Memo

To: T. Ahlborn, D. Harris, L. Sutter, R. Shuchman, and rest of Project Team

From: Q. Hong, R. Wallace, M. Forster, C. Brooks, A. Endsley, H. de Melo e Silva

CC: C. Singh

Date: January 13, 2012

Number: 25

Subject: Project Progress Update on the Economic Valuation of Technologies and Decision Support System for Bridge Condition Assessment.

In technical memorandum nº 22, the Bridge Condition Assessment Using Remote Sensors (BCAURS) team summarized research findings related to the national bridge program in the context of shrinking transportation revenue, current bridge inspection practices and cost estimates, field cost data collection using remote sensing technologies, and outcomes of the Michigan Department of Transportation (MDOT) stakeholder interviews (available at <http://www.mtri.org/bridgecondition/Tasks_and_Deliverables.html>). Since then, our major activities in Quarter 8 (September-December, 2011) for Task 6 focused on (1) reviewing economic evaluation methods, (2) estimating costs of using remote sensing technologies, (3) estimating costs to road users, and (4) documenting costs of bridge scoping. This memorandum contains a brief summary of each of these four activities.

ECONOMIC EVALUATION METHODS

The decision to integrate remote sensing technologies into bridge inspection practices can be viewed as an investment strategy for both the public and private sectors. The economic indices (e.g., capital and operational costs) are critical for quantifying and qualifying the ability of the proposed new technologies to meet the functional and operational needs of the bridge inspection process. Therefore, a high quality economic evaluation should provide “value for money” information to those making decisions about the investment of new technologies and the allocation of limited bridge inspection resources.

While the resulting information is of value to practitioners and researcher alike, the economic evaluation of remote sensing technologies tends to be very complex, because the task of evaluation involves determining the value of rapidly evolving technologies or products (both hardware and software) in an environment in which market data from real-world practices is very limited. Second, the outcome indicators of traditional bridge inspections and those derived from using remote sensing technologies are not always identical; thus, it is often difficult to create head-to-head comparisons.

For example, some remote sensing technologies are creating higher-resolution indicators of bridge condition than have traditionally been available to transportation agencies, such as the bridge deck digital elevation model (DEM) created through the 3D Optical Bridge-evaluation System (3DOBS). Third, the benefits of using remote sensing technologies and the associated Decision Support System (DSS) are not easily assigned a monetary value without linking them to a broader context, such as life-cycle cost of bridge analysis and the benefits of optimized bridge management system.

The Center for Automotive Research (CAR) team reviewed various economic evaluation techniques, including cost-utility analysis (CUA), cost-effectiveness analysis (CEA), cost-minimization analysis (CMA), cost-benefit analysis (CBA) and cost-consequence analysis (CCA). None of these techniques is absolutely perfect for application to the bridge condition assessment using remote sensors context due to the unique research questions raised, the condition of interest, and the availability of data on outcomes.

To address these challenges, the CAR research team will rely on the BCAUR team's technical assessment of each technology, a second set of interviews with MDOT stakeholders, previous research findings, and field cost collection, as well as a forecast of field costs once tested technologies have been incorporated into a standard concepts of operations (CON-OPS) for bridge assessment to develop application scenarios and conduct relative cost analysis, similar to what the cost would be once these technologies were implemented on a commercial basis. During the analysis process, the team intends to highlight the factors explored below that will influence our final evaluation approaches.

Adoption Curve

The adoption of new technology tends to follow similar patterns, and this can be expected to apply to bridge condition assessment technology as well. Thus, these technologies are likely to be adopted over time following familiar patterns, such as the one shown in Figure 1 based on theoretical models for the diffusion of innovations. This general model, of course, leaves open the questions of how many users at the top of the curve and the length of the uptake time needed to reach the peak.

Time Period of Analysis

The time period for an economic evaluation should maximize the anticipated economic efficiency of the alternatives. The capital costs should be spread over their economic life (e.g., 10 years or longer, depending on the technology). To a large extent, the time period will be determined by the technical or functional obsolescence of a product, especially when new products become available on the market. Considering the rapid development of sensing and communication technologies, the equipment replacement frequency could be as short as a few years; this frequency can be longer when transportation agencies make use of purchased technology for as long as possible in budget-limited environments. We will develop several different time-period options based on technological and equipment types, such as 5 years, 10 years, and 15 years.

