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DEPARTMENT OF TRANSPORTATION

Risk Management Strategy for Bridges and Structures

FINAL REPORT

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By: Michael Baker Jr., Inc.

Baker

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16. Abstract

This report is a study of PennDOT's Risk Assessment program and a search for ways to improve the system. Research was done via literature search of relevant documents and surveys of PennDOT District personnel and selected other states with histories of asset management policies. Input was also received from the Bridge Quality Assurance Division who manages the system. The result is a list of quick strike, median range and long range recommendation for the system. In addition, a study was performed and a software tool provided to evaluate changes to the weights applied to the factors used to calculate the risk scores.

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Task 1, Synthesis Report

Executive Summary

This interim report is a compilation of previous research and published literature in the area of asset management and risk assessment. Following intensive study, more than 1600 citations were identified, captured in a bibliography, and reviewed for applicability to this project. More than 60 of these citations were identified as potentially useful for improving the Pennsylvania Department of Transportation's (PennDOT) risk assessment spreadsheet tool. The full bibliography in chronological order is provided on CD.

PennDOT's spreadsheet tool was carefully evaluated, and District users were surveyed to identify desired functions relative to the latest technological advancements, to deliver a list of recommendations that supports PennDOT's goals. Modifications to improve the user interface are included in the proposed changes. The underlying theme of the research is that risk assessment involves much more than a static evaluation of the condition of an existing bridge or structure. Many issues are functional in nature, such as detour length, average daily traffic (ADT) volume, and functional classification, but others are related to special conditions resulting either from naturally occurring events, such as flooding and earthquakes, or man-made hazards, such as fires, traffic accidents, or acts of terrorism.

1.0 *Introduction*

1.1 *Objectives and Scope*

This report is not intended to be an exhaustive review of all literature in this field. The intention is to review and summarize the findings from a subset of literature relevant to this project. To accomplish this task, the scope of this report has been excerpted from Baker's project proposal and is presented below.

Task 1: Literature Search of Previous Risk Management Studies

Baker will comply with the directives of this task using its own in-house corporate library service. In addition to focusing on research involving bridges and highway structures, relevant literature relating to studies in nontransportation engineering disciplines , as well as literature on studies performed for other government agencies or conducted by private businesses or corporations, will be identified, and findings will be compiled.

- **1A: Identify Previous Studies**
  Baker's library staff is experienced in conducting extensive literature searches. Using both open and proprietary databases, the researchers can compile comprehensive bibliographies from a variety of sources, including monographs, serials, journal articles, internet sites, audiovisual materials, and photographs. References are housed in ProCite, a professional bibliographic management tool that allows researchers to search, sort, and output citations in any standard format.

- **1B: Review Previous Studies**
  Once a comprehensive list of documents is produced, the project team will collectively review the list and determine which documents have merit for this project. Documents that qualify will then be retrieved for content review. The content review will be assigned to the project team members who are the most qualified to evaluate the material. On this project, the research team will search for successful applications of risk management strategies in any market. With respect to nontransportation-related research, the rationale of the strategy and the applicabilty of the approach relating to structures will be weighed. The review of transportation-specific literature will focus on the type of data used, availability (i.e., is it readily available, or must it be collected?), applicability on the state and national levels, and the method of prioritization .

  A database will be developed for all documents identified in the search. Relevant documents will be marked, and all review comments will be recorded.

- **1C: Synthesis Report of Previous Studies**
  Following completion of the document reviews, an internal meeting will be held to determine whether any existing strategies support the intended outcome of this project. A list of qualifiying approaches, along with an explanation of their viability, will be compiled.

Deliverable:

- Synthesis Report: A comprehensive documentwith sufficient commentary to convey an understanding of the role that existing research should play in the development of PennDOT's Risk Management Strategy.
- Submission Materials: A reproducible MS Word document sent via e-mail or the Internet, one electronic copy on CD-ROM, three bound hard copies using GBC comb binding (or other binding system, as appropriate), and two unbound hard copies.

2.0 *Literature Review*

2.1 *Summary*

Chapter 2 presents more than 60 selected citation abstracts that are relevant to the objectives of this project. The abstracts are categorized according to source. The categories are presented in order of perceived relevance. However, it is possible that a reference document in the last category may contribute a relevant concept to the development of the final project strategy.

The document search was performed by Gina Hart, MSLIS, library and information specialist, using Baker's corporate library capabilities. The objective was to compile a bibliography of previous work on this topic, including work performed in other fields of engineering for other government agencies, or for private businesses or corporations. Review of these citations will identify measures, systems, and methods for the development of a risk management strategy to assist PennDOT in the replacement programming of bridges and structures. Additional bibliographic input was provided by Paul D. Thompson.

This report submittal includes a CD with an exported file of all of the bibliographic references to date (a total of 1,858 records that are subject to final cleanup). This information constitutes a comprehensive bibliography on the subject. However, following a detailed review of selected citations, it may be desirable to include additional highly relevant references.

The following text documents how the bibliography was developed.

2.2 *Documentation Process*

Bibliographic references are imported or entered into EndNote X2, a software tool for publishing and managing bibliographies.

2.3 *Databases Searched*

Transportation Research Information Services (TRIS). TRIS is a bibliographic database funded by sponsors of the Transportation Research Board (TRB), primarily the state Departments of Transportation and selected federal transportation agencies. TRIS Online is hosted by the National Transportation Library under a cooperative agreement between the Bureau of Transportation Statistics and TRB.

A thesaurus search using the applicable subject headings yielded the following results:

- Risk Management: Identified more than 1,000 references; 195 of these were imported into EndNote X2.
- Risk Assessment: Identified more than 1,500 references; 104 of these were imported into EndNote X2. (18 were duplicates from the risk management search conducted on 8/7)
- Bridge Management Systems: Identified 699 references; 545 of these were imported into EndNote X2 (nine were duplicates from earlier searches).
- Maintenance Management: Identified 3,580 references. Modification of the query to contain the key word "bridge" or "bridges" yielded 453 references; 204 of these were imported into EndNote X2 (72 were duplicates from earlier searches).
- Probability Theory: Identified 365 references; 15 of these were imported into EndNote X2 (four were duplicates from earlier searches)

WorldCAT. WorldCat is a union catalog that itemizes the collections of more than 10,000 libraries that participate in the OCLC global cooperative. It is built and maintained collectively by the participating libraries from more than 90 countries. Created in 1971, it contains in excess of 90 million records pointing to more than 1.2 billion physical and digital assets in more than 360 languages (as of November 2007). It is the world's largest bibliographic database.

As with TRIS, the WorldCAT search targeted subject headings that are relevant to this research topic. The following subject headings were deemed worthwhile:

- Bridges
- Bridges – Maintenance and repair
- Bridges – United States – Maintenance and repair
- Bridge failures
- Bridge failures -- Prevention
- Risk management
- Risk assessment
- Risk analysis
- Decision making
- Highway engineering – Management -- Maintenance and repair (subheading)

Asset Management

Production scheduling

- Search 1 (Subject heading contains Bridges and subject heading contains Maintenance and one of the following key word stems: Risk*, Management*, Decision*, or Priority*). Identified 719 references; 419 of these were imported into EndNote X2 (60 were duplicates from earlier searches).
- Search 2 (Subject heading contains Risk Management or Risk Assessment and one of the following key words: Bridge* or Infrastructure). Identified 434 references; 44 of these were imported into EndNote X2 (six were duplicates from earlier searches).

American Society of Civil Engineers' (ASCE) Civil Engineering Database (CEDB). The ASCE CEDB provides access to more than 100,000 bibliographic and abstracted records for all ASCE publications from 1970 to the present.

As with the other databases, a subject heading list was used as the starting point for formulating searches. The CE database's thesaurus is available online at http://cedb.asce.org/subjlst.html. Relevant subject headings include:

- Assets
- Best Management Practice
- Bridge failure
- Bridge maintenance
- Collapse
- Computer aided scheduling
- Decision making
- Decision support systems
- Deterioration
- Failures
- Forecasting
- Funding allocations
- Highway management
- Knowledge-based systems
- Life cycles
- Maintenance costs
- Management methods
- Material failure
- Predictions
- Resource management
- Risk management
- Scheduling
- Structural failure
- System analysis
- System reliability
- Systems management
- Transportation management
- Transportation networks

Note: Records from this database must be entered into EndNote X2 by hand as the database does not offer export capability. As a result, it is slow to use. Most of the records in this database also should be indexed in the TRIS database, searched earlier, so the search was limited to only highly relevant subject headings.

- Subject heading = Risk Management AND key word stem = Bridge*: A search for the subject heading "Risk Management" alone yielded 2,005 results. To focus the search, the key word stem bridge* was added, which yielded 62 records; 16 were imported into the bibliography (seven were duplicates from earlier searches).
- Subject heading = (Failure OR Collapse) AND subject heading = (Forecasting OR Predictions): Identified 25 references; one of these was imported into EndNote X2.
- Subject heading = Risk Management AND subject heading = Assets: Identified one reference that was not applicable to the research topic.
- Subject heading = Risk Management AND subject heading = Highway Management: Identified 25 references; one of these was imported into EndNote X2.
- Key word phrase = "bridge management system" OR "bridge management systems": Identified 75 references; 26 of these were imported into EndNote X2 (14 were duplicates from earlier searches).

EBSCOhost Business Source Premier. Business Source Premier is the industry's most frequently accessed business research database, providing full text for more than 2,300 journals, including full text for more than 1,100 peer-reviewed titles. Business Source Premier is superior to the competition in full-text coverage in all disciplines of business, including marketing, management, MIS, POM, accounting, finance, and economics. This database is updated daily on EBSCOhost.

- Subject heading = Transportation Management System: Identified 177 references; no references were imported into EndNote X2. (Unfortunately, the subject heading refers to shipping logistics and supply chains.)
- Subject heading = "Risk Management" AND key word stem = bridge OR highway: Identified 127 references; six of these were imported into EndNote X2 (no references were duplicates from earlier searches.)

EBSCOhost Master File Premier. Designed specifically for public libraries, this multidisciplinary database provides full text for nearly 1,750 general reference publications, with full-text information dating from 1975. Covering virtually every subject area of general interest, MasterFILE Premier also includes nearly 500 full-text reference books, full text from 86,017 biographies, 105,786 full- text primary source documents, and an Image Collection of 341,655 photos, maps, and flags. This database is updated daily via EBSCOhost.

- Subject heading = "Risk management" AND (bridge* or highway* or transportation*): Identified 95 references; none were imported into EndNote X2. Unfortunately, this subject heading refers to shipping logistics and supply chains.

American Association of State Highway and Transportation Officials (AASHTO). The AASHTO web site does not offer a bibliographic database for searching.

By searching all AASHTO publications in the bookstore for relevant titles, six new references were added to Baker's database for this project.

Center for Transportation Research (CTR). The CTR library houses nearly 30,000 volumes of transportation-related reading and reference materials. The CTR library holdings include copies of research materials –reports generated by the center, as well as materials from the Texas Transportation

Institute (TTI) at Texas A&M. The Baker library also has materials from the Southwest Regional Transportation Center, the University of Houston, Texas Tech, and The University of Texas at El Paso.

Baker also has a complete set of materials from the Transportation Research Board, as well as from the U.S. Department of Transportation and the Federal Highway Administration, and a collection of materials from various state Departments of Transportation.

- Subject heading = Bridges: Identified 218 references; none were imported into EndNote X2.
- Subject heading = Prioritization: Identified 21 references; none were imported into EndNote X2.
- Subject heading = Bridge Management: Identified nine references; one was imported into EndNote X2.

It appears that the CTR uploads its records to WorldCAT, as most of the relevant search results were already discovered through that database.

National Research Council – Canada Institute for Scientific and Technical Information (NRC-CISTI). The NRC-CISTI Catalogue allows users to search the collection and easily order documents. NRC-CISTI's collection of more than 50,000 serial titles and more than 600,000 books, reports, and conference proceedings in science, technology, engineering, and medicine is one of the largest of its kind in the world.

The NRC-CISTI Catalogue also includes records from the Canadian Agriculture Library (CAL) Main Library collection of more than 30,000 serial titles and 60,000 books, reports, and conference proceedings, and 10,000 records from the collections of NRC-CISTI's Asian Partners.

The same subject headings used in searches of TRIS and WorldCAT were applied.

- Subject heading = Prioritization: Identified 190 references; seven were imported into EndNote X2 (none were duplicates from earlier searches).
- Subject heading = Bridges and subject heading = Maintenance: Identified 121 references; 15 were imported into EndNote X2 (four were duplicates from earlier searches).
- Subject heading = Bridge failures: Identified eight references; none were imported into EndNote X2.
- Subject heading = Risk and key word stem = Bridge: Identified eight references; six were imported into EndNote X2 (two were duplicates from earlier searches).
- Subject heading = Decision Making and key word stem = Bridge: Identified five references; two were imported into EndNote X2 (none were duplicates from earlier searches).

International Bridge, Tunnel, and Turnpike Association (IBTTA). The IBTTA is the worldwide alliance of toll operators and associated industries. The IBTTA provides a forum for sharing knowledge and ideas to promote and enhance toll-financed transportation services. The IBTTA web site includes a Studies and Reports section. The studies performed and reports generated by IBTTA or others in the transportation field reflect some of the latest and most accurate information about the state of the industry and future trends.

Our literature search included review of the Studies and Reports portion of the web site that contains content from 2003 to 2008. Most of the content is related to toll systems. No citations were entered into EndNote X2.

National Technical Information Service (NTIS). The NTIS serves as the largest central resource for government-funded scientific, technical, engineering, and business information available today. For more than 60 years, NTIS has ensured timely access for businesses, universities, and the public to approximately 3 million publications covering more than 350 subjects.

The NTIS database does not have a thesaurus or enable subject-based search. Key word searches were used instead. The site also does not have an export function. Instead, once resources were identified, their records were retrieved from WorldCAT. Note: during this process, some additional citations were identified in WorldCAT – these may not have been in the NTIS database.

