

**A Summary of the 7th Quarterly Report
for the Technical Activities Council**

**Bridge Condition Assessment
Using Remote Sensors**

Michigan Technological University

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Principal Investigator:

Dr. Tess Ahlborn, P.E.
Associate Professor, Civil and Env. Engineering
Michigan Tech Transportation Institute
Michigan Technological University
1400 Townsend Drive
Houghton, MI 49931
(906) 487-2625; tess@mtu.edu

Program Manager:

Caesar Singh, P.E.
Lead Engineer/Program Manager
Research Development & Technology
RITA, U.S. Dept. of Transportation
1200 New Jersey Avenue, SE, E33-123
Washington, DC 20590
(202) 366-3252; Caesar.Singh@dot.gov

Michigan Tech

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✓ Technical Memorandum No. 21 summarizing field demonstration results of remote sensing applications for bridge condition assessment of the three bridges, including DSS and sensor evaluation and correlation to laboratory testing and modeling of remote sensing responses to bridge characteristics. (Task 5.2)	
✓ Technical Memorandum No. 22 discussing the technical and economic approach for evaluation of commercial remote sensors for bridge condition assessment. (Task 6.1, 6.2)	

EXECUTIVE SUMMARY

This quarterly report documents progress for “*Bridge Condition Assessment Using Remote Sensors*” during the seventh quarter for the period of July 1, 2011 – September 30, 2011. Our Michigan Tech research team is investigating the use of remote sensing technologies to assess the structural health of bridges and provide additional inputs to bridge asset management systems. The project is exploring correlations between commonly used inspection techniques and remote sensing systems, and developing a decision support system to combine various inputs to create a unique bridge signature that can be tracked over time.

The primary goals of this project are to:

1. Establish remotely sensed bridge health indicators.
2. Develop a baseline bridge performance metric, the “signature,” for benchmarking overall bridge condition.
3. Provide a system that enhances the ability of state and local bridge engineers to prioritize critical repair and maintenance needs for the nation’s bridges.

The project schedule is shown below with Quarter 7 activities bounded by dashed lines; note that additional time was previously requested for the Decision Support System (Task 4) in order to incorporate field demonstration data results from Task 5:

ID	Task Name	2010												2011											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Administration	[Task 1: Administration - active throughout 2010 and 2011]																							
2	Bridge Condition Characterization	[Task 2: Bridge Condition Characterization - active from Jan 2010 to Sep 2010]																							
3	Commercial Sensor Evaluation	[Task 3: Commercial Sensor Evaluation - active from May 2010 to Sep 2010]																							
4	Decision Support System	[Task 4: Decision Support System - active from Jul 2010 to May 2011]																							
5	Field Demonstration	[Task 5: Field Demonstration - active from Oct 2010 to Sep 2011]																							
6	Assessment	[Task 6: Assessment - active from Oct 2011 to Jan 2012]																							

Accomplishments for this quarter are discussed below and include progress on all tasks.

Also, according to the Revised Cost Proposal submitted June 26, 2009, and included as Attachment 2 of that cost proposal, the following deliverables were cited for Quarter 7. All technical memos are located at the end of this document and are discussed in the relevant tasks below.

- ✓ **Technical Memorandum No. 21** summarizing field demonstration results of remote sensing applications for bridge condition assessment of the three bridges, including DSS and sensor evaluation and correlation to laboratory testing and modeling of remote sensing responses to bridge characteristics. (Task 5.2)
- ✓ **Technical Memorandum No. 22** discussing the technical and economic approach for evaluation of commercial remote sensors for bridge condition assessment. (Task 6.1, 6.2)

TECHNICAL STATUS

Progress of each of the six tasks is documented below with references to the Technical Memos, which are located at the end of this document.

Task 1: Administration

Several sub-tasks within the administration have been initiated and completed.

The project website continues to be updated: www.mtti.mtu.edu/bridgecondition . This website includes an overview of the project, information related to the project schedule, tasks and deliverables, the decision support system, project team partners, and key links for the project. All presentations, papers and reports are downloadable from our website under the “Tasks & Deliverables” link.