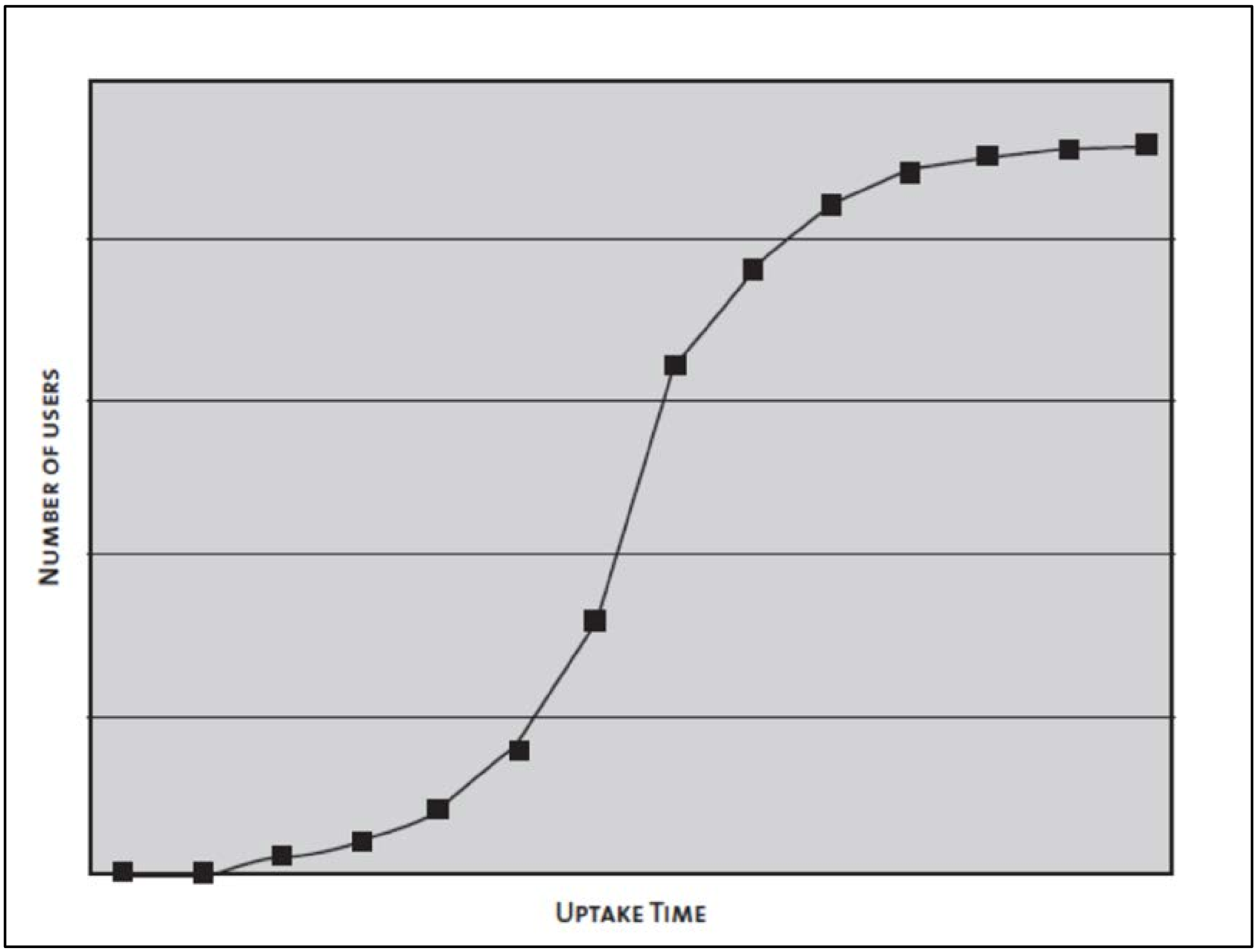

Figure 1: Generalized adoption curve for a new product or technology. Source: Robert H. Potter, Technology Valuation: An Introduction <http://www.iphandbook.org/handbook/ch09/p02/>, 2007.

