Transportation Research Board
Technical Activities Division

Committee Research Problem Statements
Design and Construction Group
Structures Section
Dynamics & Field Testing of Bridges Committee (AFF40)

Preface

An important function of the Transportation Research Board (TRB) is to stimulate research that addresses problems facing the transportation community. In support of this function, TRB technical committees identify problems, and develop and disseminate research problem statements for use by practitioners, researchers, and others. The problem statements listed below were developed by the TRB committee noted above. These problem statements should not be considered comprehensive; they may only represent a portion of overall research problems identified by committee members.

Statements

Problem Number	Priority	Problem Statement(s)	Date Posted
1	2	Remote Structure Monitoring Techniques for Health Monitoring	04/04
2	1	Remote Structure Monitoring Techniques for Health Monitoring	08/05

I. Problem 1: Remote Structure Monitoring Techniques for Health Monitoring

II. Problem Statement

The ability to monitor the condition of a structure and to detect damage at the earliest possible stage is of significant interest in many engineering disciplines. Currently, the most widely used damage detection methods rely on subjective, incremental visual assessments or localized testing techniques. These methods require the location, or possible location, of damage to be known prior to the assessment. Often, these locations can be estimated through appropriate engineering analysis. However with the increasing complexity of many of the nation’s bridges, the potential damage locations are not known or are too numerous to be economically tested or inspected using conventional damage detection techniques. As a result, health monitoring techniques have been developed and employed as a means to economically and reliably provide for an overall, continuous condition assessment of complex bridge structures. Complicating the issue is the fact that increased numbers of sensors require more complex infrastructure for installation and monitoring. Furthermore, these complex systems are subject to faults which require maintenance or failure, both of which will reduce the reliability and economy of the overall health monitoring system.

While the end product of health monitoring provides for an assessment of the global and local conditions within a bridge, the data collected must allow for the detection of changes in key bridge performance metrics such as scour, substructure movement, cracking, seismic damage, corrosion, and overloads. This requires the monitoring of behavioral information related to deflection, rotation, strain, and modal parameters (i.e., resonant frequencies, mode shapes, and modal damping). Measurement of these parameters is relatively easy, and significant research has been conducted to improve sensor technology. As such, the focus of this research is not to advance sensor technology.

Damage detection and health monitoring has been practiced in a qualitative manner, in some form or another, since the beginning of man. However, successful quantitative tools were not developed until computers became widely available. In some industries, the general development of quantitative damage assessment tools has been the subject of much research. These efforts have yielded significant advances in the past 30 years, specifically in the mechanical, nuclear, oil, and electrical power industries. For example, vibration-based damage detection technology has been developed for monitoring of rotating machinery and similarly the aerospace industry applied health monitoring techniques to monitor space shuttle performance.

While the advancements in sensors, computer technology and post-processing algorithms have been significant, their remains a need to develop an infrastructure capable of providing connectivity locally at the bridge site and more globally to the intelligent transportation system command centers. This need is amplified as the bridge industry attempts to apply health monitoring techniques to larger, more complex bridge structures, which require increasing numbers of sensors to attain a reliable level of performance for damage or event detection. The cost of hard wiring and maintaining an infrastructure system to allow communication between the sensor and the computers monitoring the subject structure increases with the numbers of sensors. The development of a remote monitoring system permits the deployment of additional sensors at minimal cost, without the long-term need for infrastructure maintenance costs. Furthermore, remote monitoring systems permit the rapid deployment and connectivity of additional sensors to monitor specific bridge concerns or events on an as-needed basis.

The work product from this research will be used by bridge owners to facilitate their efforts to maintain reliable transportation networks in which a bridge plays an important role. Advancements in remote monitoring systems will permit health monitoring to be economically employed at larger, more complex bridges, where early detection of scour, substructure movement, corrosion, cracking, and seismic damage is paramount. The work product will consist of a guide for the development of a remote monitoring infrastructure for bridge health monitoring.

III. Research Objective

Ultimately, the project goal is to improve the performance, safety and economy of our nation's bridges for the benefit of its citizens. Specifically, this project will develop and deliver a guide for the use of remote technologies for short and long-term health monitoring of critical bridge structures using state-of-the-art technologies. This will be accomplished through four distinct work tasks, including

Task I Literature Search

Synthesis of technical information for remote monitoring of bridges: The literature search indicates that many advances in sensor technology and post processing algorithms have taken place. Several states have undertaken pilot studies to implement health monitoring systems on critical bridges. While this work is beneficial to the study, it will not form the focus of the study. Rather, this literature will be studied to determine if remote monitoring was used and if so, what successes or failures did they have.