- All key words = Risk Management: Identified 484 references; 20 were imported into EndNote X2 (two were duplicates from earlier searches).
- All key words = Bridge Prioritization: Identified 23 references; 21 were imported into EndNote X2 (13 were duplicates from earlier searches).

Engineering Village Compendex. With more than 10 million records from more than 5,600 scholarly journals, trade magazines, and conference proceedings, Compendex is the most comprehensive interdisciplinary literature database available to engineers.

A comprehensive search of the Engineering Village Compendex database yielded 594 references; 137 were duplicates of earlier records.

2.4 *Transportation Agencies*

- 456. **Risk assessment and management of critical highway infrastructure.** Haimes, Y.Y., et al., 2004: p. 63 p.

This study expands upon the scope of a previous contract study for the Virginia Transportation Research Council (VTRC) concluded in March 2002. The objective is to develop methodologies for risk analysis of critical highway infrastructure at two levels: (1) system level and (2) asset level. The system-level analysis conducts risk assessment from a statewide perspective. The goal is to evaluate and prioritize infrastructure from a considerable inventory of assets. The definition of critical infrastructure offered by Presidential Decision Directive (PDD) 63 is used to determine the set of attributes that help differentiate critical from non-critical infrastructure. These attributes correspond to national, regional, and local impact of a structure's damage or complete loss. In addition, the levels of impact are utilized in prioritization: infrastructure that has potential national and regional impact is considered more important than infrastructure with local impact. Further prioritization is conducted based on the asset's need for risk management actions. The asset's current state or condition, in terms of resilience, robustness, redundancy, and security against willful threat is used to evaluate the need for management actions. A set of criteria and corresponding metrics is identified, and supporting data are gathered using information from the Federal Highway Administration National Bridge Inventory and other sources. Once the most critical infrastructure is prioritized, an in-depth risk assessment of particular assets is performed to determine specific risks and vulnerabilities. Eight case studies on selected Virginia Department of Transportation (VDOT) sites are conducted. The details of these case studies are not presented in this report. Instead, general findings are presented that can serve as a guideline for policy implementation to other similar assets. Since a small number of case studies are performed by the project team, another important goal of this study is for effective knowledge transfer of the methodology to VDOT in order to facilitate risk assessment of other critical infrastructure. For this purpose, a prototype computer tool is developed, which is designed to guide facility managers in risk assessment and management. The case studies and documentation of the computer tool are provided in supplemental documents available by request from the authors.

- 457. **Risk assessment and management of critical highway infrastructure: executive summary**. Haimes, Y.Y., et al., 2004: p. 27.

This report synthesizes for executives the contents of a more comprehensive companion document on this subject. The objective is to develop methodologies for risk analysis of critical highway infrastructures at two levels: (1) system level and (2) asset level. The system-level analysis conducts risk assessment from a statewide perspective. The goal is to evaluate and prioritize infrastructures from a considerable inventory of assets. These attributes correspond to national, regional, and local impact of an infrastructure's damage or complete loss. In addition, the levels of impact are utilized in prioritization: infrastructures that have potential national and regional impact are considered more important than those with local impact. Further prioritization is conducted based on the asset's need for risk management actions. The asset's current state or condition, in terms of resilience, robustness, redundancy, and security against willful threat is used to evaluate the need for management actions. A set of criteria and corresponding metrics is identified, and supporting data are gathered using information from the Federal Highway Administration National Bridge Inventory and other sources. Once the most critical infrastructures are prioritized, an in-depth risk assessment of particular assets is performed to determine specific risks and vulnerabilities. Eight case studies on selected Virginia Department of Transportation (VDOT) sites are conducted. The details of these case studies are not presented in this report. Instead, general findings are presented that can serve as a guideline for policy implementation to other similar assets. Since a small number of case studies are performed by the project team, another important goal of this study is for effective knowledge transfer of the methodology to VDOT, in order to facilitate risk assessment of other critical infrastructures. For this purpose, a prototype computer tool is developed, which is designed to guide facility managers in risk assessment and management. The case studies and documentation of the computer tool are provided in supplemental documents available by request from the authors.

- 532. **Element unit and failure costs and functional improvement costs for use in the MN/dot Pontis bridge management system**. Adams, T.M. and E. Juni, 2003: p. 51.

Unit costs for bridge preservation maintenance, improvement actions and user benefits are required for network-level analysis in the Pontis bridge management system (BMS). This report describes the process and results for establishing these values for the Minnesota Department of Transportation (Mn/DOT). Also provided were the transition probabilities for modeling deterioration for the bridge elements. Unit costs for preservation action performed by Mn/DOT maintenance crews were acquired from the Mn/DOT Estimating Unit. Work breakdown for maintenance actions and standard element definitions for converting cost units were developed as needed. Unit costs for preservation actions performed by contract were derived from cost data in the Mn/DOT Work Management System (WMS) warehouse through the Mn/DOT Bridge Maintenance table. Work codes in WMS were mapped to maintenance actions in Pontis. Estimates for bridge widening, raising, strengthening, and replacement costs were defined as were accident cost, vehicle operating cost, and travel time cost for calculating user-cost savings of functional improvement projects. A Windows program was developed to calculate weighted average unit cost for maintenance actions using data available in Mn/DOT's WMS warehouse. The program can be used to review maintenance costs and for on-going update of the Mn/DOT Pontis database.

- 774. **Bridge safety assurance measures taken in New York State**. O'Connor, J.S. 2000. Tampa, FL, United States: National Research Council.

A description of New York State's Bridge Safety Assurance (BSA) Program is given, and specific examples of interim countermeasures that can be taken to lessen the risk of failure due to hydraulic scour, overload, steel details, collision, concrete details, and earthquakes are provided. The BSA program was adopted to provide a systematic means of identifying situations that pose a threat to the structural integrity of bridges. A traditional bridge inspection program ascertains the condition of various bridge elements. This information is typically used to drive an agency's capital and maintenance bridge programs. New York's BSA program supplements this condition-based evaluation by taking a slightly different perspective. It assesses and rates the degree of risk that is associated with certain design details and circumstances. The program is used to evaluate a bridge by using current design practice as a reference, whereas the inspection procedures are used to rate each element of a bridge only according to its condition and ability to function as intended in the original design. Rating all bridges according to their ability to remain safe under current conditions by using today's design philosophy provides an ability to evaluate structures by using a common reference regardless of when they were built. Specific examples of retrofit work that has been undertaken as a result of the adoption of New York's BSA policy in 1992 are given.

- 900. **Development of user cost data for Florida's bridge management system**. Thompson, P.D., et al., 1999: p. 53.

The Florida Department of Transportation (FDOT) is implementing the AASHTOWare Pontis Bridge Management System (BMS) as a decision support tool for planning and programming bridge maintenance repairs, rehabilitation, improvements, and replacement for more than 6,000 bridges on the state highway network. A BMS stores inventory and inspection data in a database, and uses engineering and economic models to predict the possible outcomes of policy and program decisions. User cost models are used in Pontis to quantify, in economic terms, the potential safety and mobility benefits of functional improvements to bridges. The Pontis user cost model estimates the user benefits of three types of functional improvements: (1) Bridge widening, which primarily affects accident risk on the roadway carried by the bridge; (2) Bridge raising, which affects the ability for tall trucks to pass under the bridge; the user cost model predicts the potential savings in truck detour costs; and (3) Bridge strengthening, which affects the ability for heavy trucks to pass over the bridge; here, also, the user cost model predicts the potential savings in truck detour costs. Almost 15% of the bridges on Florida's state highway system have functional needs according to Pontis default level-of-service standards. An analysis of the Pontis user cost model found that it was overly sensitive to extremes of roadway width, yielding unrealistically high benefit estimates. A new model was developed using Florida data on bridge characteristics and traffic accidents. The new model has superior behavior and statistical characteristics on a full inventory of state highway bridges. The result is the first new model of bridge-related accident risk developed anywhere in the United States in more than 15 years, reflecting the substantial improvements in roadway and vehicle safety that have occurred in that time.

- 947. **User cost models for Wisconsin's network-level bridge management system**. Adams, T.M. and R. Sianipar, 1999: p. 70.

The performance of the Wisconsin Department of Transportation's (WisDOT) implementation of the Pontis MR&R (Maintenance Repair and Rehabilitation) Optimization and Functional Improvement models depends upon reliable estimates of the user cost parameters. The objectives of this research were to evaluate the sensitivity of optimal MR&R policies to variations in user costs of element failures, to estimate the value of the user cost parameters and the cost of improvement actions in the Functional Improvement model, and to assess the project programming recommendations from the Functional Improvement model. An analysis focused on the sensitivity of maintenance policies to changes in element failure cost, the sensitivity of failure cost to changes in transition probability and the sensitivity of maintenance policies to changes in the user cost of element failure costs. Results indicate that adding a user cost of element failure to the existing agency cost has no influence on the optimal maintenance policy. Data collected include estimates for per hour vehicle operating and travel time costs, and average daily traffic (ADT) counts on and under bridges, estimates for per incident accident costs, and actual number and cost of bridge accidents that resulted in agency property damage. Analyses included expected accident costs in each District, identification of top 10 accident-prone bridges in each District, and user costs for the posted bridges. The cost and benefit of improvement actions are independent of roadway functional class, WisDOT District, ownership, and NHS status. Because multiple alternative structure types and materials are used for each functional class, the unit costs of improvement actions should depend upon structure type and material. Similarly, legal and design standards are uniform statewide and vary only for ADT and functional class. Project programming simulation identified 182 functionally deficient bridges and 19 "economically worthy" strengthening projects with benefit/cost (B/C) ratio greater than or equal to one. The optimal priority of improvement projects is not necessarily according to maximum B/C ratio. The incremental B/C ratio method should be used to rank projects according to maximization of net benefits. Districts should make particular efforts to collect ADT data for functionally deficient bridges. Without ADT data, the benefits of widening, strengthening and raising improvement actions cannot be computed and the economic worthiness and relative ranking of improvement projects cannot be evaluated.

- 2002. NYSDOT, Hydraulic Vulnerability Manual, Bridge Safety Assurance Program, 1996.
    - NYSDOT, **Collision Vulnerability Manual**, Bridge Safety Assurance Program, 1996.
    - NYSDOT, **Overload Vulnerability Manual**, Bridge Safety Assurance Program, 1996.
    - NYSDOT, **Concrete Details Vulnerability Manual**, Bridge Safety Assurance Program, 1997.
    - NYSDOT, **Steel Details Vulnerability Manual**, Bridge Safety Assurance Program, 1999.
    - NYSDOT, **Seismic Vulnerability Manual**, Bridge Safety Assurance Program, 2002.

This series of manuals present the procedures and conventions used by the New York State Department of Transportation to assess the vulnerability of structures to natural and man-made hazards.

2.5 AASHTO

- 2002. A **Guide to Highway Vulnerability Assessment for Critical Asset Identification and Protection.** SAIC. Prepared for the American Association of State Highway and Transportation Officials' Security Task Force, National Cooperative Highway Research Program Project 20-07/Task 151B. Transportation Research Board of the National Academies. 2002.

This report presents a set of widely-accepted principles for risk assessment and management, with a focus on man-made hazards.

- 2008. **Pontis Mini Design Study 2: Risk.** Thompson, Paul D. Internal working memorandum, 2008. 15p.

This unpublished working document describes the risk assessment and risk management framework proposed for Pontis 5.2. Once finalized and approved by the AASHTO Pontis Task Force, the plan is to publish it or make it available to Pontis licensees in a form yet to be determined. This should be within the timeframe of the PennDOT study.

2.6 NCHRP Reports

- 107. **Multi-Objective Optimization for Bridge Management Systems**. Patidar, V., et al., NCHRP Report, 2007(590): p. 139.

This report describes the development of methodologies for network- and project-level optimization of multiple, user-specified performance criteria. Included in the criteria are a set of risk assessment performance measures. Bridge management software modules to implement the methodologies were also developed. The report details the development of methodologies, which include risk management capabilities for identifying, selecting, prioritizing and funding risk mitigation projects. The software modules, user's manual, and demonstration database are provided on an accompanying CD-ROM. The material in this report will be of immediate interest to bridge managers and planners. The risk management framework has been adapted for use in AASHTO's Pontis 5.2, due for release near the end of 2009.

- 2003. **Effect of Truck Weight on Bridge Network Costs**. Fu, Gongkang, Jihang Feng, Waseem Dekelbab, Fred Moses, Harry Cohen, Dennis Mertz, and Paul Thompson. National Cooperative Highway Research Program Report 495. Transportation Research Board of the National Academies. 2003. 200p.

This report describes a new method for assessing the costs of increasing truck weight limits on given routes or groups of bridges. Included in the methodology is a simplification of published AASHTO methods for computing the probability of fatigue failure and estimating fatigue life.

- 2003. **Bridge Life Cycle Cost Analysis**. Hawk, Hugh. National Cooperative Highway Research Program Report 483. Transportation Research Board of the National Academies. 2003. 150p.

This report documents the state of the practice in life cycle cost analysis at the time of writing, and describes how the analysis methods relate to risk assessment and uncertainty of inputs.

2.7 Technical Journals/Publications

- 14. **Cost Effectiveness of Risk Mitigation Strategies for Protection of Buildings Against Terrorist Attack**. Stewart, M.G., Journal of Performance of Constructed Facilities, 2008. **22**(2): pp. 115-120.

The technical note considers the cost effectiveness of risk mitigation measures for protection of buildings to terrorist threats. Protective measures might include vehicle barriers, perimeter walls, blast resistant glazing, strengthened perimeter columns, etc. Indicative values of attack probability and characteristics of commercial buildings in the United States are described. The cost effectiveness of protective measures are calculated from a preliminary economic decision analysis that includes cost of the protective measures, attack probability, reduction in risk due to protective measures, and failure consequences. Economic risks due to terrorism are compared with risks from hurricane and seismic hazards.

- 48. **Bridge functionality relationships for improved seismic risk assessment of transportation networks**. Padgett, J.E. and R. DesRoches, Earthquake Spectra, 2007. **23**(1): p. 115-130.

