the remaining 10% of bridge inspection time.

As made clear above, three activities account for 90% of an inspector's hours. The remaining 10% are spent on other activities, such as training and supporting local programs. MDOT bridge inspectors are required to accept 24 hours training every five years.

Preparation for inspection takes about 15 minutes a bridge.
Field inspection takes about 90 to 120 minutes a bridge.
Data entry takes about 30 minutes a bridge.

Normally we can do about 4-5 bridges a day. There are no field inspections from December to March, but we undertake other activities such as maintenance.

9. When conducting a field inspection, which element-level inspection requires most of the inspector's time (including inspection and equipment set-up and break-down hours): the deck, superstructure, substructure, or approach?

It depends on a bridge's condition and type. For steal-beam bridges, the superstructure takes most time, followed by decks, substructure, and approach. A typical 3-5 span bridge will require 4-6 hours inspection time. The deck, superstructure, and substructure will each take about 30% of the total inspection time. The remaining 10% of time is spent on approaches. Hours spent on element-level inspection:

a. The Deck – 1.5 hrs.
b. Superstructure – 1.5 hrs.
c. Substructure – 1.5 hrs.
d. Approach – 0.5 hrs.

Completing all the component steps in deck inspection takes a lot of time.

10. How difficult is it to close traffic lanes when conducting field inspections? How often do closures take place? What is the average expense of deploying traffic lane closures?

The cost to set up of traffic closures ranges from $2,000 to $30,000, depending on how many levels of magnitude. The typical cost range is between $2,000 and $3,000. The set-up time usually only requires 15–20 minutes. Switch the closure to another lane will also take about 15 minutes. We usually do not close traffic unless we have to. There are other restrictions too, such as hours, for traffic control. Usually lane closures occur from 10:00 am to 2:00 pm for inspection purpose.

Traffic closures never happen during routine inspections. After routine inspection, 5-7% of the bridges will require in-depth inspections, which then require traffic control. We spent about one million contract dollars on in-depth inspections in the Metro Region.

11. How much time did it take your team to complete inspections for following bridges? Did you need special access equipment? If so, how much time did it take to set up? Did the inspections require traffic control?

- *Freer Road over I-94:* 30 minutes for preparation
  90 to 120 minutes for inspection
  30 minutes for data entry

- *Willow Road over US-23:* 15 minutes for preparation
  One to two hour for inspection
  30 minutes for data entry

- *Mannsiding Road over US-127:* 30 minutes for preparation
  Two to Three hours for inspection
  30 minutes for data entry

Usually it takes about 4-6 hours per bridge; contractors try to have it done within two hours

Benefits and Limitations of New Technologies

12. We will conduct a second-round interview on this topic later. But based on what you have observed from the BCAURS field demonstration, how much potential do you see for using remote sensing technologies for bridge condition assessment?

Thermal IR seems promising. It can allow us to get deck bottom delamination data without closing traffic. Kansas and the University of Missouri may be using these applications already. 3D photos are also useful. They are useful in creating a reliable record that can be compared with damages caused by accidents.
GPS tagging is not very promising because it takes too much time to do it.

13. One last question: what technical capabilities would the remote sensing technologies have to have to supplement or even replace current bridge inspection techniques?

Remote Sensing has great potential, as long as it is easy to use, easy to deploy, and easy to interpret the data/results. If it meets all these criteria then we will go for it. It's our goal to use less money to do more things, and using technologies definitely will help us achieve this goal. On top of that, remote sensing will not only support the bridge management system (MBI and Pontis), but also TMS.

If remote sensing inspection could get the results currently obtained through scoping, and if it's cost effective, then the new technology will be a great value to us.