The following publications were documented for this quarter:

- Vaghefi, K., Oats, R.C., Harris, D.K., Ahlborn, T.M., Brooks, C.N., Endsley, K.A., Roussi, C., Shuchman, R., Burns, J.W., and Dobson, R., Evaluation of Commercially Available Remote Sensors for Highway Bridge Condition Assessment, *Journal of Bridge Engineering* 1, 202 (2011). (in press)
http://ascelibrary.org/beo/resource/1/jbenxx/v1/i1/p202_s1?isAuthorized=no
- Abstract “Remote Sensing of Bridge Condition for Asset Management Decision Support” submitted to SPIE Smart Structures/NDE 2012 Conference for inclusion in the Sensors and Smart Structures Technologies for Civil, Mechanical and Aerospace Systems session, March 11-15, 2012. Authored by T. Ahlborn (MTU), D. Harris (MTU), C. Brooks (MTRI) and K.A. Endsley (MTRI).
- Ahlborn, T.M, Vagehfi, K., Harris, D.K., and C.N. Brooks, “Measuring and Communicating Bridge Performance with Remote Sensing Technologies,” 91st Annual Meeting of the Transportation Research Board, Washington DC, January 22-26, 2012 (Paper submitted and accepted for presentation and publication).
- Vaghefi, K., Henrique de Melo e Silva, Harris, D.K., Ahlborn, T.M., “Application of Thermal IR Imagery for Concrete Bridge Inspection,” *Precast/Prestressed Concrete Institute Convention and National Bridge Conference*, Salt Lake City, Utah, October 22-26, 2011 (Paper submitted and accepted for presentation and publication).

Task 2: Bridge Condition Characterization

This task consists of several sub-tasks including feasibility studies including limited laboratory and small scale field investigation and demonstration. The structural model aspect was limited in this quarter as the technology selection has shifted towards condition assessment, however future modeling components will be necessary for correlation with global system response from digital image correlation and LiDAR. Progress has been completed on these sub-tasks through several activities; however the majority of these activities were geared towards the field demonstration task in this quarter.

Specific details of the field demonstration are included in **Technical Memorandum No. 21**; however, activities relevant to this task included preparation for the logistical challenges for field deployment such as equipment down-selection (e.g. longer focal length lens for Digital Image Correlation, grid pattern configuration for Thermal IR and 3D Optics, and resolution testing for the Michigan Tech LiDAR system).

Preliminary results from the field demonstration will be used in future sections of this task as the project team moves towards the development of a bridge signature and integration of the results in to the DSS.

Task 3: Commercial Sensor Evaluation

The commercial sensor evaluation was completed during Quarter 3 and is documented in the report *An Evaluation of Commercially Available Remote Sensors for Assessing Highway Bridge Condition*. The report can be downloaded from www.mtti.mtu.edu/bridgecondition by clicking on “Tasks and Deliverables” and “Deliverable 3-A”. It continues to inform our study and has served a steady reference during project work.

Task 4: Decision Support System

Progress on the Bridge Condition Decision Support System (DSS) has continued since the previous quarter in order to create a user-friendly, stable, and robust framework for integrating remote sensing results while providing access to existing bridge condition data. Several bugs and initial demonstrations of functionality in the early version, which was available during the last DSS Focus Group meeting, have been fixed. Map marker symbology can now be classified by any NBI rating or sufficiency. Multiple selections in the metrics table can now be made and the map will fit to any number of selected bridges. Driving directions to a given bridge are also now available through a pop-up utility that accepts an MDOT regional office, street address or latitude-longitude coordinate pair as an origin. Query-building utilities have also been built to allow arbitrary sorting and filtering of the database from within the application. These fixes were done based on DSS Focus Group feedback and internal review with the project team.

During the past quarter, a key feature added has been the ability to perform spatial queries (e.g. find bridges in a given area). The user can now draw a polygon on the web mapping screen within their browser, and bridges within that area will be selected and available for display. Additionally, MDOT users can now choose to display MDOT regions or counties and select all the bridges within that area, which mimics their existing manual workflow for evaluating bridges.