Relationships between bridge damage and the resulting loss of functionality of the bridge are critical to assessing the impact of an earthquake event on the performance of the transportation network. This study addresses this data need by use of a Web-based survey of central and southeastern U.S. Department of Transportation bridge inspectors and officials. Results of the 28 responses are analyzed and offer a link between various types of bridge component damage and the expected level of allowable traffic carrying capacity due to closure decisions and repair procedures. This data is utilized to assess the probability of meeting various damage states, expressed in terms of restoration of functionality, and subsequently facilitate the refinement of component limit-state capacities for analytical fragility curve development. The bridge functionality relationships and methodology outlined serve as the basis for refinement of critical tools in the seismic risk assessment framework and improved assessment of transportation network performance. *2007, Earthquake Engineering Research Institute.*

- 83. **A fuzzy group decision making approach for bridge risk assessment**. Wang, Y.-M. and T.M.S. Elhag, Computers and Industrial Engineering, 2007. **53**(1): p. 137-148.

This paper proposes a fuzzy group decision making (FGDM) approach for bridge risk assessment. The FGDM approach allows decision makers (DMs) to evaluate bridge risk factors using linguistic terms such as Certain, Very High, High, Slightly High, Medium, Slightly Low, Low, Very Low or None rather than precise numerical values, allows them to express their opinions independently, and also provides two alternative algorithms to aggregate the assessments of multiple bridge risk factors, one of which offers a rapid assessment and the other one leads to an exact assessment. A case study is investigated using the FGDM approach to illustrate its applications in bridge risk assessment. It is shown that the FGDM approach offers a flexible, practical and effective way of modeling bridge risks. *2007 Elsevier Ltd. All rights reserved.*

- 97. **Inspection and risk assessment of concrete culverts under Ohio's highways**. Masada, T., et al., Journal of Performance of Constructed Facilities, 2007. **21**(3): p. 225-233.

In 2003 the Ohio Department of Transportation (ODOT) implemented a new culvert management program. Simultaneously, a team of researchers from the Ohio Research Institute for Transportation and the Environment (ORITE) and engineers from a private consulting firm conducted a joint study to evaluate the effectiveness of field culvert inspection and rating procedures proposed by the ODOT's new program and describe the best remedial measures currently available for highway culverts. This paper focuses on the first component and addresses it relative to concrete culverts. The new inspection procedure for concrete culverts was applied at 25 sites. Inspection data were examined to detect common problems existing at concrete culvert sites in Ohio. The field data were also analyzed using statistical software to identify factors that contribute to the degradation of concrete culverts. Despite the limited amount of data, the results indicated that the ODOT approach was basically sound. The final segment of the paper presents a risk assessment method developed by the ORITE researchers. The proposed risk assessment method computes the overall structural health rating for any inspected culvert and recommends a course of action

- 139. **A Risk-Cost Optimized Maintenance Strategy for Corrosion-Affected Concrete Structures**. Li, C.-Q., R.I. Mackie, and W. Lawanwisut, Computer-Aided Civil and Infrastructure Engineering, 2007. **22**(5): pp. 335-346.

Corrosion of reinforcing steel in concrete is the main cause of premature failures of reinforced concrete structures located in chloride-laden environments. It is also observed that some severely deteriorated concrete structures survive for many years without maintenance. This raises the question of why and how to maintain corrosion-affected concrete structures, in particular in a time where there is an increasing paucity of resources. This paper aims to formulate a maintenance strategy based on risk-cost optimization of a structure during its entire service life. A time-dependent reliability method is used to determine the probability of exceeding a limit state at each phase of the service life. To facilitate practical application of the formulated maintenance strategy, an algorithm is developed and programmed in a user-friendly manner with a working example. A merit of the proposed maintenance strategy is that models used in risk assessment for corrosion-affected concrete structures are related to some of the design criteria used by practitioners. It is found in this research that there exists an optimal level of maintenance for cracking and delamination that returns the minimum total cost for the structure over its entire life. The maintenance strategy presented herein can help structural engineers, operators, and asset managers develop a cost-effective management scheme for corrosion-affected concrete structures.

- 389. **Transportation security administration's infrastructure security assessment tools**. Orgill, J. 2005. Boston, MA, United States: Transportation Research Board, Washington, DC 20001, United States.

The Transportation Security Administration (TSA), U.S. Department of Homeland Security, is best known for its progress in improving air transportation security. TSA is also responsible for protecting U.S. highway systems from threat exploitation to promote the free flow of commerce. High-profile, symbolic, or nationally critical transportation assets are perceived to be the priority for government programs, but programs also are available to assist the security posture of less-prominent transportation assets. TSA, with cooperation from FHWA, AASHTO, and other industry experts, has created self-assessment modules for highway bridges, tunnels, and operations centers. These web-based tools were designed to be easy to use at no external cost to the user while providing a uniform approach to the assessment process. The tools are designed to evaluate corporate security and asset-specific practices and protocols and provide stakeholders with a threat-based assessment method to analyze organizational security processes to improve their security posture. TSA will leverage the data to analyze the common baseline mitigation approaches and best practices being used by various assets. Additionally, on the basis of input from experts in the field, TSA has incorporated a vulnerability rating section that helps users understand whether they are within accepted practices and a countermeasure listing to help them understand potential mitigation strategies. This self-assessment tool, in conjunction with other TSA tools, will improve the nation's posture against terrorist threats. Additional information is available at www.tsa.gov/risk.

- 435. **Lifetime performance analysis of existing prestressed concrete bridge superstructures**. Akgul, F. and D.M. Frangopol, Journal of Structural Engineering, 2004. **130**(12): pp. 1889-1903.

A general method for lifetime performance analysis of existing prestressed concrete girder bridges is presented in this article. Only the superstructure components are considered. The framework for the methodology is established by identifying four distinct categories: limit state equations, random variables, deterministic parameters, and constant coefficients. The limit state equations are derived by strictly adhering to the load and capacity formulas and requirements set forth in AASHTO specifications. Generality is pursued by establishing parametric limit state equations such that the formulas are applicable to any type of prestressed concrete bridge having similar superstructure components. For time-variant performance analysis, special emphasis is placed on the corrosion penetration modeling in prestressed concrete girders. The developed methodology is applied to seven existing bridges located in Colorado to obtain the lifetime performance of these prestressed concrete girder bridges in the bridge network. Once the values associated with random variables, deterministic parameters, and constant coefficients are assigned, component reliability indices for the slab and the girders are calculated for each bridge. Detailed results are presented for an individual bridge, whereas the lifetime reliability profiles are presented for selected bridges. The focus of the paper is on the formulation and the overall methodology rather than the analysis of the results.

- 436. **Lifetime performance analysis of existing steel girder bridge superstructures**. Akgul, F. and D.M. Frangopol, Journal of Structural Engineering, 2004. **130**(12): pp. 1875-1888.

A general method for lifetime performance analysis of existing steel girder bridges is presented in this article. Only the superstructure components are considered. The formulation is established by identifying four distinct categories: limit state equations, random variables, deterministic parameters, and constant coefficients. The limit state equations are derived by strictly adhering to the load and capacity formulas and requirements set forth in AASHTO specifications. Generality is pursued by establishing parametric limit state equations such that the formulas are applicable to any type of steel bridge having similar superstructure components. The application of the developed formulation to lifetime performance analysis of four steel girder bridges located in an existing bridge network in Colorado is also presented. Performance analysis results are presented in two main categories: initial reliability indices and lifetime reliability profiles. Once the values associated with random variables, deterministic parameters, and constant coefficients are assigned, component reliability indices for the slab and the girders are calculated for each bridge. Detailed results are presented for an individual bridge and the lifetime reliability profiles are presented for two bridges. For time-variant performance analysis, special emphasis is place on the corrosion penetration modeling in the girders. An attempt has been made to adopt such models to the atmospheric and environmental conditions of Colorado. Limitations to such an approach are also described. The focus of the paper is on the formulation and the overall methodology rather than the analysis of the results.

- 466. **Risk-based method for selecting bridge scour countermeasures**. Johnson, P.A. and S.L. Niezgoda, Journal of Hydraulic Engineering, 2004. **130**(2): p. 121-128.

Bridge engineers are often faced with the task of selecting and designing effective bridge scour countermeasures. The selection of an appropriate countermeasure is dependent on whether the problem is local scour at the pier or abutment, contraction scour across the bed at the bridge opening, reach-wide channel degradation, or lateral channel movement. Confidence in a given countermeasure depends on prior experience in using the measure, cost, maintenance, and the ability to detect failure. The use of countermeasures often introduces uncertainty due to a lack of systematic testing and unknown potential for failure. In this paper, a risk-based method for ranking, comparing, and choosing the most appropriate scour countermeasures is presented using failure modes and effects analysis and risk priority numbers (RPN). Failure modes and effects analysis incorporates uncertainty in the selection process by considering risk in terms of the likelihood of a component failure, the consequence of failure, and the level of difficulty required to detect failure. Risk priority numbers can provide justification for selecting a specific countermeasure and the appropriate compensating actions to be taken to prevent failure of the countermeasure.

- 522. **Determining appropriate fatigue inspection intervals for steel bridge members.** Lovejoy, S.C., Journal of Bridge Engineering, 2003. **8**(2): p. 66-72.

As part of the National Bridge Inspection Standards, owners of public bridge structures are required to perform a Fracture Critical Inspection on steel superstructures that contain primary structural elements having no load path redundancy, e.g., two girder systems. Such inspections are looking to identify damage or deterioration such as corrosion and fatigue cracking that may lead to failure of the critical member. The Oregon Department of Transportation is responsible for the inspection of 196 fracture critical structures that are subjected to widely varying service and environmental conditions. These conditions range from coastal bridges in a fairly corrosive environment with moderate traffic volumes, to large and complex structures in urban areas that experience large volumes of traffic, to very benign conditions in the sparsely populated eastern regions with very low traffic volumes. In response to these widely varying service conditions, Oregon has developed a method to better categorize steel superstructures for fatigue inspection priority and frequency. This method is not only proving to save unnecessary inspection costs but increasing the inspection quality by concentrating resources where they are most needed. This paper presents a simple and practical method of evaluating fatigue inspection periods.

- 577. **Modeling infrastructure deterioration risks using Bayesian mixtures**. Maes, M.A., International Journal of Modeling and Simulation, 2003. **23**(1): p. 43-51.

A major aspect of assessing the long-term reliability of deteriorating structures is the need to integrate the results of different inspections in time, within the models used to analyze the progress of deterioration. This article presents a framework for such an analysis. The article focuses on reinforced concrete structures subject to chloride corrosion, as this represents the single largest form of deterioration of infrastructure in Europe and North America. The analysis focuses on special extensions of the Empirical Bayes method where the non-observable parameter is a discrete random variable with a relatively small number of outcomes. Various likelihood functions are derived. They are based on mixtures of "deterioration scenarios." The authors show how the method can be used to calibrate the response of a stochastic deterioration model, and to update a time-dependent structural reliability analysis. An example relating to long-term chloride corrosion in a reinforced concrete bridge slab is presented.

- 578. **Multiple limit states and expected failure costs for deteriorating reinforced concrete bridges**. Stewart, M.G. and D.V. Val, Journal of Bridge Engineering, 2003. **8**(6): p. 405-415.

Accurate predictive analyses such as those associated with structural reliability and life-cycle costing are needed for the development of Bridge Management Systems. The present paper presents models for reliability and life-cycle cost analyses of reinforced concrete bridges damaged by corrosion. A stochastic deterioration process for corrosion initiation and propagation and then crack initiation and propagation are used to examine the effect of cracking, spalling, and loss of reinforcement area on structural strength and reliability. This will enable expected costs of failure for serviceability and ultimate strength limit states to be calculated and compared for different repair strategies and inspection intervals. It was found that, for a typical reinforced concrete slab bridge, the reduction of structural capacity at the time of severe cracking or spalling is relatively modest and causes probabilities of collapse conditional on spalling to increase by about an order of magnitude. Hence, expected costs of failure for serviceability were significantly higher than the expected costs of failure for ultimate strength limit states.

- 595. **Rating and reliability of existing bridges in a network**. Akgul, F. and D.M. Frangopol, Journal of Bridge Engineering, 2003. **8**(6): p. 383-393.

Currently, the load rating is the method used by State DOTs for evaluating the safety and serviceability of existing bridges in the United States. In general, load rating of a bridge is evaluated when a maintenance, improvement work, change in strength of members, or addition of dead load alters the condition or capacity of the structure. The AASHTO LRFD specifications provide code provisions for prescribing an acceptable and uniform safety level for the design of bridge components. Once a bridge is designed and placed in service, the AASHTO Manual for Condition Evaluation of Bridges provides provisions for determination of the safety and serviceability of existing bridge components. Rating for the bridge system is taken as the minimum of the component ratings. If viewed from a broad perspective, methods used in the state-of-the-practice condition evaluation of bridges at discrete time intervals and in the state-of-the-art probability-based life prediction share common goals and principles. This paper briefly describes a study conducted on the rating and system reliability-based lifetime evaluation of a number of existing bridges within a bridge network, including prestressed concrete, reinforced concrete, steel rolled beam, and steel plate girder bridges. The approach is explained using a representative prestressed concrete girder bridge. Emphasis is placed on the interaction between rating and reliability results in order to relate the developed approach to current practice in bridge rating and evaluation. The results presented provide a sound basis for further improvement of bridge management systems based on system performance requirements.

- 606. **Risk-based expenditure allocation for infrastructure improvement**. Ayyub, B.M. and C. Popescu, Journal of Bridge Engineering, 2003. **8**(6): p. 394-404.

Traditional methods of modeling and simulating lifecycle for infrastructure management, including bridge management systems, commonly do not account for risk associated with potential failure scenarios. These methods need to be reexamined to take advantage of risk technologies. In this paper, methods for performing reliability computations and managing information that are suitable for risk-informed expenditure allocation in lifecycle management are proposed. The methods include structural reliability assessment methods and the analytic hierarchy method for multi-criteria ranking. The paper also presents the advantages of using web-based computing through an example of system reliability assessment software that can be used in an interactive web environment.