APPENDIX B: FIELD COST DATA COLLECTION SPREADSHEETS

Bridge Name: Freer Rd over I - 94						
	3D Optics (3DO)	**Street-view Style Photography (SVSP)**	**Thermal Infrared (ThIR)**	**Light Detection and Ranging (LiDAR)**	**Synthetic Aperture Radar (SAR)**	**Digital Image Correlation (DIC)**
Inspection date 8/1/11						
# of persons operating the equipment	2	2	4-5 for grid creation 2-3 for Camera cart setup 1-2 to operate			
Equipment #1	Nikon D5000	Cannon SX110IS	FLIR i7 (Hand-Held)	LEICA C-10 ($140K)	Synthetic Aperture Radar	Canon EOS 7D
Equipment #2	Ford F-150	Cannon SX110IS	FLIR SC 640	8 Trimax	Laptop	70-200 MM lens
Equipment #3	8 bit controller	Laptop	Laptop			
Equipment #4		Ford F-150	Cart			
Equipment #5						
Equipment #6						
Equipment set-up starts	10:35	9:00				
Equipment set-up ends	10:55	9:15				
1st run starts	11:10	10:00				
1st run ends	11:12	10:10				
Position, direction, and coverage area	SE > NE (1 Lane)	SE > NE (1lane)				
# of traffic lanes closed	Both	Both				
2nd run starts	11:14	10:11				
2nd run ends	11:16	10:13				
Position, direction, and coverage area	NW > SW (1 Lane)	NW > SW (1lane)				
# of traffic lanes closed	Both	Both				
3rd run starts	11:17	10:13				
3rd run ends	11:20	10:15				
Position, direction, and coverage area	SE > NE (1 Lane)	SE > NE (1lane)				
# of traffic lanes closed	Both	Both				
4th run starts	11:21	10:14				
4th run ends	11:24	10:15				
Position, direction, and coverage area	NW > SW (1 Lane)	NW > SW (1lane)				
# of traffic lanes closed	Both	Both				
5th run starts			**Underside of Bridge inspeciton** 18 min to gear up 45 min to use handheld LiDAR Unit for underside			
5th run ends						
Position, direction, and coverage area						
# of traffic lanes closed						
Equipment break-up starts						
Equipment break-up ends						

Table B1: Day 1 Field Demonstration.

Bridge Name: Freer Rd. Bridge over I-94							
	3D Optics (3DO)	**Street-view Style Photography (SVSP)**	**Thermal Infrared (ThIR)**	**Light Detection and Ranging (LiDAR)**	**Synthetic Aperture Radar (SAR)**	**Digital Image Correlation (DIC)**	**GIGAPAN (Panoramic)**
Inspection date 8/2/11							
# of persons operating the equipment	2	2	4-5 for grid creation 2-3 for Camera cart setup 1-2 to operate	2	2 or 3		1
Equipment #1	Nikon D5000	Cannon SX110IS	FLIR i7 (Hand-Held)	Leica C-10	Synthetic Aperture Radar	Canon EOS 7D	Cannon SX110IS
Equipment #2	Ford F-150	Cannon SX110IS	FLIR SC 640	Built in Lieca GPS	Laptop	70-200 MM lens	GigaPan
Equipment #3	8 bit controller	Laptop	Laptop	Control Targets			
Equipment #4		Ford F-150	Cart				
Equipment #5						``	
Equipment #6							
Topside, Underside, or Profileof Bridge	**Topside**	**Underside**	**Underside of Bridge inspeciton** **18 min to gear up** **45 min to use handheld Thermal IR Flir i7 Unit for underside**	**Underside and Profile**	**Topside**		Underside
Equipment set-up starts				10:17 AM	10:11 AM		10 min
Equipment set-up ends				11:08	11:12 AM		
1st run starts				**11:15**	Started at 1:00 pm		9:30 AM
1st run ends				12:37	Ends at 3:30		10:15 AM
Position, direction, and coverage area				North Face			South Face of Bridge
# of traffic lanes closed				1 Lane			1 Lane
2nd run starts				12:38			11:00
2nd run ends				13:52			11:52
Position, direction, and coverage area				North East Face			North Face of Bridge
# of traffic lanes closed				1 Lane			
3rd run starts				2:17 PM			
3rd run ends				3:30 PM			
Position, direction, and coverage area				South Face			
# of traffic lanes closed				1 Lane			
4th run starts							
4th run ends							
Position, direction, and coverage area							
# of traffic lanes closed							
5th run starts			**Underside of Bridge inspeciton** 18 min to gear up 45 min to use handheld LiDAR Unit for underside				
5th run ends							
Position, direction, and coverage area							
# of traffic lanes closed							
Equipment break-up starts							
Equipment break-up ends							

Table B2: Day 2 Field Demonstration.