The Bridge Condition DSS has several additional new features, including:

- Access to the MDOT Structurally Deficient Bridges as a separate data set
- Access to bridge history data to see how bridge condition is changing over time
- The ability to import and access the latest version of the Pontis-type Transportation Management System's (TMS) Bridge Management System tables
- Access to 34 columns of bridge related data including Sufficiency Rating, Deck Rating, Superstructure Rating, Substructure Rating, Year Built, Year of last Bridge Overlay, Main Material Type, Average Daily Traffic, and other information important to understanding overall bridge condition
- The ability to graph National Bridge Inventory (NBI) ratings in pie charts for use in DOT reporting, which was requested as a priority by the DSS Focus Group

Figure 1 shows an example screenshot of the current version of the DSS.

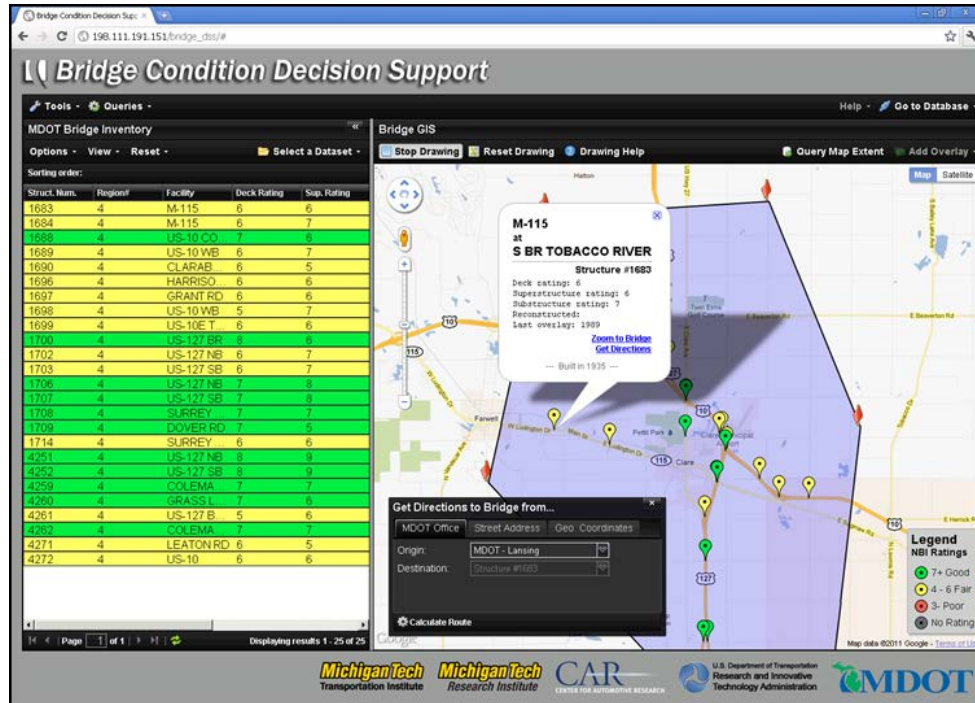


Figure 1: An example screenshot of the current Quarter 7 version of the Bridge Condition Decision Support System. Note the spatial query polygon.

- ✓ **Technical Memorandum No. 21** summarizes the field demonstration results of remote sensing applications for bridge condition assessment of the three bridges, including DSS and sensor evaluation and correlation to laboratory testing and modeling of remote sensing responses to bridge characteristics.

As related to Task 4, a full list of existing and upcoming functionality is detailed in this quarter's **Tech Memo 21**. The most critical next step will be to integrate the remote sensing-based indicators of bridge condition; mostly generated from the August 2011 field collects. For example, 3-D optics and LiDAR are expected to generate percent spalled area for bridge decks based on analysis results so far; thermal infrared and radar are expected to generate percent area of delaminations for the bridge, and the BridgeViewer Remote Camera System is generating a location-tagged inventory of photos for the study bridges. These types of data are being integrated into the DSS. The project team is also developing ways of integrating these new condition indicators with the existing NBI type of data into an overall bridge health signature, which will continue over the next quarter.