- 791. **Economic evaluation of bridge seismic retrofit improvements**. Baker, B. and R. Miller, Transportation Research Record, 2000(1732): p. 80-90.

Travel-related and damage-avoidance benefits and costs of conducting seismic retrofit improvements to arterial bridges are examined, with consideration of the risk posed by a relatively low probability but high damage earthquake (a design level event). The city of Seattle's arterial bridges and viaduct structures serve as vital components of the urban road network, providing for the ongoing transportation needs of citizens and commerce. Failure of these bridges in the event of an earthquake would have significant negative impacts for the movement of people and goods, and thus on the local economy. Shoring up the city's bridges to resist earthquake damage would clearly bring benefits, thereby preventing the impassable arterial bottlenecks that would otherwise occur. The question is whether or not the potential benefits of seismic retrofit improvements warrant their investment costs, thereby providing an economically efficient use of public dollars. For the purpose of addressing this question, a methodology for evaluating the potential benefits and costs associated with bridge seismic retrofit improvements is presented, quantifying these impacts for a two-phase retrofit program and considering the results in light of risk and uncertainty. The evaluation procedures developed consider a major earthquake with defined probability and compare the travel-related and damage-avoidance benefits that would be generated by retrofit improvements with their associated implementation costs. Emphasis is placed on travel impacts because researchers would find non-transportation economic impacts extremely difficult to quantify without knowing all of the other physical, built environment impacts that would occur with a major seismic event. Standard measures of economic feasibility are reported, and in the case of Seattle, seismic retrofit improvements demonstrate moderate positive economic rates of return. The implications posed by expected utility theory for risk-averse decision makers in such cases involving earthquake uncertainty are also discussed.

2.8 *National Infrastructure Protection Plan*

- 232. National Infrastructure Protection Plan. 2006: 196p.

Protecting the critical infrastructure and key resources (CI/KR) of the United States is essential to National security, public health and safety, economic vitality, and way of life. Attacks on CI/KR could significantly disrupt the functioning of government and business alike and produce cascading effects far beyond the targeted sector and physical location of the incident. Direct terrorist attacks and natural, manmade, or technological hazards could produce catastrophic losses in terms of human casualties, property destruction, and economic effects, as well as profound damage to public morale and confidence. Attacks using components of the Nation’s CI/KR as weapons of mass destruction could have even more devastating physical and psychological consequences. The overarching goal of the National Infrastructure Protection Plan (NIPP) is to: Build a safer, more secure, and more resilient America by enhancing protection of the Nation’s CI/KR to prevent, deter, neutralize, or mitigate the effects of deliberate efforts by terrorists to destroy, incapacitate, or exploit them; and to strengthen national preparedness, timely response, and rapid recovery in the event of an attack, natural disaster, or other emergency. The NIPP provides the unifying structure for the integration of existing and future CI/KR protection efforts into a single national program to achieve this goal. Protection includes actions to mitigate the overall risk to CI/KR assets, systems, networks, functions, or their inter-connecting links resulting from exposure, injury, destruction, incapacitation, or exploitation. In the context of the NIPP, this includes actions to deter the threat, mitigate vulnerabilities, or minimize consequences associated with a terrorist attack or other incident. Protection can include a wide range of activities, such as hardening facilities, building resiliency and redundancy, incorporating hazard resistance into initial facility design, initiating active or passive countermeasures, installing security systems, promoting workforce surety programs, and implementing cyber security measures, among various others. Achieving the NIPP goal requires actions to address a series of objectives that include: (1) Understanding and sharing information about terrorist threats and other hazards; (2) Building security partnerships to share information and implement CI/KR protection programs; (3) Implementing a long-term risk management program; and (4) Maximizing efficient use of resources for CI/KR protection. These objectives require a collaborative partnership between and among a diverse set of security partners, including the Federal Government; State, Territorial, local, and tribal governments; the private sector; international entities; and nongovernmental organizations. The NIPP provides the framework that defines the processes and mechanisms that these security partners will use to develop and implement the national program to protect CI/KR across all sectors over the long term.

2.9 *U.S. Coast Guard*

- 137. **Risk-Based Decision Making: A Tool for Effective Management**. Myers, J.J., Proceedings, 2007. **64**(1): pp. 6-9.

The U.S. Coast Guard has always been concerned with managing risks. Over the course of its history and under various names (e.g., U.S. Lighthouse Service, U.S. Lifesaving Service), Coast Guard personnel have worked to prevent shipwrecks, rescue mariners in distress, and mitigate the consequences of marine casualty incidents. As a service, the Coast Guard fully comprehends the underlying principles of risk assessment and management. The more formalized approach currently in place began in the late 1990s, when the Office for Marine Safety and Environmental Protection published the first edition of the U.S. Coast Guard's Risk-Based Decision Making Guidelines, a guide for decision makers on the use of risk assessment, risk management, and risk communication. This was basically a parallel process to the adoption of operational risk management principles for Coast Guard tactical operations. This article provides an overview of the Guidelines, discussing risk-based decision making, risk assessment, risk management, impact assessment, and risk communication strategies.

2.10 *Conference Proceedings*

- 336. **A Mathematically Guided Strategy for Risk Assessment and Management**. Cooper, A., The First International Conference on Safety and Security Engineering (SAFE/05), 2005: pp. 105-114.

Strategies of risk assessment and management of high consequence operations are often based on factors such as physical analysis, analysis software and other logical processing, and analysis of statistically determined human actions. Conventional analysis methods work well for processing objective information. However, in practical situations, much or most of the data available are subjective. Also, there are potential resultant pitfalls where conventional analysis might be unrealistic, such as improperly using event tree and fault tree failure descriptions where failures or events are soft (partial) rather than crisp (binary), neglecting or misinterpreting dependence (positive, negative, correlation), and aggregating nonlinear contributions linearly. There are also personnel issues that transcend basic human factors statistics. For example, sustained productivity and safety in critical operations can depend on the morale of involved personnel. In addition, motivation is significantly influenced by latent effects which are pre-occurring influences. This paper addresses these challenges and proposes techniques for subjective risk analysis, latent effects risk analysis and a hybrid analysis that also includes objective risk analysis. The foal is an improved strategy for risk management.

- 339. **Models for evaluating the costs of bridge failure**. Wong, S.M., C.J. Onof, and R.E. Hobbs, Proceedings of the Institute of Civil Engineers: Bridge Engineering, 2005. **158**(3): p. 117-128.

One of the key factors in evaluating the risk level of a structure such as a bridge should be an examination of the failure consequences, considering that the risk equals the probability of failure times the consequences of failure. In the present study, possible failure consequences of bridge element and system failures have been identified, and a cost-evaluation method has been adopted. The major costs involved are the rebuilding costs, traffic delay costs, access and traffic management costs, casualty costs, repair costs and some other indirect costs. However, there has been a lack of information in evaluating the casualty costs. The paper focuses on the casualty costs and presents some simple models that can be used to evaluate such costs. In addition, several case studies have been performed using the cost models, and the results are presented. Based on the case studies, empirical costs models are proposed for evaluating the total costs of element and system failures.

- 734. **Reliability-Based Optimal Planning of Maintenance and Inspection**. Sorensen, J.D. and M.H. Faber, First US/Japan Workshop on Life-Cycle Cost Analysis and Design of Civil Infrastructure Systems, 2001: pp. 271-288.

Major deterioration mechanisms for infrastructure systems such as bridges, tunnels and dams are chloride initiated corrosion of reinforced concrete and fatigue damage in steel structures. Corrosion of the reinforcement is a significant problem for a large number of reinforced concrete structures since it can result in very expensive maintenance and repair actions. Furthermore, a substantial decrease of the load-bearing capacity may occur, leading to an unacceptable level of safety for the structure. One mode of corrosion initiation is that the chloride content around the reinforcement exceeds a critical threshold value. In the present paper a statistical model is described by which the chloride content in a reinforced concrete structure can be predicted. The model is used in reliability-based inspection and maintenance planning for concrete structures. For steel structures a simplified and generic approach for risk-based inspection planning of fatigue sensitive structural details is described. Fatigue sensitive details are categorized according to their Fatigue Design Factor (FDP) and SN curve. Using a fracture mechanics model calibrated on a probabilistic basis to the appropriate SN-curve, cost-optimal inspection and repair planning can be performed. The procedure is illustrated by an example that considers inspection planning of welded longitudinal stiffeners in steel bridges.

- 800. **Examination of alternative strategies for integration of seismic risk considerations in bridge management systems**. Small, E.P., Eighth International Bridge Management Conference, 2000(498): p. 16.

The development of models for consideration of natural hazard and extreme events in bridge management systems has been recognized as a need for future research and development. Two alternative approaches have been proposed for the integration of such models. The first approach is based on existing prioritization procedures and employs a value-mapping approach to convert priority indices to economic measures. Alternatively, a rigorous risk-based procedure could be developed. The applicability of using a value-based approach for seismic vulnerability mitigation is first examined. Prioritization procedures developed by the Federal Highway Administration, state Departments of Transportation, and through independent research efforts are utilized and prioritization performed on a sample data set. It is seen that required information for prioritization is not available in current bridge inventory and inspection databases and additional information requirements are documented. For examination, this required information was culled through available plans or assumed based on the configuration. It is shown that use of the prioritization procedures developed similar network-level cost estimates; however, there is wide variance in specific projects and projected needs. An alternative approach is therefore proposed based on component level fragility relationships. The approach is demonstrated for the sample bridges and compared to results obtained through prioritization procedures. Methods for integration of the procedures are examined and demonstrated for Pontis and BRIDGIT.

- 1117. **Development and implementation of New York state's comprehensive bridge safety assurance program**. Shirole, A.M., Fourth International Bridge Engineering Conference, 1995. 1: pp. 187-196.

Since 1990 the New York State Department of Transportation has been proactively involved in the planning, development, and implementation of its long-range comprehensive bridge safety assurance program. This program will be integrated into the Department's bridge management system to provide important safety-based bridge information for capital and maintenance program planning. The development and implementation of procedures used to assess the vulnerability of existing bridges to six potential causes or modes of failure--hydraulic, structural steel detail deficiencies, collision, overload, structural concrete detail deficiencies, and earthquake--are discussed. Furthermore, the development and implementation of an overall bridge safety assurance policy aimed at the design and construction of new bridges, retrofitting bridges during their planned rehabilitation, and programming the remaining bridges for necessary actions to eliminate or reduce their vulnerability to catastrophic failure are also discussed.

- 2007. **Risk Management: Federal Perspective**. Yew, Connie. PowerPoint presentation to the FHWA, Asset Management Conference, New Orleans, 2007.

Presents an up-to-date official perspective on risk assessment and management from an official of the Federal Highway Administration.

2.11 *ASCE*

- 36. **Using risk to manage bridges with unknown foundations**. In *World Environmental and Water Resources Congress 2007,* Stein, S.M. and K.A. Sedmera, K.C. Kabbes, Editor. 2007, ASCE: Tampa, Florida. p. 1-13.

Research recently funded by the National Cooperative Highway Research Program (NCHRP) focused on developing risk-based guidelines to assist bridge owners in evaluating and prioritizing various courses of action for managing bridges with unknown foundations for scour failure. These guidelines will soon be finalized and made available to bridge owners nationwide. As of 2006, more than 57,000 bridges over water have unknown foundations. Managing these bridges for risk of failure is extremely difficult since a critical scour depth cannot be determined in the absence of foundation information. The guidelines developed under this research project focus on the following: 1) Simple estimation of risk of failure as a function of estimated failure probability and associated economic losses, 2) Establishing minimum performance standards for various bridge classifications, and 3) Justifying appropriate data collection activities (including nondestructive testing of foundations), scour monitoring activities, and scour countermeasures. These guidelines present a logical plan of action for bridges with unknown foundations. Given the large population of such bridges and the potential cost of management options, these guidelines will assist bridge owners in selecting and prioritizing management activities. The guidelines were recently tested by applying them to sixty bridges in six states with a variety of physical settings, structural conditions, and traffic loads: 30 bridges with known foundations and scour evaluations (i.e. for validation), and 30 bridges with unknown foundations (i.e. for demonstration). The results from these case studies, which were shared and discussed with state officials, show that the proposed methodology yields reasonable management plans.

- 1087. **Reliability concept and application in bridge management system**. Tao, Z. and B.J. Stearman. 1996. Worcester, MA, USA: ASCE, New York, NY, USA.

Structural reliability theory provides DOT agencies a rational tool to assess bridge safety in a bridge management system (BMS). Reliability-based safety measures can be developed on bridge element, project, and network levels. Their applications in BMS result in greater emphasis on bridge safety in developing maintenance and budget allocation policies.

- 1098. **Vulnerability assessment within BMS**. Small, E.P. and S.B. Chase. 1996. Worcester, MA, USA: ASCE, New York, NY, USA.

Bridge Management Systems (BMS) have received significant research attention. Primary developments focus upon optimization of bridge network needs with respect to maintenance, repair and rehabilitation along with functional improvement. National BMS developments include Pontis and Bridgit. Neither system considers potential retrofitting expenditures to mitigate potential natural hazard and extreme event damage. The integration of natural hazard vulnerability considerations within BMS structures promises a significant contribution. This paper examines issues relating to and uncertainties involved in the integration of such vulnerability assessment schemes. Seismic hazards are isolated to examine integration issues. Approaches taken by Pontis and Bridgit are discussed and selected seismic vulnerability assessment procedures summarized. Pertinent assessment variables are isolated and associated uncertainties are discussed. Methodologies for incorporation of vulnerability assessment within BMS concludes the presentation.

- 1215. **Application of scour hazard analysis and management**. Grivas, D.A., K.E. Giles, and E. Holmberg. 1993. Denver, CO, USA: Publ. by ASCE, New York, NY, USA.

A phased study for the assessment of bridge scour vulnerability is presented. Its objectives are to: (a) initiate a field assessment program, (b)establish data handling capabilities, (c) identify uncertainties in the scour predictions process, and (d) determine whether existing statistical models can be modified to improve scour predictions at New York State Thruway Authority (NYSTA) bridge crossings. Field scour vulnerability assessments are implemented in prioritized order for each of the 160 NYSTA bridges over water. A relational database is created to store scour data and facilitate data access and manipulation. Scour prediction models and conclusions are presented and discussed.