Bridge Name: Willow Rd. Bridge over US 23							
	3D Optics (3DO)	Street-view Style Photography (SVSP)	Thermal Infrared (ThIR)	Light Detection and Ranging (LiDAR)	Synthetic Aperture Radar (SAR)	Digital Image Correlation (DIC)	GIGAPAN (Panoramic)
Inspection date 8/3/11			Insufficent Light				
# of persons operating the equipment	2	2		2	2		1
Equipment #1	Nikon D5000	Cannon SX110IS		Leica C-10	Radar	Canon EOS 7D	Cannon SX110IS
Equipment #2	Ford F-150	Cannon SX110IS		Built in Lieca GPS	Generator	70-200 MM lens	GigaPan
Equipment #3	8 bit controller	Laptop		Control Targets	Laptop		
Equipment #4		Ford F-150			Special Radar Cable		
Equipment #5					Supporting Structure		
Equipment #6					Antenna Above		
Topside, Underside, or Profileof Bridge	Topside	Topside		Underside and Profile	Underside		Underside
Equipment set-up starts	11:37	9:30					5 min
Equipment set-up ends	11:45	9:45					
1st run starts	12:09	10:07			9:30		9:30 AM
1st run ends	12:10	10:10			1:30 PM		10:15 AM
Position, direction, and coverage area	NW > NE (1 Lane)	SE > NE (1lane)			2 centimeter horizontal increments per scan. Scans are still 10 ft per		North Bound (Underside)
# of traffic lanes closed	Both	Both					
2nd run starts	12:13	10:11					
2nd run ends	12:15	10:13					
Position, direction, and coverage area	SE > SW (1 Lane)	NW > SW (1lane)					
# of traffic lanes closed	Both	Both					
3rd run starts	12:17	10:13					
3rd run ends	12:19	10:15					
Position, direction, and coverage area	NW > NE (1 Lane)	SE > NE (1lane)					
# of traffic lanes closed	Both	Both					
4th run starts	12:21	10:14					
4th run ends	12:24	10:15					
Position, direction, and coverage area	SE > SW (1 Lane)	NW > SW (1lane)					
# of traffic lanes closed	Both	Both					
5th run starts							
5th run ends							
Position, direction, and coverage area							
# of traffic lanes closed							
Equipment break-up starts							
Equipment break-up ends							

Table B3: Day 3 Field Demonstration.