Deliverable: Synthesis report.

Task II Remote System Design

A synthesis of available remote monitoring systems, sensors, data acquisition equipment, etc will be performed. Specifically, the connectivity of the available sensors and data acquisition systems will be studied to determine how a remote monitoring system can be employed and reliable data transmission achieved. The performance of various remote monitoring systems will be studied to gauge performance characteristics under extreme temperature variations; traffic vibrations; extreme loading events such as permit loading, floods, earthquakes, and high winds; moisture; vandalism; corrosion; magnetic, radio wave, solar, or microwave interference; and etc.

Deliverable: Design specifications for various remote monitoring systems for bridge health monitoring.

Task III System Validation

Development of an "of-the-shelf" remote monitoring system. Based on the study of Task 1 and II, the researchers will validate the performance of a health monitoring system using various remote monitoring systems. The systems will be tested under controlled conditions at field test sites to study the remote monitoring systems hysteric behavior, durability, reliability and maintenance. *Deliverable:* A Remote Monitoring Design Guide including summary report of system performance, with final recommendations for specifications for an "of-the-shelf" remote monitoring system. More over the recommendations must be capable of supporting remote monitoring system design to accommodate site specific designs.

Task IV Long Term System Validation

Illustrated Example of the Remote Monitoring System. Using the remote monitoring system proposed in Task III, the final configuration will be implemented at a test bridge and its performance evaluated over a period of 1 year. *Deliverable:* Summary report of system performance, with recommendations for improvement and projected cost-benefit analysis to owner.

IV. Funding and Time

Recommended Funding:
An estimate of the funds necessary to accomplish the objectives stated above is $200,000 for labor and $50,000 for equipment procurement.

Research Period:
The research period is 2 months for Task I, 2 months for Task II, 3 months for Task III and 12 months for Task IV, for a total project duration of 20 months, including NHCRP review time.

V. Urgency, Payoff Potential, and Implementation

This research needs statement was suggested by members of TRB Committee AFF40, Dynamics and Field Testing of Bridges Committee. It is also aligned with a Thrust/Business Need as addressed by NCHRP 20/07. Specifically, the Maintenance, Rehabilitation and Construction thrust/business needs area listed the following as a research need: *Remote structure monitoring techniques and systems for scour detection, substructure movement, cracking, seismic damage, corrosion, and overloads*.

The members of the committee considered this topic to be interest to bridge owners and public stakeholders, as a means to improve bridge reliability through use of bridge performance data to maximize maintenance and rehabilitation dollars over the bridge's life span.

Significant research has been conducted on improving many aspects of the available health monitoring systems, with the exception of research into remote monitoring. Consequently, the funds expended through this study can be maximized to bring state-of-the-art sensor technology, computers, and post-processing algorithms to bear for health monitoring of our bridge structures. The remote monitoring infrastructure is the key to taking advantage of these advancements in the most economical manner.

The Remote Monitoring Design Guide will be useful to all bridge owners contemplating implementation of a remote monitoring system for health monitoring. The past work and health monitoring guides developed by FHWA and others will be useful in guiding the selection of sensors for particular applications. However this guide will allow states to economically and rapidly install monitoring systems on critical bridges.

VI. Literature Search Summary

A literature search using the following key words was performed: health monitoring, structure monitoring, remote monitoring, bridge health, and several other combinations which yielded null hits. Searches were conducted using TRIS online and Research in Progress databases. Up to 90 hits were recorded. Most nearly all hits pertain to more conventional health monitoring, wherein wire infrastructure is utilized between sensors and the data station; advances in sensor technology; or advances in post processing algorithms. The authors of this research needs statement concede that significant research and case studies have been performed with regard to the study of sensor technology, post processing algorithms and case studies. As described in Section V, Research Objective, the objective of this research is not to study these areas of health monitoring further but rather improve the remote monitoring infrastructure so as to take maximum advantage of the improvements in these areas.