- 1273. **Risk analysis of river bridge failure**. Annandale, G.W. 1993. San Francisco, CA, USA: Publ. by ASCE, New York, NY, USA.

The proposed procedure to determine the risk of river bridge failure is based on observations and analysis of river bridge failure data of more than 300 U.S. bridges, 180 South African bridges and 100 New Zealand bridges. The objective of the guideline is to offer a consistent, affordable procedure which can be used to determine the risk of river bridge failure. The procedure has two Risk Assessment options and one Risk Management option. The procedure can be used for various purposes, e.g. prioritizing maintenance of river bridge systems, or selecting between optional river bridge designs.

2.12 *International Research*

- 281. **Application of risk and reliability to the management of bridges**. Pardi, L., et al. 2005. Guildford, United Kingdom: Thomas Telford Services Ltd, London, E14 4JD, United Kingdom.

Developments and application of risk and reliability methods in the field of bridge management are constantly increasing to face safety and security aspects within limited budget constraints. The level of maturity of these methods varies significantly between different sectors and countries and there is a lot of potential for technology transfer. This paper presents a study undertaken within the EU thematic network SAFERELNET which aims at evaluating the current level of applications of these methods for the highway sector compared to other sectors and countries. The main barriers of progress are identified and recommendations are made for further work required to promote these applications in order to reach the level of application of other industrial sectors and maximize the benefits from their use.

- 303. **Demand for Risk Mitigation in Transport**. Rundmo, T. and B.-E. Moen, Road Safety on Four Continents: 13th International Conference, 2005: p. 10p.

This paper aims at examining risk perception, worry and demand for risk mitigation in transport and to compare judgments among lay people, politicians and experts. The results are based on three self completion questionnaire surveys carried out during autumn and winter 2004. The first study was among a representative sample of the Norwegian population (n = 1716), the second sample were a group of Norwegian politicians (n = 146) and the third a group of experts on transport safety (n = 26). Studies carried out previously have given support to the idea that consequences are more important for demands for risk mitigation than probability assessments. In the present study it is hypothesized that this may be because they are associated with worry and that worry is better related to demands for risk mitigation than evaluation of consequences. The results of SEM-modeling showed that worry was a stronger and more significant predictor of demands for risk mitigation compared to consequences. Probability assessment was a totally insignificant predictor. In accordance with studies carried out previously, the results showed that experts demanded less risk reduction than lay people and politicians. The results indicate that this is because they stress the probability more than the other two groups.

- 989. **Risk-based approach to the assessment of existing bridges**. Stewart, M.G. 1998. Sydney, Aust: ARRB Transport Research Ltd, Vermont, Australia.

Bridge performance can often be expressed in a reliability format, typically as the probability of failure. Information about present and anticipated bridge reliabilities, in conjunction with decision models, provides a rational and powerful decision-making tool for the structural assessment of bridges. For assessment purposes, an updated reliability (after an inspection) may be used for comparative or relative risk purposes. This may include the prioritization of risk management measures (risk ranking) for inspection, maintenance, repair or replacement. A risk-cost-benefit analysis may be used to quantify the expected cost of a decision. The present paper will present a broad overview of the concepts, methodology and immediate applications of risk-based assessments of bridges. In particular, two practical applications of reliability-based bridge assessment are considered. For example, a risk-cost-benefit analysis suggests that proof load testing may not be cost effective if the costs of bridge failure (unsuccessful test) and the test itself are considered.

2.13 *Text Books*

- 218. **Infrastructure Risk Management Processes: Natural, Accidental, and Deliberate Hazards**. 2006: p. 301p.

This book contains eight papers on infrastructure risk management procedures and processes. The papers cover risk management for potable water, electric power, transportation, and other infrastructure systems threatened by earthquakes, tsunamis, landslides, severe storms, saboteurs, and various other hazards.

- 473. **Time-dependent interaction between load rating and reliability of deteriorating bridges**. Akgul, F. and D.M. Frangopol, Engineering Structures, 2004. **26**(12): p. 1751-1765.

Prioritization and allocation of federal funds for nationwide bridge replacements and rehabilitations are based on ratings listed in the National Bridge Inventory database. Distribution of funds is based on the sufficiency rating, represented by a formula considering structural safety, functional obsolescence, and essentiality for public use. Possessing the highest weight in sufficiency rating formula, load rating is a crucial measure for bridge management. While load rating represents the current practice in bridge evaluation, reliability methods, taking into account live load increase and material deterioration models, are more commonly used for lifetime bridge assessment. In this paper, time-dependent relationship between the reliability-based analysis results, representing the future trend in bridge evaluation, and the load ratings is investigated for different types of bridges located within an existing bridge network. The comparisons between live load rating factors and reliability indices are made over the lifetime of each bridge in the network. The rating-reliability profile and rating-reliability interaction envelope concepts are introduced. Furthermore, the rating-reliability profiles are collectively examined in order to evaluate the time-dependent performance of the overall bridge network. 2004 Elsevier Ltd. All rights reserved.

- 604. **Risk-based approach to the determination of optimal interventions for bridges affected by multiple hazards**. Adey, B., R. Hajdin, and E. Bruhwiler, Engineering Structures, 2003. **25**(7): p. 903-912.

Decision makers use bridge management systems to determine the optimal allocation of available resources. These systems are currently focused on the structural condition of deteriorating bridges with respect to traffic loads. Bridges, however, are affected by multiple hazards, such as flooding and earthquakes, and not only traffic loading. These multiple hazards should be considered in these management systems when determining the optimal intervention. A risk-based approach can be used to determine the optimal intervention for a bridge subjected to multiple hazards. It requires the determination of the likely 'levels of service' to be provided by the bridge, (e.g. both lanes of traffic open, only one lane of traffic open or both lanes closed), the evaluation of the probability of having these levels of service due to the multiple hazards as well as the consequences of each of these levels of service, and selecting the interventions to minimize the risk of inadequate service. This article gives the methodology to be used when determining the optimal intervention for a bridge affected by multiple hazards. The risk-based approach is illustrated using a simple example in which the optimal intervention of two interventions is found. *2003 Elsevier Science Ltd. All rights reserved.*

- 807. **Fundamentals of risk analysis and risk management**. Molak, V. [Book; Computer File; Internet Resource Date of Entry: 20041006] 2000; 1 electronic text (472 p.): PDF file.]. Available from http://www.engnetbase.com/books/1305/l1130%5Ffm.pdf.

This book bridges the gap between the many different disciplines used in applications of risk analysis to real world problems. Contributed by some of the world's leading experts, it creates a common information base and language for all risk analysis practitioners, risk managers, and decision makers. Valuable as both a reference for practitioners and a comprehensive textbook for students, Fundamentals of Risk Analysis and Risk Management is a unique contribution to the field. Its broad coverage ranges from basic theory of risk analysis to practical applications, risk perception, legal and political issues, and risk management.

2.14 *Expert Research*

- 2. **An adaptive neuro-fuzzy inference system for bridge risk assessment**. Wang, Y.-M. and T.M.S. Elhag, Expert Systems with Applications, 2008. **34**(4): p. 3099-3106.

Bridge risks are often evaluated periodically so that the bridges with high risks can be maintained timely. This paper develops an adaptive neuro-fuzzy system (ANFIS) using 506 bridge maintenance projects for bridge risk assessment, which can help Highways Agency to determine the maintenance priority ranking of bridge structures more systematically, more efficiently and more economically in comparison with the existing bridge risk assessment methodologies which require a large number of subjective judgments from bridge experts to build the complicated nonlinear relationships between bridge risk score and risk ratings. The ANFIS proves to be very effective in modeling bridge risks and performs better than artificial neural networks (ANN) and multiple regression analysis (MRA). *2007 Elsevier Ltd. All rights reserved.*

- 21. **An integrated AHP-DEA methodology for bridge risk assessment**. Wang, Y.-M., J. Liu, and T.M.S. Elhag, Computers and Industrial Engineering, 2008. **54**(3): p. 513-525.

The traditional analytic hierarchy process (AHP) method can only compare a very limited number of decision alternatives, which is usually not more than 15. When there are hundreds or thousands of alternatives to be compared, the pairwise comparison manner provided by the traditional AHP is obviously infeasible. In this paper we propose an integrated AHP-DEA methodology to evaluate bridge risks of hundreds or thousands of bridge structures, based on which the maintenance priorities of the bridge structures can be decided. The proposed AHP-DEA methodology uses the AHP to determine the weights of criteria, linguistic terms such as High, Medium, Low and None to assess bridge risks under each criterion, the data envelopment analysis (DEA) method to determine the values of the linguistic terms, and the simple additive weighting (SAW) method to aggregate bridge risks under different criteria into an overall risk score for each bridge structure. The integrated AHP-DEA methodology is applicable to any number of decision alternatives and is illustrated with a numerical example. *2007 Elsevier Ltd. All rights reserved.*

- 184. **Computational Aspects of Risk-Based Inspection Planning**. Straub, D. and M.H. Faber, Computer-Aided Civil and Infrastructure Engineering, 2006. **21**(3): pp. 179-192.

This study uses a generic approach to develop a computationally efficient method for the calculation of risk-based inspection (RBI) plans founded on Bayesian decision theory. After an introduction in RBI planning, the computational aspects of the methodology are presented. The derivation of inspection plans through interpolation in databases with predefined generic inspection plans is demonstrated and the accuracy of the methodology is investigated. The generic RBI has successfully been implemented in industrial projects.

- 251. **Risk Based Decision Making in Integrated Asset Management: From Development of Asset Management Frameworks to the Development of Asset Risk Management Plans**. Stapelberg, R.F. 2006: CIEAM Cooperative Research Centre for Integrated Engineering Asset Management. 301p.

- 456. **Risk assessment and management of critical highway infrastructure**. Haimes, Y.Y., et al., 2004: p. 63 p.

This study expands upon the scope of a previous contract study for the Virginia Transportation Research Council (VTRC) concluded in March 2002. The objective is to develop methodologies for risk analysis of critical highway infrastructure at two levels: (1) system level and (2) asset level. The system-level analysis conducts risk assessment from a statewide perspective. The goal is to evaluate and prioritize infrastructure from a considerable inventory of assets. The definition of critical infrastructure offered by Presidential Decision Directive (PDD) 63 is used to determine the set of attributes that help differentiate critical from non-critical infrastructure. These attributes correspond to national, regional, and local impact of a structure's damage or complete loss. In addition, the levels of impact are utilized in prioritization: infrastructure that has potential national and regional impact is considered more important than infrastructure with local impact. Further prioritization is conducted based on the asset's need for risk management actions. The asset's current state or condition, in terms of resilience, robustness, redundancy, and security against willful threat is used to evaluate the need for management actions. A set of criteria and corresponding metrics is identified, and supporting data are gathered using information from the Federal Highway Administration National Bridge Inventory and other sources. Once the most critical infrastructure is prioritized, an in-depth risk assessment of particular assets is performed to determine specific risks and vulnerabilities. Eight case studies on selected Virginia Department of Transportation (VDOT) sites are conducted. The details of these case studies are not presented in this report. Instead, general findings are presented that can serve as a guideline for policy implementation to other similar assets. Since a small number of case studies are performed by the project team, another important goal of this study is for effective knowledge transfer of the methodology to VDOT in order to facilitate risk assessment of other critical infrastructure. For this purpose, a prototype computer tool is developed, which is designed to guide facility managers in risk assessment and management. The case studies and documentation of the computer tool are provided in supplemental documents available by request from the authors.

- 457. **Risk assessment and management of critical highway infrastructure: executive summary**. Haimes, Y.Y., et al., 2004: p. 27 p.

This report synthesizes for executives the contents of a more comprehensive companion document on this subject. The objective is to develop methodologies for risk analysis of critical highway infrastructures at two levels: (1) system level and (2) asset level. The system-level analysis conducts risk assessment from a statewide perspective. The goal is to evaluate and prioritize infrastructures from a considerable inventory of assets. These attributes correspond to national, regional, and local impact of an infrastructure's damage or complete loss. In addition, the levels of impact are utilized in prioritization: infrastructures that have potential national and regional impact are considered more important than those with local impact. Further prioritization is conducted based on the asset's need for risk management actions. The asset's current state or condition, in terms of resilience, robustness, redundancy, and security against willful threat is used to evaluate the need for management actions. A set of criteria and corresponding metrics is identified, and supporting data are gathered using information from the Federal Highway Administration National Bridge Inventory and other sources. Once the most critical infrastructures are prioritized, an in-depth risk assessment of particular assets is performed to determine specific risks and vulnerabilities. Eight case studies on selected Virginia Department of Transportation (VDOT) sites are conducted. The details of these case studies are not presented in this report. Instead, general findings are presented that can serve as a guideline for policy implementation to other similar assets. Since a small number of case studies are performed by the project team, another important goal of this study is for effective knowledge transfer of the methodology to VDOT, in order to facilitate risk assessment of other critical infrastructures. For this purpose, a prototype computer tool is developed, which is designed to guide facility managers in risk assessment and management. The case studies and documentation of the computer tool are provided in supplemental documents available by request from the authors.

- 463. **A risk-based approach to setting priorities in protecting bridges against terrorist attacks**. Leung, M., J.H. Lambert, and A. Mosenthal, Risk Analysis, 2004. **24**(4): p. 963-984.

This article presents an approach to the problem of terrorism risk assessment and management by adapting the framework of the risk filtering, ranking, and management method. The assessment is conducted at two levels: (1) the system level, and (2) the asset-specific level. The system-level risk assessment attempts to identify and prioritize critical infrastructures from an inventory of system assets. The definition of critical infrastructures offered by Presidential Decision Directive 63 was used to determine the set of attributes to identify critical assets-categorized according to national, regional, and local impact. An example application is demonstrated using information from the Federal Highway Administration National Bridge Inventory for the State of Virginia. Conversely, the asset-specific risk assessment performs an in-depth analysis of the threats and vulnerabilities of a specific critical infrastructure. An illustration is presented to offer some insights in risk scenario identification and prioritization, multi-objective evaluation of management options, and extreme-event analysis for critical infrastructure protection.