Geographic Scope of the Analysis

The area included in the analysis will be the State of Michigan, which has 4,465 state-owned National Bridge Inventory (NBI) length bridges and 6,500 local NBI-length bridges. As new bridge condition assessment technologies are adopted, we can expect them to be applied to more and more bridges over time related to the adoption rate discussed previously. We can also assess the potential for broad deployment in adjacent states, such as Indiana, Illinois, Wisconsin, and Ohio, to reduce marginal costs. This latter approach is particularly useful if the likely CON-OPS is for departments of transportation (DOTs) to contract out remote sensing services for bridge condition assessment, as needed, rather than engage in an outright purchase of hardware. DOTs frequently contract out current remote sensing data needs, such as high-resolution aerial photography collection and LiDAR data collection, from commercial services firms such as Woolpert (<http://www.woolpert.com/>) and Aerocon (<http://www.aerocon.com/>), and may choose to do so for new remote sensing technologies as well. These two possibilities – to purchase hardware or to purchase services – may well be the most important distinction in developing the CON-OPS; and the recommended option may vary by technology.

CALCULATION OF COSTS

Many factors must be considered during the process of estimating the costs of using remote sensing technologies, such as technology costs (e.g., equipment and or hardware), labor costs (e.g., operation of sensors, analysis of data), software costs (e.g., needed analytic tools), scheduled maintenance of equipment and hardware, additional costs for data storage and transfer, and road user costs due to traffic disruption.

Some of the above cost elements are relatively straightforward to be measured based on available market data and our field demonstration cost data collection efforts. Other ones with greater uncertainty are not very easy to be measured, such as final labor costs associated with inspection and data processing times. We propose to distinguish experimental or research-stage costs and concept of operations (CON-OPS) costs for real-world applications, and would expect CON-OPS costs to come down when technologies mature.

One example of these cost estimates is presented in Table 1 for the Thermal Infrared (ThIR) bridge condition assessment technology. Similar analyses are planned for development for the other project technologies, such as the 3DOBS, Ultra Wide Band Imaging Radar System (UWBIRS), Digital Image Correlation (DIC), the Bridge Viewer Remote Camera System (BVRCS), and Light Detecting and Ranging (LiDAR).

Road User Costs

Currently, routine bridge inspections generally do not require traffic lane closures. Several remote sensing technologies, however, will need to close the traffic, at least based on currently developed implementations. The user costs represent the inconvenience and expenses incurred by the bridge users due to lane closures and traffic disruption, which include the travel delay costs, vehicle-operating costs (VOC), and crash costs. These costs could be minimized as remote sensing technologies such as the 3DOBS are improved to work at highway speeds.

Thermal Infrared	Cost Elements	Research-Stage Cost Measurement	CONOPS Cost Estimates
Equipment	FLIR SC640 Thermal IR Camera (307,200 pixels)	$20,000 - $40,000	$20,000
	or FLIR i7 Thermal IR Camera (handheld, 14,400 pixels)	$2,000	$2,000
	or FLIR optical and ThIR Camera (handheld, 19,200 pixels)	$4,195	$4,000
	or FLUKE Ti10	$4,495	$4,000
	Cart with fabricated hitch (height=6.2ft)	$100	$100
	GPS installed on the cart	$100	$100
	Laptop computer	$800	$800
Software	ThermaCAM software (professional edition)	$7,000	$7,000
Labor	# of persons to do the survey	2 persons	One person
	Set-up time	60 minutes	15 minutes
	Running (3 span, 2-lane bridge)	90 minutes	30 Minutes
	Break-up	20 minutes	15 minutes
	Total hours	2.5	1.0
Road user costs	Traffic disruption	ThIR camera mounted on a cart; one lane closed each time	ThIR camera mounted on a vehicle that is driven at a lower speed
Post-processing hours	To quantify surface condition by creating delamination map and calculating percentage of delamination etc.	> 40 hours	< 8 hours

Table 1: Cost estimates for using ThIR technology.