Two hits of note were compiled. The first was a 2003 joint Rhode Island/FHWA study entitled, "Remote Bridge Monitoring: A Survey" authored by Parameswaran, V.N.; Shukla, A and McEwen, E. The survey reported a summary of state-of-the-art techniques for bridge monitoring, critical Rhode Island bridge details for which monitoring would be required, and appropriate sensor configuration and monitoring schemes to accomplish the monitoring of the proposed Providence River Bridge. Another project recently undertaken by ISIS Canada is closely aligned with the research objectives stated herein. The study was focused on five efforts, as follows: 1) wireless transmission; 2) various sensor interfaces and data compression; 3) dial-out remote monitoring; 4) remote connection to Internet and satellite; and 5) microchip data acquisition systems. Additionally, the American Association of Railroad's Transportation Technology Center Inc. (TTCI) has tested some wireless products and systems for communications; track monitoring; crossing monitors; train tracking and control; remote monitoring of hot boxes, track heaters, lubricators, and other devices, etc.

The existing data base must be utilized to achieve Task I and II, but the results of the proposed research will be unique and will represent an useful piece of work for bridge owners contemplating future health monitoring applications on their bridges.

VII. Person(s) Developing the Problem Statement

Richard A. Walther, PE, SE
Consultant and Unit Manager
Wiss, Janney, Elstner Associates, Inc.
333 North Avenue
Wakefield, MA 01880
Tel: 781.213.9266
Fax: 781.213.9267
Email: rwalther@wje.com

Mr. Walther is the chair of TRB Committee AFF40, Dynamics and Field Testing of Bridges Committee.

VIII. Problem Monitor

Dr. Steven Chase, PE
FHWA
Turner Fairbanks Highway Research Center

6300 Georgetown Pike
McLean, VA 22101

Richard A. Walther, PE, SE
Consultant and Unit Manager
Wiss, Janney, Elstner Associates, Inc.
333 North Avenue
Wakefield, MA 01880

IX. Date and Submitted by

Date: April 15, 2004

Mary Lou Ralls, P.E.
Chair, TRB AFF00 Structures Section
State Bridge Engineer
Texas Department of Transportation
125 E. 11th St.
Austin, TX 78701
Phone: 512-416-2183
Fax: 512-416-3144
Email: mralls@dot.state.tx.us

I. Problem 2: Remote Structure Monitoring Techniques for Health Monitoring

II. Research Problem Statement

The ability to monitor the condition of a structure and to detect damage at the earliest possible stage is of significant interest in many engineering disciplines. Currently, the most widely used damage detection methods rely on subjective, incremental visual assessments or localized testing techniques. These methods require the location, or possible location, of damage to be known prior to the assessment. Often, these locations can be estimated through appropriate engineering analysis. However with the increasing complexity of many of the nation's bridges, the potential damage locations are not known or are too numerous to be economically tested or inspected using conventional damage detection techniques. As a result, health-monitoring techniques have been developed and employed as a means to economically and reliably provide for an overall, continuous condition assessment of complex bridge structures. Complicating the issue is the fact that increased numbers of sensors require more complex- infrastructure for installation and monitoring. Furthermore, these complex systems are subject to faults that require maintenance or failure, both of which will reduce the reliability and economy of the overall health-monitoring system.

While the end product of health-monitoring provides for an assessment of the global and local conditions within a bridge, the data collected must allow for the detection of changes in key bridge performance metrics such as scour, substructure movement, cracking, seismic damage, corrosion, and overloads. This requires the monitoring of behavioral information related to deflection, rotation, strain, and modal parameters (i.e., resonant frequencies, mode shapes, and modal damping). Measurement of these parameters is relatively easy, and significant research has been conducted to improve sensor technology. As such, the focus of this research is not to advance sensor technology.

Damage detection and health-monitoring has been practiced in a qualitative manner, in some form or another, since the beginning of man. However, successful quantitative tools were not developed until computers became widely available. In some industries, the general development of quantitative damage assessment tools has been the subject of much research. These efforts have yielded significant advances in the past 30 years, specifically in the mechanical, nuclear, oil, and electrical power industries. For example, vibration-based damage detection technology has been developed for monitoring of rotating machinery and similarly the aerospace industry applied health-monitoring techniques to monitor space shuttle performance.