- 465. **Risk-based asset management methodology for highway infrastructure systems**. Dicdican, R.Y., Y.Y. Haimes, and J.H. Lambert, 2004: p. 25 p.

Maintaining the infrastructure of roads, highways, and bridges is paramount to ensuring that these assets will remain safe and reliable in the future. If maintenance costs remain the same or continue to escalate, and additional funding is not made available, the highway agency may need to reduce new construction or cut back on maintenance, or both. There is a close relationship between the cost of optimally scheduled preventive maintenance versus the cost of emergency maintenance or replacement. The study develops a systemic risk-based asset management methodology to manage the maintenance of highway infrastructure systems. The decision making methodology is used to harmonize and coordinate the actions of the different units and levels in a hierarchical organization. The systemic methodology enables the filtering and assessment of assets for maintenance while addressing the potential for extreme events. The methodology balances the costs, benefits, and risks of maintenance and inspection policies as applied to various types of assets. Three objective functions are used in evaluating options and strategies: minimizing short-term cost, minimizing long-term cost, and maximizing the remaining service life of highway assets. A constraint function harmonizes the remaining service life across assets to eliminate infeasible options. The methodology is generally applicable to the asset management of large-scale dynamic systems that exhibit similar characteristics as highway systems.

- 731. **Reliability-based assessment of ageing bridges using risk ranking and life cycle cost decision analyses**. Stewart, M.G., Reliability Engineering and System Safety, 2001. **74**(3): p. 263-273.

Information about present and anticipated bridge reliabilities, in conjunction with decision models, provides a rational and powerful decision-making tool for the structural assessment of bridges. For assessment purposes, an updated reliability (after an inspection) may be used for comparative or relative risk purposes. This may include the prioritization of risk management measures (risk ranking) for inspection, maintenance, repair or replacement. A life-cycle cost analysis may also be used to quantify the expected cost of a decision. The present paper will present a broad overview of the concepts, methodology and immediate applications of risk-based assessments of bridges. In particular, two practical applications of reliability-based bridge assessment are considered - risk ranking and life-cycle cost analysis. *2001 Elsevier Science Ltd. All rights reserved.*

- 732. **Reliability-based bridge assessment using risk-ranking decision analysis**. Stewart, M.G., D.V. Rosowsky, and D.V. Val, Structural Safety, 2001. **23**(4): p. 397-405.

Information about present and anticipated bridge reliabilities can be used in conjunction with decision models to provide a rational decision-making tool for the assessment of bridges and other structural systems. The present paper presents a broad overview of reliability-based assessment methods and will then focus on decision-making applications using updated time-dependent estimates of bridge reliabilities considering a risk-ranking decision analysis. A practical application of reliability-based safety assessment is illustrated herein which relates the effects of bridge age, current and future (increasing) traffic volume and loads, and deterioration on the reliability and safety of ageing RC bridges. *2002 Elsevier Science Ltd. All rights reserved.*

3.0 Acknowledgements

This synthesis report is a collaborative work of Michael Baker, Jr. Inc. and Paul D. Thompson.

4.0 Sources

- Transportation Research Board: Transportation Research Information Services
- WorldCAT
- American Society of Civil Engineers: Civil Engineering Database
- EBSCOhost Business Source Premier
- EBSCOhost Master File Premier
- American Society of State Highway and Transportation Officials
- Center for Transportation Research
- National Research Council – Canada Institute for Scientific and Technical Information
- International Bridge, Tunnel, and Turnpike Association
- National Technical Information Service
- Engineering Village Compendex

Task 2, Research Survey Report

Executive Summary

This interim report is a compilation of research based on two surveys commissioned to characterize the current PennDOT risk assessment program. The first survey was distributed within PennDOT's District offices to solicit feedback and ideas for the improvement of the state's current risk assessment program. The second survey was distributed to other states to solicit information on their risk assessment programs for comparison with PennDOT's system.

Relevant results from the PennDOT District and state surveys are summarized below. The recommendations developed as part of Task 3 are based on these items in conjunction with additional supporting results from the surveys.

PennDOT and State Survey Results

- The magnitude of each state's risk assessment program correlates to the total number of bridges and the number of structurally deficient bridges within the state. States with fewer structurally deficient bridges address deficiencies earlier and maintain a less comprehensive risk assessment or asset management system.
- State agencies rely heavily upon regional or District offices to refine their initial list for prioritization of repairs, based on knowledge of local structures and costs. No state makes programming decisions based solely on assessment data.
- Several states have procedures for distinguishing between preventative maintenance and repair or rehabilitation projects. District survey results indicated a desire for a prioritized list that identifies preservation project candidates.
- Load capacity and observed scour rating were identified as more accurate indicators of risk in risk assessment systems than structural condition and waterway adequacy appraisal ratings.
- Utility lines carried by structures, the proximity of service-sensitive facilities, and impacts from overweight-oversized vehicles are not considered factors in state risk assessment programs.
- The majority of state respondents do not consider seismic vulnerability in their program. States in zones 3 and 4 had seismic assessment modules.
- Accident history at the bridge location and damage from vehicular impact are not considered on a statewide level. However, these items are considered at the District level when manual reviews of the initial prioritization are performed.
- Although assessments of vulnerability to terrorist attack have been performed to comply with federal requirements, terrorism vulnerability is not currently considered in state risk assessment systems. Problematic details (e.g., rocker bearings and inadequate bridge barriers) are considered in other state risk assessment programs. This information is desired by District offices.
- Districts indicated that there is too great a focus on bridges along routes with a high average daily traffic (ADT) volume and that attention may be diverted from low-ADT-volume routes, which carry the majority of structurally deficient bridges. State survey results indicated that the majority of low-ADT-volume structures are owned and programmed for repair by local agencies. By contrast, in Pennsylvania, the state owns a significant number of low-ADT-volume structures.
- District survey results indicate a desire for legacy risk assessment priority lists to be archived and made available through BMS2 to facilitate the retrieval of information.

1.0 Introduction

1.1 Objectives and Scope

This report summarizes and evaluates risk management strategies currently implemented by PennDOT and by transportation agencies throughout the nation and identifies potential areas for improvement. The Task 1 Literature Search and Synthesis Report revealed that only a select number of states have performed advanced studies of risk management. Review of the published study results reveals a number of risk assessment issues that are not addressed in PennDOT's current risk assessment program.

The specific "new issues" not currently evaluated as part of PennDOT's risk assessment program include the utilities supported by the bridge, the proximity of nearby critical facilities, impacts to the bridge from heavy users, the seismic vulnerability of the structure, and the accident history at the bridge site. To evaluate national risk assessment practices, a risk management strategy questionnaire was administered to the agents responsible for risk assessment. Nine states were surveyed. The surveyed states and the specific areas of risk assessment for which they support advanced studies or research are identified below.

Virginia	System-level and asset-level assessment (To be completed)
Minnesota	Unit costs and user benefits
New York	Bridge safety assurance – Interim countermeasures to lessen the risk of failure from hydraulic scour, overloading, steel details, collision impacts, concrete details, and earthquakes. Also, the consideration of bridge failure history.
Florida	Collection of user cost data for (1) Bridge widening, (2) Bridge raising, and (3) Bridge strengthening
Wisconsin	User costs of element failures
California	Procedures for risk assessment and mitigation
Texas	Overall risk assessment work
Michigan	Overall risk assessment work
Idaho	Security-based prioritization

The process of administration and results from the national survey are presented in Section 3, National Survey of this report.

The Task 2 scope was significantly modified to include a survey of PennDOT District Bridge Engineers (DBE) that examined the "new issues" as well as the current risk assessment system. Feedback for the weighting of risk factors within the current risk assessment formula and suggestions for overall system improvements and customizations were requested. This information was used to develop Task 3 recommendations.

2.0 PennDOT District Survey

Baker contacted PennDOT's DBEs via telephone to explore near-term improvements to the Department's risk assessment program. During each telephone call, the DBE was advised that a formal survey would be forwarded for review, and a telephone interview would subsequently be conducted to complete the survey.

2.1 District Contacts

District survey contacts are listed below.

District Bridge Engineers Contact Information:

District	District Br. Engineer	Phone	Risk Management Support	Phone
1-0	Bill Koller wkoller@state.pa.us	(814) 678-7106	Mark Bredl ABE Bridge Insp.	(814) 678-7162
2-0	George Prestash gprestash@state.pa.us	(814) 765-0479	George Uhl Cvl Eng Mgr Brdgs	(814) 765-0483
3-0	Gary Williams garwilliam@state.pa.us	(570) 368-4262	Jeff Levan CE Manager	(570) 368-4304
4-0	Harold Hill hshill@state.pa.us	(570) 963-4091	Lee Soong lsoong@state.pa.us BMS Coord.	(570) 963-3078
5-0	Karl Kroboth kkroboth@state.pa.us	(610) 871-4575	Kamlesh Ashar kashar@state.pa.us Civil Engineer Manager Bridge	(610) 871-4588
6-0	Henry Berman hberman@state.pa.us	(610) 205-6637	Peter Berg pberg@state.pa.us Bridge Inspection	(610) 205-6638
8-0	Harivadan Parikh hparikh@state.pa.us	(717) 787-4774	Ray Ebersole ABE Bridge Insp.	(717) 783-5006
9-0	Ralph Destefano rdestefano@state.pa.us	(814) 696-7180	Lance Eckenrode	(814) 696-7183 ABE Bridge Insp.
10-0	Jim Andrews jandrews@state.pa.us	(724) 357-2821	Tom Knieriem Bridge Inspection	(724) 357-2428
11-0	Lou Ruzzi lruzzi@state.pa.us	(412) 429-4893	Jason Zang Bridge Inspection	(412) 429-4912
12-0	Don Herbert dherbert@state.pa.us	(724) 439-7311	Olin Trauth BMS Coordinator	(724) 439-7281

2.2 *District Surveys*

Please refer to **APPENDIX A** for a sample of the survey.

2.3 *District Survey Responses*

Baker staff interviewed the DBE in each District and recorded survey responses, including supporting comments. The completed survey answer sheet for each District is provided as **APPENDIX B – District Survey Results**.

2.4 *District Response Summary*

- Bridge accident history is considered a safety issue rather than a risk management issue for bridge replacement. Cause of accident information is required to assess bridge-related safety issues.
- The utilities supported by a structure, the proximity of service-sensitive facilities, and impacts from heavy users should be grouped as a single risk factor. The new factor would be assigned by the Districts.
- Bridge type should be a risk factor (e.g., pinned connected trusses could be problematic in a District).
- Bridges with precast parapet installations need to be addressed.
- Bridges with an integral deck, such as slab bridges, are typically given too high a priority because defects are counted twice – in the rating of the deck and the superstructure.
- "Super" loads and heavy vehicles requiring a permit should be considered a risk factor.
- The addition of risk factors may result in the grouping of bridge projects by deficiencies and compromise the decision-making process.
- The structural deficiency risk score should reflect only issues that relate to structural deficiency and not functional issues, such as waterway appraisal (Refer to Table 12 of the Risk Assessment for PennDOT-Owned Bridges and Structures Part A: Risk Assessment).
- Overemphasis on routes with high ADT volumes may divert attention from the low-ADT-volume routes, which carry the greatest number of structurally deficient bridges.
- The business route plan number could inaccurately reflect traffic counts.
- With Act 44, bond money, and the Economic Stimulus Package, legislators place top priority on projects identified in the Transportation Improvement Program (TIP) and on bridge replacements, which reduces the number of preservation projects.
- TIP bridges should be identified or omitted in the reprioritization.
- District 1-0 has advanced maintenance force capabilities, and the prioritization must include projects that support this.
- Updated lists should identify candidates for preservation.
- The Districts desire the ability to adjust priorities for individual projects.
- Old risk assessment lists should be archived for future review and comparison. The Districts find that using the spreadsheet to view all risk assessment data is convenient, as it is not always necessary to query a database for information. The development of future applications should facilitate the Districts' ability to select and manipulate data outside of the risk management application. The Districts agree that the ability to query directly from BMS2 would be very valuable.
- The Districts recommended adding the following columns to the spreadsheet: Date of Last Load Rating / Inspection Date / CoRe Elements.
- The risk spreadsheet should operate on real-time data, linking to BMS2 and the Multimodal Project Management System (MPMS). Linking to BMS2 would be useful in responding to central office requests.
- The new strategy should include District-specific cost factors that the Districts can maintain. To facilitate special analyses at the District level, the functionality of BMS2 should be enhanced to

accommodate general user-defined importance factors. This will reduce the need to adjust a ranking after an assessment is run.
- The Districts suggest modifying BMS2 to automatically account for District-specific cost factors and eliminate the need for the post-assessment adjustment of data.
- Risk assessment should be one of the tools to program projects. The projects that are the easiest and quickest to perform are those that do not involve right-of-way services, such as deck rehabilitations and painting. The spreadsheet tool is very cumbersome, and much time is wasted in navigating through the data. The new tool should retain the ability to customize reports by enabling changes in formatting and providing for the color coding of the data.
- The development of the new tool should accommodate the needs identified on the Districts' final (reprioritized) recommendations list.
- The new software interface should provide a list of standard queries for various types of projects. The standard query leadoff question should be "What do you want to do?" The software also should provide the option for the Districts to customize each query by modifying query language or by adding or subtracting query items. Training would be beneficial if a new tool, other than the spreadsheet, is implemented. Training should address methods of extracting data and not the intricacies of software functionality.
- In lieu of training, a quality user manual, a webinar, or a brief one- to two-hour presentation at a bridge engineers meeting would meet users' needs.
- If a training program is provided, it should also be offered to support staff at PennDOT's central office.

Risk Factor Weights and Importance

The following list summarizes the risk factor weights compiled through the analysis of District survey data. Refer to the Tabulation of Risk Factor Weight Feedback table.