The first meeting of the DSS Focus Group occurred on April 18, 2011 in Lansing at the MDOT Construction and Technology Office, with key representatives attending, including MDOT staff Steve Cook, David Juntunen, Richard Kathrens, and Jason DeRuyver. TAC member Amy Trahey of Great Lakes Engineering Group provided input representative of a firm that inspects bridges for MDOT. Their input helped the project team understand key desired features (such as the ability to display color-coded markers representing NBI ratings and information showing MDOT progress towards strategic goals) and this guidance has helped direct development of the DSS since then. Another review with this DSS Focus Group is planned during the next quarter, in addition to making the DSS available to the Technical Advisory Committee for their review and input.

Task 5: Field Demonstration

A significant portion of our field demonstration was completed during this last quarter, including deployment of several technologies on three bridges in Michigan. The bridges provided a variety of conditions from poor to good and were the same type (prestressed concrete I-beam with concrete deck) to provide comparability between remote sensing results but under different condition states. Two were near the Michigan Tech Research Institute in Washtenaw County, enabling easy deployment of several remote sensing technologies and providing a base of operations. One bridge was in mid-Michigan, near the town of Clare, and was selected because it is a relatively poor condition concrete I-beam bridge. Bridge structure numbers and dates of deployment were:

- MDOT structure n^o 10940 – Freer Road over I-94, Washtenaw County, Aug. 1-3, 2011

- MDOT structure n^o 10892 – Willow Road over US-23, Washtenaw County, Aug. 3-5, 2011
 - MDOT structure n^o 1713 – Mannsiding Road over US-127 north bound, Clare County, Aug. 8-10, 2011
- ✓ **Technical Memorandum No. 21** summarizes the field demonstration results of remote sensing applications for bridge condition assessment of the three bridges, including DSS and sensor evaluation and correlation to laboratory testing and modeling of remote sensing responses to bridge characteristics.

As related to Task 5, Tech Memo 21 describes the technologies deployed. Each technology description also includes a discussion on the ease of deployment and preliminary results of the processed data, as well as benefits, limitations and next steps.

- 3D OPTICAL BRIDGE-EVALUATION SYSTEM (3DOBS), a demonstration of 3D optics technology for surface condition assessment
- BRIDGE VIEWER REMOTE CAMERA SYSTEM (BVRCS), a demonstration of Google Street View style photography technology including geo-tagging of a photo inventory
- GIGAPAN SYSTEM (GigaPan), a method of collecting multiple digital photographs and stitching them into a single gigapixel (or larger) image, enhancing the photo inventory
- THERMAL INFRARED (ThIR), a demonstration of imagery based on thermal changes in the scanned system used to detect surface and subsurface condition
- DIGITAL IMAGE CORRELATION (DIC), a method to determine global movement of a bridge system under static and dynamic loading
- LIGHT DETECTING AND RANGING (LiDAR), a scanning method to capture a complete a 3D point cloud rendering of the numerous faces of the bridge structure for surface condition assessment and inventory
- ULTRA WIDE BAND IMAGING RADAR SYSTEM (UWBIRS), a demonstration of synthetic aperture radar, using measurements to sense the interior of concrete bridge components and identify potential structural defects such as delaminations

Additional technologies under investigation that were not linked to the field demonstrations above are also discussed in Tech Memo 21 and include:

- Using Synthetic Aperture Radar (SAR) speckle to assess bridge deck condition and also to image the interior of a box-beam
- Using Interferometric Synthetic Aperture Radar (InSAR) to assess bridge settlement
- Using Multispectral Satellite Imagery (MSI) to assess bridge deck condition

Task 6: Assessment

Discussions on the assessment task of the project have continued this quarter and have focused primarily on the challenges associated with the technical assessment and the inputs required from project partners to allow for a realistic evaluation. We have further refined our economic valuation approaches for Task 6, including conducting a comprehensive literature review and investigating bridge inspection costs using conventional methods. We have found annual cost information for Wisconsin and Connecticut, and worked with Michigan DOT personnel to better detail their typical bridge inspection costs.

- ✓ **Technical Memorandum No. 22** discussing the technical and economic approach for evaluation of commercial remote sensors for bridge condition assessment. (Task 6.1, 6.2)

Tech Memo 22 (TM22) first briefly reviews the DSS because it will provide the necessary environment for helping MDOT and other DOTs in understanding if the remote sensing technologies evaluated in this project can help advance bridge condition assessment in a sufficiently cost-effective manner. This will be possible once the DSS has been further developed to include the remote sensing results and resulting condition indicators.