While the advancements in sensors, computer technology and post-processing algorithms have been significant; there are two remaining needs. First, a need to develop an infrastructure capable of providing connectivity locally at the bridge site and more globally to the intelligent transportation system command centers. This need is amplified as the bridge industry attempts to apply health-monitoring techniques to larger, more complex bridge structures, which require increasing numbers of sensors to attain a reliable level of performance for damage or event detection. The cost of hard wiring and maintaining an infrastructure system to allow communication between the sensor and the computers monitoring the subject structure increases with the numbers of sensors. The development of a remote monitoring system permits the deployment of additional sensors at minimal cost, without the long-term need for infrastructure maintenance costs. Furthermore, remote monitoring systems permit the rapid deployment and connectivity of additional sensors to monitor specific bridge concerns or events on an as-needed basis.

The second need, and probably the least investigated, is the need for a general “design methodology” to achieve system integration, measurement calibration and validation for sensing and monitoring. As noted below there has been research into remote monitoring to determine its viability, but there has been little development into the monitoring design to determine heuristics of sensor use, number, location, and sampling rate. Ultimately, there is a need to improve monitoring design for this methodology to become an effective tool for the bridge owner.

Bridge owners to facilitate their efforts to maintain reliable transportation networks in which a bridge plays an important role will use the work product from this research. Advancements in remote monitoring systems and system design will permit health monitoring to be economically employed at larger, more complex bridges, where early detection of scour, substructure movement, corrosion, cracking, and seismic damage is paramount. The work product will consist of a guide for the development of a remote monitoring infrastructure for bridge health monitoring.

III. Literature Search Summary

A literature search using the following key words was performed: health monitoring, structure monitoring, remote monitoring, bridge health, and several other combinations that yielded several hits. Searches were conducted using TRIS online and Research in Progress databases. Up to 90 hits were recorded. Most nearly all hits pertain to more conventional health-monitoring, wherein wire infrastructure is utilized between sensors and the data station; advances in sensor technology; or advances in post processing algorithms. The authors of this Research Needs Statement concede that significant research and case studies have been performed with regard to the study of sensor technology, post processing algorithms and case studies. For example, Departments of Transportation in Connecticut and New York have studied remote monitoring and found it to be a feasible methodology. Connecticut is currently monitoring several bridges. However, as described in Section V, Research Objective, the objective of this research is not to study these areas of health-monitoring further but rather improve the remote monitoring infrastructure so as to take maximum advantage of the improvements in these areas while developing a guide specification for system integration.

Two hits of note were compiled. The first was a 2003 joint Rhode Island/FHWA study entitled, "Remote Bridge Monitoring: A Survey" authored by Parameswaran, V.N.; Shukla, A and McEwen, E. The survey reported a summary of state-of-the-art techniques for bridge monitoring, critical Rhode Island bridge details for which monitoring would be required, and appropriate sensor configuration and monitoring schemes to accomplish the monitoring of the proposed Providence River Bridge. Another project recently undertaken by ISIS Canada is closely aligned with the research objectives stated herein. The study was focused on five efforts, as follows: 1) wireless transmission; 2) various sensor interfaces and data compression; 3) dial-out remote monitoring; 4) remote connection to Internet and satellite; and 5) microchip data acquisition systems. Additionally, the American Association of Railroad's Transportation Technology Center Inc. (TTCI) has tested some wireless products and systems for communications; track monitoring; crossing monitors; train tracking and control; remote monitoring of hot boxes, track heaters, lubricators, and other devices, etc.

The existing data base must be utilized to achieve Task I and II, but the results of the proposed research will be unique and will represent an useful piece of work for bridge owners contemplating future health monitoring applications on their bridges.

IV. Research Objective

Ultimately, the project goal is to improve the performance, safety and economy of our nation's bridges for the benefit of its citizens. Specifically, this project will develop and deliver a guide for the use of remote technologies for short and long-term health monitoring of critical bridge structures using state-of-the-art technologies. This will be accomplished through four distinct work tasks, including

Task I Literature Search. Synthesis of technical information for remote monitoring of bridges: The literature search indicates that many advances in sensor technology and post processing algorithms have taken place. Several states have undertaken pilot studies to implement health-monitoring systems on critical bridges. While this work is beneficial to the study, it will not form the focus of the study. Rather, this literature will be studied to determine if remote monitoring was used and if so, what successes or failures did they have. Deliverable: Synthesis report.