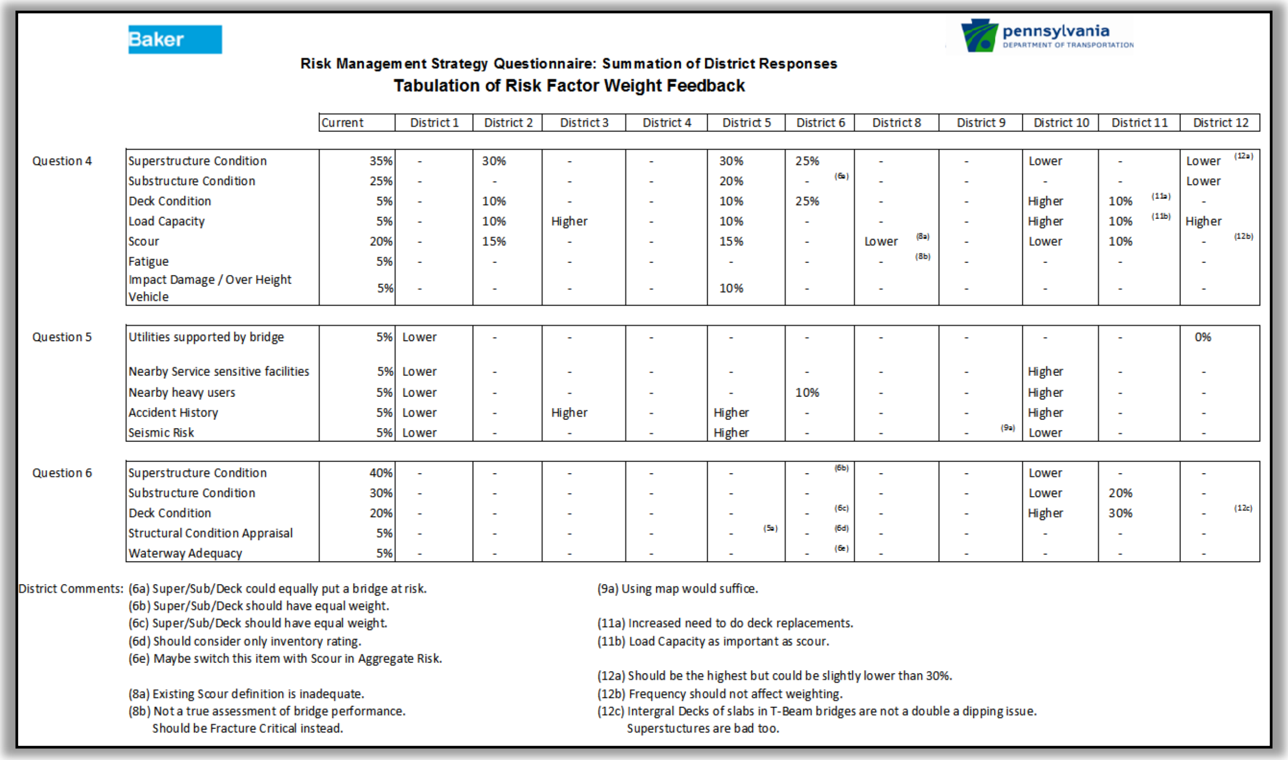
Question 4 – Existing Aggregate Risk Weights – Data Analysis
- Superstructure Condition: Decrease aggregate risk weighting for superstructure. (District responses were consistent for this item)
- Substructure Condition: Decrease aggregate risk weighting for substructure. (District responses were consistent for this item)
- Deck Condition: Increase aggregate risk weighting for deck. (District responses were consistent for this item)
- Load Capacity: Increase aggregate risk weighting for load capacity. (District responses were consistent for this item)
- Scour: Decrease aggregate risk weighting for scour. (District responses were consistent for this item)
- Impact Damage/Overheight Vehicle: Increase aggregate risk weighting for impact damage/ overheight vehicles. (District responses were consistent for this item)

Question 5 – Proposed Aggregate Risk Weights – Data Analysis
- Utilities Supported by Bridge: Decrease proposed aggregate risk for weighting utilities. (District responses were consistent for this item)
- Nearby Service-Sensitive Facilities: General trend was neutral regarding the proposed aggregate risk weighting for service- sensitive facilities. (District responses varied for this item)
- Nearby Heavy Users: General trend was for increasing the proposed aggregate risk weighting for heavy users. (District responses varied for this item)
- Accident History: General trend was for increasing the proposed aggregate risk weighting for accident history. (District responses varied for this item)

- Seismic Risk: General trend was for decreasing the proposed aggregate risk weighting for seismic vulnerability. (District responses varied for this item)

Question 6 – Structurally Deficient (SD) Risk Weights – Data Analysis

- Superstructure Condition: Decrease SD risk weighting for superstructure. (District responses were consistent for this item)
- Substructure Condition: Decrease SD risk weighting for substructure. (District responses were consistent for this item)
- Deck Condition: Increase SD risk weighting for deck. (District responses were consistent for this item)
- Structural Condition Appraisal: General trend was neutral regarding the proposed SD risk weighting for structural condition appraisal.
- Waterway Adequacy: General trend was neutral regarding the SD risk weighting for waterway adequacy.



Baker

pennsylvania DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Questionnaire: Summation of District Responses

Tabulation of Risk Factor Weight Feedback

		Current	District 1	District 2	District 3	District 4	District 5	District 6	District 8	District 9	District 10	District 11	District 12
Question 4	Superstructure Condition	35%	-	30%	-	-	30%	25%	-	-	Lower	-	Lower (12a)
	Substructure Condition	25%	-	-	-	-	20%	- (6a)	-	-	-	-	Lower
	Deck Condition	5%	-	10%	-	-	10%	25%	-	-	Higher	10% (11a)	-
	Load Capacity	5%	-	10%	Higher	-	10%	-	-	-	Higher	10% (11b)	Higher
	Scour	20%	-	15%	-	-	15%	-	Lower (8a)	-	Lower	10%	- (12b)
	Fatigue	5%	-	-	-	-	-	-	- (8b)	-	-	-	-
	Impact Damage / Over Height Vehicle	5%	-	-	-	-	10%	-	-	-	-	-	-
Question 5	Utilities supported by bridge	5%	Lower	-	-	-	-	-	-	-	-	-	0%
	Nearby Service sensitive facilities	5%	Lower	-	-	-	-	-	-	-	Higher	-	-
	Nearby heavy users	5%	Lower	-	-	-	-	10%	-	-	Higher	-	-
	Accident History	5%	Lower	-	Higher	-	Higher	-	-	-	Higher	-	-
	Seismic Risk	5%	Lower	-	-	-	Higher	-	-	- (9a)	Lower	-	-
Question 6	Superstructure Condition	40%	-	-	-	-	-	- (6b)	-	-	Lower	-	-
	Substructure Condition	30%	-	-	-	-	-	-	-	-	Lower	20%	-
	Deck Condition	20%	-	-	-	-	-	- (6c)	-	-	Higher	30%	- (12c)
	Structural Condition Appraisal	5%	-	-	-	-	- (5a)	- (6d)	-	-	-	-	-
	Waterway Adequacy	5%	-	-	-	-	-	- (6e)	-	-	-	-	-

District Comments: (6a) Super/Sub/Deck could equally put a bridge at risk.
(6b) Super/Sub/Deck should have equal weight.
(6c) Super/Sub/Deck should have equal weight.
(6d) Should consider only inventory rating.
(6e) Maybe switch this item with Scour in Aggregate Risk.

(8a) Existing Scour definition is inadequate.
(8b) Not a true assessment of bridge performance.
Should be Fracture Critical instead.

(9a) Using map would suffice.

(11a) Increased need to do deck replacements.
(11b) Load Capacity as important as scour.

(12a) Should be the highest but could be slightly lower than 30%.
(12b) Frequency should not affect weighting.
(12c) Intergral Decks of slabs in T-Beam bridges are not a double a dipping issue.
Superstuctures are bad too.

3.0 National Survey

Baker telephoned representatives from the states identified as having some form of structure risk assessment program. State agents most directly responsible for the risk assessment program were targeted (see Section 3.1). During each telephone call, the contact was advised that a formal survey would be forwarded for review, and a telephone interview would subsequently be conducted to complete the survey.

3.1 State Contacts

State survey contacts are listed below.

Florida

Richard Kerr
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Florida Department of Transportation
605 Suwannee Street
Mail Stop 52
Tallahassee, FL 32399-0450
(850) 410-5757 x108
Richard.Kerr@dot.state.fl.us

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salampalli@dot.state.ny.us

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3.2 State Survey Questionnaire

Please refer to **APPENDIX C – State Survey Questionnaire** for a sample of the survey.

3.3 State Survey Responses

During the interviews, Baker staff documented state contacts' responses to survey questions. The completed survey answer sheet for each state is provided as **APPENDIX D –State Survey Results**.

NOTE: The review of survey responses indicates that each state's approach to bridge and structure risk management is determined by the total number of bridges as well as the number of structurally deficient bridges for which it is responsible. Each completed questionnaire includes an introductory summary of the state's responses.

3.4 State Response Summary

Does your state have a Risk Assessment for structures based on bridge safety inspection data?

- Florida does not currently have a risk assessment program.
- Wisconsin currently has multiple independent assessment programs. Scour/ flood zones, load capacity, and vulnerability are examples. There is no umbrella program currently to tie them all together.
- Texas does not have a centralized risk assessment system. All Districts act independently within the state to handle the maintenance and replacement of District bridges.
- California has an extensive risk assessment program. It is based on the use of multi-objective utility functions (weighting) that combine various components of risk into a single quantified assessment. Factors such as the Bridge Health Index (BHI), ADT, detour length, bridge barriers (rails), scour, and seismic retrofit needs are used to determine the risk assessment score. California used the methodology outlined in NCHRP 590 to calculate individual risk weight.
- New York has a vulnerability assessment program that is not probability based. There are 17,400 bridges in the state, 7,500 of which are local. Thirty percent of the bridges are SD, which is comparable to the percentage of SD bridges in Pennsylvania. Although New York's inventory is comparable to that of Pennsylvania, the risk assessment program is not as comprehensive. New York has several modules to assess vulnerability but does not combine the results of each module to generate an overall risk score.
- Michigan has a bridge strategic plan that incorporates both condition-state ratings and deterioration rate assessments to determine costs for replacement, rehabilitation, or preservation. The program is used to determine funding allocations for state and local bridges, but final prioritization is performed by the regional office. There are 4,500 NBIS and 6,500 local bridges statewide. Twelve percent of these bridges are SD. The state Transportation Department's emphasis is broader than "risk assessment," and the agency does little regarding analytical "risk" assessment.
- Minnesota does not apply a probabilistic approach with its risk assessment system. The state uses a matrix of conditions to evaluate the need for bridge rehabilitation, replacement, or preservation. An initial prioritized list is generated and provided to the regional offices. The regional offices restructure and reprioritize the list based on intimate knowledge of the structures in the region. There are 3,600 bridges on the state system; 105 are SD. There are also 9,500 local bridges that are not handled by the state system.
- Virginia has a prioritization system to determine bridge funding. The system considers 10 factors with associated weights on a fractional scale from 0 to 1. The weighted factors are summed, and a calculation is run to determine the highest-priority structures. The state is in the process of developing a score-based system. There are 19,400 structures on the statewide system; approximately 1,650 are SD.

- Idaho does not have a centralized risk assessment system. All Districts act independently to handle the maintenance and replacement of District bridges.

Does your state have a Risk Assessment for structures for seismic vulnerability? Scour? Coastal/hurricane? Other?

- Florida is currently developing a wave vulnerability assessment program with the University of Florida.
- Wisconsin does not consider seismic or coastal conditions. However, barge impacts to structures over the Mississippi River are considered.
- California has individual seismic and scour programs. The results from these programs are incorporated into the final risk assessment score (total utility factor).
- New York stated that vulnerability assessments are conducted for the following categories: scour seismic, overload, steel details, concrete details, and collision.
- Michigan is beginning to perform asset management and is preparing action plans for its scour-critical bridges.
- Minnesota stated that scour is considered by the regional offices and is not part of the initial matrix-based prioritization.
- Virginia does not consider seismic or coastal or hurricane vulnerabilities in its risk assessment. However, Virginia does consider scour as one of the 10 risk factors

Are any of the following items a factor in the states' Risk Assessment? If so, how are they used in calculating the risk?

- ***Superstructure Rating***
    - Florida would consider equally weighting superstructure and substructure.
    - Wisconsin does not consider superstructure ratings a significant priority.
    - California uses element-level ratings. Weighting was determined based on the methodology outlined in NCHRP 590.
    - New York bridge ratings are performed using both NBI ratings and element-level ratings established by New York. The NBI ratings are only performed to comply with federal coding guidelines.
    - Michigan says superstructure rating is a factor in its bridge strategic plan.
    - Minnesota only considers superstructure ratings for structurally deficient bridges
    - Virginia considers general condition ratings as one of the 10 factors for prioritization. The lowest ratings obtained from superstructure, substructure, deck, and culvert evaluation are used in the assessment.

- ***Substructure Rating***
    - Florida would consider equally weighting superstructure and substructure.
    - Wisconsin does not consider substructure ratings a significant priority.
    - California uses element-level ratings. Weighting was determined based on the methodology outlined in NCHRP 590.
    - New York bridge ratings are conducted using both NBI ratings and element- level ratings established by New York. The NBI ratings are only performed to comply with federal coding guidelines.
    - Michigan says substructure rating is a factor in the bridge strategic plan.
    - Minnesota only considers substructure ratings for structurally deficient bridges.
    - Virginia considers general condition ratings as one of the 10 factors for prioritization. The lowest ratings obtained from superstructure, substructure, deck, and culvert evaluations are used in the assessment.

- ***Deck Rating***
  - Florida does not consider deck ratings a significant issue because structures are not subjected to freeze-thaw cycles, and deicing chemicals are not required. Deck ratings are only considered if the deck is in poor condition.
  - Wisconsin does not consider substructure ratings a significant priority.
  - California uses element-level ratings. Weighting was determined based on the methodology outlined in NCHRP 590.
  - New York bridge ratings are performed using both NBI ratings and element-level ratings established by the state. The NBI ratings are only performed to comply with federal coding guidelines.
  - Michigan says deck rating is a factor in the bridge strategic plan.
  - Minnesota stated that deck condition is the primary factor in the decision matrix for determining the level of preventative maintenance to be programmed.
  - Virginia considers general condition ratings as one of the 10 factors for prioritization. The lowest ratings obtained from superstructure, substructure, deck, and culvert evaluations are used in the assessment.