Bridge Name: Willow Rd. Bridge over US 23							
	3D Optics (3DO)	Street-view Style Photography (SVSP)	Thermal Infrared (ThIR)	Light Detection and Ranging (LiDAR)	Synthetic Aperture Radar (SAR)	Digital Image Correlation (DIC)	GIGAPAN (Panoramic)
Inspection date 8/4/11			**Insufficent Light**				
# of persons operating the equipment	2	2		2	2		1
Equipment #1	Nikon D5000	Cannon SX110IS		LEICA C-10 ($140K)	Radar	Canon EOS 7D	Cannon SX110IS
Equipment #2	Ford F-150	Cannon SX110IS		8 Trimax	Generator	70-200 MM lens	GigaPan
Equipment #3	8 bit controller	Laptop		Control Targets	Laptop		
Equipment #4		Ford F-150			Special Radar Cable		
Equipment #5					Supporting Structure		
Equipment #6					Antenna Above		
Topside, Underside, or Profileof Bridge	**Underside**	**Underside**		**Underside and Profile**	**Underside**		Underside
Equipment set-up starts	11:45	9:30			11:15 AM		5 min
Equipment set-up ends	12:01	9:45			11:40 AM		
1st run starts	12:07	10:07		11:54	12:00a		2:30 PM
1st run ends	12:12	10:10		12:37	1:30 PM		4:00 PM
Position, direction, and coverage area	NW > NE (1 Lane)	SE > NE (1lane)		Underside and Profile of So	2 centimeter horizontal increments per scan. Scans are still 10 ft per		South Bound (Underside)
# of traffic lanes closed	Both	Both		1 Lane	Lane Closer Ends at 1:30, Radar Stops Prematurely.		
2nd run starts	12:14	10:11					
2nd run ends	12:16	10:13					
Position, direction, and coverage area	SE > SW (1 Lane)	NW > SW (1lane)					
# of traffic lanes closed	Both	Both					
3rd run starts	12:17	10:13					
3rd run ends	12:20	10:15					
Position, direction, and coverage area	NW > NE (1 Lane)	SE > NE (1lane)					
# of traffic lanes closed	Both	Both					
4th run starts	12:21	10:14					
4th run ends	12:24	10:15					
Position, direction, and coverage area	SE > SW (1 Lane)	NW > SW (1lane)					
# of traffic lanes closed	Both	Both					
5th run starts							
5th run ends							
Position, direction, and coverage area							
# of traffic lanes closed							
Equipment break-up starts							
Equipment break-up ends							

Table B4: Day 4 Field Demonstration.

Bridge Name: Willow Rd. Bridge over US 23							
	3D Optics (3DO)	Street-view Style Photography (SVSP)	Thermal Infrared (ThIR)	Light Detection and Ranging (LiDAR)	Synthetic Aperture Radar (SAR)	Digital Image Correlation (DIC)	GIGAPAN (Panoramic)
Inspection date 8/5/11							
# of persons operating the equipment							
Equipment #1							
Equipment #2							
Equipment #3							
Equipment #4							
Equipment #5							
Equipment #6							
Topside, Underside, or Profileof Bridge							
Equipment set-up starts				Crew arrives around 15:45:00 for one scan			Crew arrives around 15:45:00 for one scan
Equipment set-up ends							
1st run starts							
1st run ends							
Position, direction, and coverage area							
# of traffic lanes closed							
2nd run starts							
2nd run ends							
Position, direction, and coverage area							
# of traffic lanes closed							
3rd run starts							
3rd run ends							
Position, direction, and coverage area							
# of traffic lanes closed							
4th run starts							
4th run ends							
Position, direction, and coverage area							
# of traffic lanes closed							
5th run starts							
5th run ends							
Position, direction, and coverage area							
# of traffic lanes closed							
Equipment break-up starts							
Equipment break-up ends							

Table B5: Day 5 Field Demonstration.