Calculations of road user costs require much location-specific information, such as length of highway affected by the activity, traffic speed during activity, normal traffic speed, annual average daily traffic (AADT), annual average daily truck traffic (AADTT), work zone crash rates, vehicle operating costs, etc. The CAR research team will rely on existing research findings and apply them accordingly to the scenarios we are going to develop. For example, one study suggested that road user cost due to bridge inspections could range from $20,000 to $32,000 per occurrence.[1]

Another example is the lane rental fee, which appears to be more appropriate for our analysis. Lane rental is commonly used in the roadway construction contracting process, meaning that

[1] Hank Bonstedt. Life Cycle Cost Analysis for Bridges <http://caba-bridges.org/Presentations/files/LCCA.ppt>. Accessed on December 8, 2011.

the contractor has to pay for the time or right to use lanes during construction operations. This time component is converted to a cost to the contractor based on estimated road user costs, depending on, for example, whether one lane is occupied as opposed to a lane and a shoulder. In addition, rental rates can be different depending on the time of day (e.g., peak or off-peak travel hours). A detailed example of a lane rental fee is presented in Table 2 (year 2000 dollars).

Lane Type	Daily Fees (dollars/day)	Hourly Fees (6:30 a.m.-9:00 a.m.) (dollars/h)	Hourly Fees (9:00 a.m.-3:00 p.m.) (dollars/h)
One lane	20,000	2,000	500
One shoulder	5,000	500	125
One lane and shoulder	25,500	2,500	625
Two lanes	45,000	4,500	1,250
Two lanes and shoulder	50,000	5,000	1,375

Table 2: Example Lane Rental Fees. Source: Transportation Research Board, Reducing and Mitigating Impacts of Lane Occupancy During Construction and Maintenance: A Synthesis of Highway Practice NCHRP SYNTHESIS 293, 2000.

BRIDGE SCOPING AND THE BENEFITS OF REMOTE SENSING TECHNOLOGIES

Bridge scoping is a more in-depth bridge inspection process than the standard bridge inspections that evaluate a bridge for various repair alternatives and recommend the most economical rehabilitation or treatment, then develop a scope of work and cost estimate for the selected alternative. The work for each bridge scoping includes two major steps: site review and engineering analysis.[2] According to MDOT, about 167 state-owned bridges were scoped in 2010 at a total cost of $1,557,960, or $9,329 per bridge, on average. All bridge scoping was conducted by engineering contractors (that is, none was done in house).

The outcome indicators of several of the remote sensing technologies field tested are similar to the outputs required in bridge scoping, such as measures of extent of delamination, spalling, and crack areas, and calculation of deterioration percentage. These measures are critical input in developing repair strategies and cost estimates and certainly should be included in benefit estimates in our economic evaluation process.

[2] Great Lakes Engineering Group, LLC <http://www.glengineering.com/services_scoping.htm>. Accessed on December 28, 2011.

DSS AND ITS ROLE IN ECONOMIC EVALUATION

As described in technical memorandum n° 22, the DSS will provide the necessary environment for helping transportation agencies understand if the remote sensing technologies evaluated through this project can provide the information needed to help advance cost-effective bridge condition assessment. During this past quarter, the project team focused on improving the functionality and user-friendliness of the DSS interface, integrating direct exports of current bridge condition data from the MDOT Transportation Management System, generating an example bridge condition health signature, and the starting of integration of remote sensing results such as geo-tagged photo inventory points and the high-resolution bridge deck DEM. Figure 2 shows an example of integrating the BVRCS photo inventory points into the DSS.