Task II Remote System Design. A synthesis of available remote monitoring systems, sensors, data acquisition equipment, etc will be performed. Specifically, the connectivity of the available sensors and data acquisition systems will be studied to determine how a remote monitoring system can be employed and reliable data transmission achieved. The performance of various remote monitoring systems will be studied to gauge performance characteristics under extreme temperature variations; traffic vibrations; extreme loading events such as permit loading, floods, earthquakes, and high winds; moisture; vandalism; corrosion; magnetic, radio wave, solar, or microwave interference; and etc. Deliverable: Design specifications for various remote-monitoring systems for bridge health-monitoring.

Task III System Validation. Develop an "off-the-shelf" remote monitoring system. Based on the study of Task 1 and II, the researchers will validate the performance of a health-monitoring system using various remote monitoring systems. The systems will be tested under controlled conditions at field test sites to study the remote monitoring systems hysteric behavior, durability, reliability and maintenance. Deliverable: A Remote Monitoring Design Guide including summary report of system performance, with final recommendations for specifications to achieve remote monitoring system design for site specific designs. Key to this effort will be the development of criteria of what to monitor, how many sensors to employ and the sampling rate to achieve desired results, without mistakenly interpreting results.

Task IV Long Term System Validation: Illustrated Example of the Remote Monitoring System. Using the remote monitoring system proposed in Task III, the final configuration will be implemented at a test bridge and its performance evaluated over a period of 1 year. Deliverable: Summary report of system performance, with recommendations for improvement to the recommended specifications and long-term projected cost-benefit analysis to owner.

V. Estimate of Problem Funding and Research Period

Recommended Funding:
An estimate of the funds necessary to accomplish the objectives stated above is $200,000 for labor and $50,000 for equipment procurement.

Research Period:
The research period is 2 months for Task I, 2 months for Task II, 3 months for Task III and 12 months for Task IV, for a total project duration of 20 months, including NHCRP review time.

VI. Urgency, Payoff Potential, and Implementation

Members of TRB Committee AFF40, Dynamics and Field Testing of Bridges Committee suggested this research needs statement. It is also aligned with a Thrust/Business Need as addressed by NCHRP 20/07. Specifically, the Maintenance, Rehabilitation and Construction thrust/business needs area listed the following as a research need: Remote structure monitoring techniques and systems for scour detection, substructure movement, cracking, seismic damage, corrosion, and overloads.

The members of the committee considered this topic to be interest to bridge owners and public stakeholders, as a means to improve bridge reliability through use of bridge performance data to maximize maintenance and rehabilitation dollars over the bridge's life span. The investment into monitoring offering the most significant payoff is the reliable and timely interpretation of sensor output during and immediately following a hazard, to assure bridge safety. At the same time, the potential intrinsic benefits of remote monitoring is the accumulation of bridge performance data for slower occurring events such as scour, deterioration of concrete due to chemical attacks, corrosion, gradual loss of prestress, etc.

Significant research has been conducted on improving many aspects of the available health monitoring systems, with the exception of research into remote monitoring. Consequently, the funds expended through this study can be maximized to bring state-of-the-art sensor technology, computers, and post-processing algorithms to bear for health monitoring of our bridge structures. The remote monitoring infrastructure is the key to taking advantage of these advancements in the most economical manner.

The Remote Monitoring Design Guide will be useful to all bridge owners contemplating implementation of a remote monitoring system for health monitoring. The past work and health monitoring guides developed by FHWA and others will be useful in guiding the selection of sensors for particular applications. However this guide will allow states to economically and rapidly install monitoring systems on critical bridges.

VII. Person(s) Developing the Problem

TRB Committee AFF40 developed this problem statement. Committee Chair Richard A. Walther is serving on behalf of the committee as the problem statement developer. Mr. Walther's contact information is as follows:

Wiss, Janney, Elstner Associates, Inc.
330 Pfingsten Road
Northbrook, IL 60062
Tel: 847.753.6549
Fax: 847.291.9599
Email: rwalther@wje.com

VIII. Problem Monitor

To be assigned by NCHRP

IX. Date and Submitted by

Date: May 9, 2005

Stan Woods, PE
Chair, AASHTO T-18, Bridge Management, Evaluation & Rehabilitation
Wisconsin Department of Transportation
4802 Sheboygan Avenue, #601
Madison, WI 53702
Email: stan.woods@dot.state.wi.us
Tel: 608.266.8348

TRB Committee AFF40, Dynamics and Field Testing of Bridges Committee
Richard A. Walther, Chair