Bridge Name: Mannsiding Rd over US-127								
	3D Optics (3DO)	Street-view Style Photography (SVSP)	Thermal Infrared (ThIR)	Light Detection and Ranging (LiDAR) - MDOT	Light Detection and Ranging (LiDAR) - Mich Tech	Synthetic Aperture Radar (SAR)	Digital Image Correlation (DIC)	GIGPAN
Inspection date 8/8/2011								
# of persons operating the equipment	2	2	4-5 for grid creation 2-3 for Camera cart setup 1-2 to operate	1-2		2		1
Equipment #1	Nikon D5000	Cannon SX110IS	FLIR i7 (Hand-Held)	LEICA C-10	RIEGL	Synthetic Aperture Radar	Canon EOS 7D	Cannon SX110IS
Equipment #2	Ford F-150	Cannon SX110IS	FLIR SC 640	8 Trimax	Nikon D30	Laptop	70-200 MM lens	Gigapan (need model)
Equipment #3	8 bit controller	Laptop	Laptop		Calibrated Lens			
Equipment #4		Ford F-150	Cart		8 Trimax			
Equipment #5					Dell Computer			
Equipment #6								
	Topside	Topside	Topside					
Equipment set-up starts	11:10	15 Min	Grid Creation 9:30 am	Initial Setup 11:30 am		30 min		10 Min
Equipment set-up ends	11:25		10:15 am	12:30 pm				
1st run starts	11:30	12:10	11:48	1:05 pm		2:45		10:30
1st run ends	11:33	12:14	12:10	2:05 pm		3:45		11:00
Position, direction, and coverage area	Mannsiding Rd WB (NB Bridge)	Mannsiding Rd WB (NB Bridge)	Mannsiding Rd. WB (NB Bridge)	US-127 NB south side		Mannsiding Rd. EB (NB Bridge)		South Face of SB Bridge
# of traffic lanes closed	1 Lane	1 Lane	1 Lane	1 Lane		1 Lane		1 Lane
2nd run starts	11:34	12:15	12:40	2:30 pm				
2nd run ends	11:37	12:20	12:52	3:15 pm				
Position, direction, and coverage area	Mannsiding Rd EB (NB Bridge)	Mannsiding Rd WB (NB Bridge)	Mannsiding Rd. WB (SB Bridge)	US-127 SB south side				
# of traffic lanes closed	1 Lane	1 Lane	1 Lane	1 Lane				
3rd run starts	3:20	3:00						
3rd run ends	3:24	3:07						
Position, direction, and coverage area	Mannsiding Rd WB (SB Bridge)	Mannsiding Rd WB (SB Bridge)						
# of traffic lanes closed	1 Lane	1 Lane						
4th run starts	3:25	3:08						
4th run ends	3:27	3:12						
Position, direction, and coverage area	Mannsiding Rd WB (SB Bridge)	Mannsiding Rd WB (SB Bridge)						
# of traffic lanes closed	1 Lane	1 Lane						
5th run starts								
5th run ends								
Position, direction, and coverage area								
# of traffic lanes closed								
Equipment break-up starts								
Equipment break-up ends								

Table B6: Day 6 Field Demonstration.

Bridge Name: Mannsiding Rd over US-127								
	3D Optics (3DO)	**Street-view Style Photography (SVSP)**	**Thermal Infrared (ThIR)**	**Light Detection and Ranging (LiDAR) - MDOT**	**Light Detection and Ranging (LiDAR) - Mich Tech**	**Synthetic Aperture Radar (SAR)**	**Digital Image Correlation (DIC)**	**GIGPAN**
Inspection date 8/9/2011								
# of persons operating the equipment	2	2	4-5 for grid creation 2-3 for Camera cart setup 1-2 to operate	2	2	3	1-3	1-3
Equipment #1	Nikon D5000	Cannon SX110IS	FLIR i7 (Hand-Held)	LEICA C-10 ($140K)	RIEGL	Synthetic Aperture Radar	Canon EOS 7D	Cannon SX110IS
Equipment #2	Ford F-150	Cannon SX110IS	FLIR SC 640	8 Trimax	Nikon D30	Laptop	70-200 MM lens	Gigapan (need model)
Equipment #3	8 bit controller	Laptop	Laptop		Calibrated Lens			
Equipment #4		Ford F-150	Cart		8 Trimax			
Equipment #5					Dell Computer			
Equipment #6								
Equipment set-up starts	11:30	8:30	8:30	10:30	8:30	8:30	90 minutes to set up, inlcuding marks	
Equipment set-up ends	11:55	8:55	9:50	11:00	10:30	9:30		
1st run starts	12:00	10:58	10:00	11:00	10:30	Did not start due to failed motor. It will take about 30 minutes to run both directions of the top bridge. To complete the 10 ft x 10 ft 3D scan, it will require 4 - 5 hours.	Survey did not start due to rain	
1st run ends	12:05	11:00	10:15	11:45	11:15			
Position, direction, and coverage area	Mannsiding Rd WB (E. Section)	US-127 NB Right Lane	Mannsiding Rd WB E. Section	US-127 NB north side	US-127 NB north side		US-127 NB north side	
# of traffic lanes closed	1	1	1	1	1		1	
2nd run starts	12:05	11:01	Each lane was divided into four segments and it takes about 2 hours to complete all eight segments of Mannsiding Rd (east section)					
2nd run ends	12:10	11:03						
Position, direction, and coverage area	Mannsiding Rd WB (E. Section)	US-127 NB Right Lane						
# of traffic lanes closed	1	1						
3rd run starts								
3rd run ends								
Position, direction, and coverage area								
# of traffic lanes closed								
4th run starts			Takes about 30 minutes to complete under-the-bridge photography (NB US-127)					
4th run ends								
Position, direction, and coverage area								
# of traffic lanes closed								
5th run starts				Depending on resolutions, each scan will take about 5-30 minutes. # of scans for each bridge will depend on the configurations. For example, Mannsiding Rd will need 22 scans. No wet condition				
5th run ends								
Position, direction, and coverage area								
# of traffic lanes closed								
Equipment break-up starts			Takes about 15 minutes to break-up					
Equipment break-up ends								