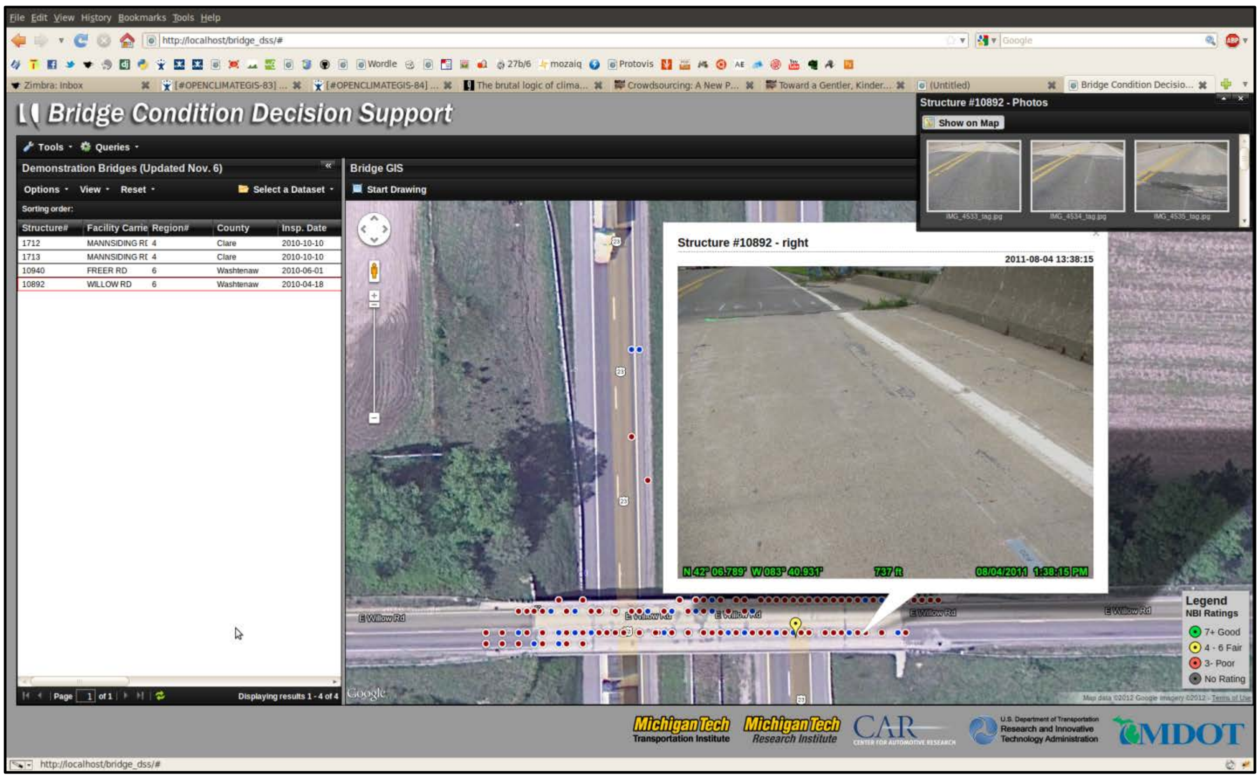

Figure 2: An example of the BVRCS geo-tagged photo inventory points being integrated into the updated DSS. Work on integrating advanced remote sensing results such as 3D optical spall detection data and ThIR delamination detection data is continuing.

Once the DSS development is completed, especially the integration of remote sensing indicators of bridge condition, then the DSS can be used for helping with the technical and economic assessment of the project results. A major focus of the next January-March quarter is taking the DSS as far as possible towards completion, although work in the following quarter is also anticipated. A meeting with the DSS focus group, established at the recommendation of the project Technical Advisory Committee, is planned for early March, 2012. A major updated release of the DSS will be made available for that meeting and it is anticipated that this version of the DSS will be sufficiently advanced to help with economic evaluation. For example, it should be possible to estimate the productivity savings of MDOT for its bridge condition evaluation processes if they were using the DSS as part of their day-to-day bridge asset management and bridge repair planning methods. It is that type of economic evaluation that the project team anticipates completing with help of the DSS.

NEXT STEPS

The CAR research team will continue to work closely with the Michigan Tech Transportation Institute and the Michigan Tech Research Institute to complete Task 6: Economic Evaluation of Remote Sensing Technologies. Specifically, CAR researchers will focus on following steps to complete this effort:

- Finalize cost estimates (both research stage and within a CON-OPS for sustainable adoption within a bridge operations and maintenance program).

- Finalize assumptions, application scenarios, and evaluation approaches.

- Conduct second-round interviews with MDOT stakeholders in March, 2012, with a focus on agency valuation of the outputs of the tested remote sensing technologies.

- Analyze how the DSS can enable more cost-efficient bridge asset management if used as part of MDOT planning processes.

- Prepare a final study report that compares costs and benefits and provides recommendations on cost-effective use of remote sensing for bridge condition assessment (i.e., documents which technologies provide the highest added value per implementation and operation cost).