TM22 mostly focuses on the start of the economic evaluation of the remote sensing technologies and how they fit within current assessment methods. It reviews the current amount spent annually on bridge maintenance and improvement, such as the almost \$5 billion spent in 2009 by the FHWA for the Highway Bridge Program. It reviews the importance of Bridge Management Systems in helping to support cost-efficient decision making in a budget-limited environment using an asset management focus. The team's Bridge Condition DSS is designed to build from this investment in Bridge Management Systems by being able to integrate existing historical and recent inspection data with condition assessment results from newer technologies.

Current inspection practices are listed, with a focus on non-destructive evaluation methods such as chain drags, live load vehicles, and hammer sounding to find delaminations. Cost ranges for example State, County, and City DOTs are referenced as examples. For example, Connecticut appears to be spending \$8135 per bridge for its inspection services, Wisconsin spends an average of \$917 per bridge in recent years, Armstrong County of Pennsylvania spends \$2398 per bridge for inspections, and some Oklahoma Counties spend about \$300 to \$500 per bridge inspection. The source of these varying costs is under further investigation, but highlights the challenge in finding newer technologies that can be used in such a cost-limited environment. Michigan has an annual budget for bridge operations of \$185 million to cover its 4465 state-owned bridges. Typical inspection time for a bridge ranges from 2 hours to a full day, although more detailed scoping and more complex structures can take longer. The project team expects that remote sensing technologies may be more cost-competitive in the short

term for the more detailed scoping process or for more complex and larger bridge structures.

Estimates for costs of using the remote sensing technologies are given a preliminary evaluation, but it is critical to remember that the project team is discussing technologies in varying levels of readiness for real-world implementation. Once these technologies are implemented on a commercial basis, the cost of using these technologies would be expected to fall significantly. Fortunately, some technologies, such as 3-D optics and the BridgeViewer Remote Camera System are close to implementation-level with low costs to use in their current form, so the team expects some technologies to be cost-competitive even in the short term of 1-2 years. The next step for cost evaluation is to quantify the current costs and estimate their costs once reaching the implemented stage. Evaluation of the benefit of the DSS will also be performed, as well as a more detailed technical evaluation of the final technology results, and these will be included as part of the final deliverable.

PROBLEMS ENCOUNTERED

No technical problems were encountered during this quarter. As previously discussed with our project manager and to ensure a quality final report with adequate review time, we will submit a no-cost time extension in the next quarter.

FUTURE PLANS

From a technical perspective, the primary focus of the activities in Quarter 8 will focus on the further development of the DSS and a down-selecting of technologies for the technical and economic valuations. An updated timeline and milestones will be included with the no-cost time extension.

ADVISORY/STEERING COMMITTEE MEETING

Members of the Technical Advisory Committee include:

Steve Cook – Michigan Department of Transportation
C. Douglas Couto – Transportation Research Board
Michael Johnson – CALTRANS
Dan Johnston – Independent Materials Consultant
Dennis Kolar – The Road Commission for Oakland County
Duane Otter – Transportation Technology Center, Inc.
Keith Ramsey – Texas Department of Transportation
Roger Surdahl – Federal Highway Administration
Peter Sweatman – University of Michigan Transportation Research Institute
Carin Roberts-Wollmann – Virginia Tech
Amy Trahey – Great Lakes Engineering Group

Charles Ishee, of the Florida Department of Transportation, retired during this past quarter. The project team wishes him well and thanks him for his time of service.

TAC members were provided with the field demonstration plan for review and comment. No comments were received. Members will be provided with a summary of Quarter 7 activities.

ATTACHMENT Listing – Quarter 7

- Technical Memorandum No. 21 summarizing field demonstration results of remote sensing applications for bridge condition assessment of the three bridges, including DSS and sensor evaluation and correlation to laboratory testing and modeling of remote sensing responses to bridge characteristics.
- Technical Memorandum No. 22 discussing the technical and economic approach for evaluation of commercial remote sensors for bridge condition assessment.