Table B7: Day 7 Field Demonstration.

Bridge Name: Mannsiding Rd over US-127								
	3D Optics (3DO)	Street-view Style Photography (SVSP)	Thermal Infrared (ThIR)	Light Detection and Ranging (LiDAR) - MDOT	Light Detection and Ranging (LiDAR) - Mich Tech	Synthetic Aperture Radar (SAR)	Digital Image Correlation (DIC)	GIGPAN
Inspection date 8/10/2011								
# of persons operating the equipment	2-3		4-5 for grid creation 2-3 for Camera cart setup 1-2 to operate	2	2	3	1-4	
Equipment #1	Nikon D5000	Cannon SX110IS	FLIR i7 (Hand-Held)	LEICA C-10 ($140K)	RIEGL	Synthetic Aperture Radar	Canon EOS 7D	Cannon SX110IS
Equipment #2	Ford F-150	Cannon SX110IS	FLIR SC 640	8 Trimax	Nikon D30	Laptop	70-200 MM lens	Gigapan (need model)
Equipment #3	8 bit controller	Laptop	Laptop		Calibrated Lens			
Equipment #4		Ford F-150	Cart		8 Trimax			
Equipment #5					Dell Computer			
Equipment #6								
Equipment set-up starts	10:10			12:00	8:30	8:30	8:30	
Equipment set-up ends	10:30			12:30	9:15	1:00	9:00	
1st run starts	10:33			12:30	9:15	1:00	9:10	
1st run ends	10:35			1:00	Seventh scan ends at 2:30?	Completed three transmission measurements at 1:25	9:40	
Position, direction, and coverage area	Mannsiding Rd WB (E. Section)			US-127 NB under the bridge	US-127 NB under the bridge	Mannsiding Rd WB (E. Section)	US-127 NB north side face	
# of traffic lanes closed	1			1	1	1+1	1 +1	
2nd run starts	10:35			1:00	7 scans today. Each will take about 30-45 minutes (including 1-2 minutes initial scan, 3 minutes target scan, and 15 minutes final scan)		Truck from Clare County Road Commision makes eight runs on top of bridge, lasting about one hour (9:10 - 10:10)	
2nd run ends	10:37			1:30				
Position, direction, and coverage area	Mannsiding Rd WB (E. Section)			US-127 NB under the bridge				
# of traffic lanes closed	2			1				
3rd run starts	10:45			1:30				
3rd run ends	10:47			1:50				
Position, direction, and coverage area	Mannsiding Rd WB (E. Section)			US-127 NB under the bridge				
# of traffic lanes closed	2			1				
4th run starts	10:55							
4th run ends	10:57							
Position, direction, and coverage area	Mannsiding Rd EB (E. Section)							
# of traffic lanes closed	1							
5th run starts				9 scans on Monday, 7 scans on Tuesday, and 6 scans on Wednesday				
5th run ends								
Position, direction, and coverage area								
# of traffic lanes closed								

Table B8: Day 8 Field Demonstration.

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