- ***Culvert Rating***
  - Florida relies on condition-state ratings for prioritizing the repair or replacement of culverts.
  - Wisconsin does not consider culvert ratings a significant priority.
  - California uses element-level ratings. Weighting was determined based on the methodology outlined in NCHRP 590.
  - New York bridge ratings are performed using both NBI ratings and element-level ratings established by the state. The NBI ratings are only performed to comply with federal coding guidelines.
  - Michigan says culvert rating is a factor in its bridge strategic plan.
  - Minnesota only considers culvert ratings for structurally deficient bridges.
  - Virginia considers general condition ratings as one of the 10 factors for prioritization. The lowest ratings obtained from superstructure, substructure, deck, and culvert evaluations are used in the assessment.

- ***Load Capacity (Operating Rating Loads)***
  - Florida considers load capacity to be important for truck routing and permitting. The state currently uses LRFR.
  - Wisconsin considers load capacity a high priority item. An independent load capacity assessment program is currently in place.
  - California incorporates load capacity as part of its Strengthening under Mobility Needs which is one of five utility components needed to calculate the risk score.
  - Michigan stated that load capacity is not a factor. Its policy has always been to avoid posting bridges on the state trunkline system. The bridges are strengthened, if required.
  - Minnesota considers load capacity on the regional level, but it is not considered in the matrix.
  - Virginia considers load capacity in prioritization.

- ***Scour Vulnerability (NBI item 113 Scour Critical Bridges)***
  - Florida considers scour a low-priority item unless scour is observed to be severe.
  - Wisconsin considers scour a high-priority item. An independent scour assessment program is currently in place.
  - California incorporates scour as part of scour needs, which is one of the utility components needed to calculate the risk score.
  - Michigan recently began using a new scour module within its bridge strategic plan.
  - Minnesota considers scour vulnerability on the regional level, but it is not considered in the matrix.
  - Virginia considers scour in prioritization.

- ***Clearance Data***
  - Florida considers clearance a priority item for frequently impacted bridges and the state's turnpike system.
  - Wisconsin considers clearance a high priority for structures as it may be a factor in vehicular impact.
  - California incorporates clearance data as part of Raising under Mobility Needs when calculating the risk score.
  - New York uses clearance data in collision vulnerability assessment.
  - Michigan does not consider clearance a high priority for structures.
  - Minnesota does not consider clearance as part of its assessment.
  - Virginia only uses clearance data for long-range planning. It is not a factor in initial prioritization.

- ***Structural Condition Appraisal***
  - Florida does not consider structural condition appraisal a significant issue.
  - Wisconsin considers load capacity a more relevant metric of risk than structural condition appraisal.
  - California does not consider structural condition appraisal as part of its assessment.
  - Michigan considers load capacity as part of its bridge strategic plan.
  - Minnesota considers structural condition appraisal on the regional level, but it is not considered in the matrix.
  - Virginia considers structural condition appraisal to determine deficiency

- ***Waterway Adequacy Appraisal***
  - Florida does not consider waterway adequacy appraisal a significant issue.
  - Wisconsin considers observed scour a more relevant metric of risk than waterway adequacy appraisal.
  - California does not consider waterway adequacy appraisal as part of its assessment.
  - New York uses waterway adequacy in the hydraulic (scour) vulnerability module.
  - Michigan does not consider waterway adequacy appraisal a high priority for structures.
  - Minnesota considers waterway adequacy appraisal on the regional level, but it is not considered in the matrix.
  - Virginia considers waterway adequacy appraisal to determine deficiency.

- ***ADT/ADTT***
  - Florida does not use ADT to prioritize state bridges. However, ADT is used when local bridges are prioritized.
  - Wisconsin does not consider ADT/ADTT a significant issue during prioritization.

  - California considers ADT for three utility components when calculating the risk score. It is used in rehabilitation and replacement needs, scour needs, and seismic retrofit needs.
  - New York uses ADT or ADTT in vulnerability assessment modules, such as fatigue life and steel details.
  - Michigan does not consider ADT or ADTT a significant issue during prioritization.
  - Minnesota considers ADT or ADTT a significant factor in the decision matrix.
  - Virginia considers ADT or ADTT a significant issue during prioritization.

- ***Size***
  - Florida does not consider structure size a significant issue during prioritization.
  - Wisconsin does not consider structure size a significant issue during prioritization.
  - California does not consider structure size a significant issue during prioritization.
  - New York does not consider structure size a significant issue during prioritization.
  - Michigan does consider size a significant issue during prioritization. The deck area is monitored and taken into consideration in the asset management program, and large-deck bridges are managed in a special program.
  - Minnesota does not consider structure size a significant issue during prioritization.
  - Virginia considers deck size as one of the 10 factors in its prioritization.

- ***Detour Length***
  - Florida only considers detour length a significant issue in its Keys.
  - Wisconsin does not consider detour length a significant issue during prioritization.
  - California considers detour length a factor in risk assessment.
  - New York does not consider detour length a significant issue during prioritization.
  - Michigan does not consider detour length a significant issue during prioritization.
  - Minnesota does not consider detour length a significant issue during prioritization.
  - Virginia considers detour length as one of the 10 factors in its prioritization.

- ***Seismic vulnerability***
  - Florida does not consider seismic vulnerability a significant issue during prioritization.
  - Wisconsin does not consider seismic vulnerability a significant issue during prioritization.
  - California addresses seismic issues through an internal program. Its seismic program consists of more than 30 individual parameters, such as details, soil types, bearing types, distance to fault lines, and peak rock accelerations. Bearings other than neoprene and sliding plate are considered high risk.
  - New York has a separate seismic vulnerability assessment module.
  - Michigan is not in a highly seismic region; therefore, seismic vulnerability is not considered a significant issue during prioritization.
  - Minnesota is not in a highly seismic region; therefore, seismic vulnerability is not considered a significant issue during prioritization.
  - Virginia is not in a highly seismic region; therefore, seismic vulnerability is not considered a significant issue during prioritization.

- ***Vehicular impact***
  - Florida considers only barge impact for structures over navigable waterways.
  - Wisconsin considers vehicular impact a high-priority item due to high frequency of occurrence. Vehicular impact is related to clearance.
  - California only considers vehicular impact on deck for use with the bridge rail upgrade needs component of the risk assessment. Approach roadway alignment and speed are also considered.

  - New York considers vehicular impact in the collision vulnerability assessment module.
  - Michigan does not consider vehicular impact a significant issue during prioritization. Michigan has developed policy as to what bridges need to meet the current standards when doing 4R work.
  - Minnesota considers vehicular impact on the regional level, but it is not considered in the decision matrix.
  - Virginia only uses vehicular impacts for long-range planning. It is not a factor in initial prioritization.

- ***Accident history at the bridge location***
  - Florida does not consider accident history a significant issue during prioritization.
  - Wisconsin does not consider accident history a significant issue during prioritization.
  - California does not consider accident history in the initial risk score, but it is used for final prioritization. California indicated that accident history would be considered if an adequate database of information were available.
  - New York only considers accident history on the regional level. Accident history is not considered at the central office level during the prioritization of structures.
  - Michigan does not consider accident history a significant issue during prioritization.
  - Minnesota considers accident history on the regional level, but it is not considered in the decision matrix.
  - Virginia only uses accident history for long-range planning. It is not a factor in initial prioritization.

- ***Fatigue and Fracture (NBI item 92 Critical Feature Inspection)***
  - Florida only considers fatigue and fracture when fatigue-related issues are detected, not simply because a structure has fatigue-prone details.
  - Wisconsin considers fatigue and fracture a high-priority item. An independent fatigue and fracture-critical assessment program is currently in place.
  - California incorporates fatigue in the calculation of the BHI. Information is taken from element-level “smart flags” for fatigue and pack rust.
  - New York considers fatigue and fracture in the steel details vulnerability assessment module.
  - Michigan considers fatigue and fracture as part of the bridge strategic plan. Michigan policy is to always ensure that fracture-critical bridge elements are maintained in good or fair condition.
  - Minnesota considers fatigue and fracture on the regional level, but it is not considered in the decision matrix.
  - Virginia considers fatigue and fracture as one of the 10 factors in its prioritization.

- ***State specific bridge types or details***
  - Florida does not consider bridge type or details a significant issue during prioritization.
  - Wisconsin does not consider bridge type or details a significant issue during prioritization.
  - California stated that bridge rails are problematic in the state – particularly railings that do not meet NCHRP 230 crash test standards. These include timber rail, steel tube rail, and concrete picket rail. Rocker bearing condition and structure age (older structures equal lack of confinement steel) are also considered.
  - New York does not consider bridge type or details during prioritization.
  - Michigan does not consider bridge type or details a significant issue.
  - Minnesota considers overlay types and rebar protection in the decision matrix.
  - Virginia does not consider bridge type or details a significant issue.

- ***Service sensitive facilities such as hospitals, heavy users and manufacturers near a bridge***
  - Florida does not consider service-sensitive facilities a significant issue during prioritization.
  - Wisconsin does not consider service-sensitive facilities a significant issue during prioritization.
  - California does not consider service-sensitive facilities directly during prioritization. The state feels that ADT covers this issue adequately.
  - New York does not consider service-sensitive facilities as part of the automatic vulnerability assessment. However, this factor is considered on the regional level when programming structures.
  - Michigan does not consider service-sensitive facilities a significant issue in initial prioritization. Michigan is a decentralized state –these types of decisions are handled by its Transportation Service Centers (TSCs).
  - Minnesota does not consider service-sensitive facilities in the decision matrix.
  - Virginia does not consider service-sensitive facilities a factor during the initial prioritization. However, these facilities can be considered on the District level.

- ***Vulnerability of terrorist attacks***
  - Florida does not consider vulnerability to terrorist attacks a significant issue during prioritization.
  - Wisconsin performed a vulnerability assessment approximately three to four years ago and identified approximately 75 bridges as vulnerable based on federal criteria.
  - California does not consider vulnerability to terrorist attacks as part of risk assessment. Seismic typically controls over blast.
  - New York considers vulnerability to terrorist attacks only for new and signature structures within the state. This equates to approximately 1,000 structures statewide.
  - Michigan does not consider vulnerability to terrorist attacks a significant issue. However, security assessments are performed on long-span, authority-managed bridges.
  - Minnesota performed a vulnerability-to-terrorist attack assessment in 2002 and developed a list of 15 bridges with the highest ADTs that equated to the highest risk of terrorist attack. However, no replacements are scheduled based on risk of terrorist attack.
  - Virginia does not consider terrorist attack in prioritization.

- ***Permit routes for overweight/oversized vehicles***
  - Florida does not consider permit routes for overweight - oversized vehicles a significant issue during prioritization.
  - Wisconsin does not currently consider permit routes for overweight-oversized vehicles a significant issue during prioritization.
  - California does not consider permit routes for overweight-oversized vehicles a significant issue during prioritization.
  - New York does not currently consider permit routes for overweight-oversized vehicles a significant issue during prioritization.
  - Michigan does not consider permit routes for overweight-oversized vehicles a significant issue.
  - Minnesota does not consider permit routes for overweight-oversized vehicles in the decision matrix.
  - Virginia does not consider permit routes in prioritization.

- ***Utilities supported by structure***
  - Florida only considers structure-supported utilities a significant issue in its Keys portion.
  - Wisconsin does not consider structure-supported utilities a significant issue during prioritization.

  - California does not consider structure-supported utilities a significant issue during the initial screening process. However, it can be a factor during final prioritization, as part of seismic risk.
  - New York does not consider structure-supported utilities a significant issue during prioritization.
  - Michigan does not consider structure-supported utilities a significant issue.
  - Minnesota does not consider structure-supported utilities in the decision matrix.
  - Virginia does not consider structure-supported utilities in prioritization.

- ***Based on experience with events regarding failures, what data would be worthwhile to use in aiding your Risk Assessment?***
  - Florida indicated that no additional data needs to be considered as part of its program.
  - Wisconsin indicated that beyond ADT and ADTT counts, traffic patterns of heavy users would be beneficial for a risk assessment system.
  - California indicated that more detailed seismic information would be beneficial.
  - New York wants to implement more optimization capabilities (i.e., optimize assets and more efficiently obtain costs).
  - Michigan experiences difficulty in identifying problematic details, such as link plate and rocker bearing deficiencies. More data on these items would be beneficial.
  - Minnesota would like more details documented on two-girder systems with fatigue- prone details and fracture-critical details.
  - Virginia indicated that no additional data needs to be considered as part of its program.

- ***Are external influences (i.e. stakeholder views, user costs, public opinion, economic factors…) considered in the states' Risk Assessment? If so, how are they considered?***
  - Florida stated that a pool of money is allocated to each District to fund improvements. Funding is not an issue in Florida. There is minimal legislative influence on the prioritization of structure replacement. Public opinion is considered regarding historic structures.
  - Wisconsin stated that external influences are always a factor. However, public safety always outweighs external influences in prioritizing structure replacement or rehabilitation.
  - California stated that external influences include detour length and ADT. In risk assessment, the analysis of bridges overrides politics.
  - New York stated that only regional offices consider external influences in performing programming. The central office does not consider external influences in performing statewide programming.
  - Michigan considers external factors through a five- year call for projects and the MPO process.
  - Minnesota stated that external influences are considered entirely at the regional level. Expansion projects are undertaken if the existing structure is in good condition but the cost to replace is less than the cost to widen.
  - Virginia stated that during the development of its six- year plan, feedback is solicited from the public. The plan is sent to the Commonwealth Transportation Board, which consists of government officials and business leaders, for review. The board determines final project selection.

- ***How do repair and replacement costs influence the states' Risk Assessment?***
  - Florida indicated that replacement costs are not considered.
  - Wisconsin had no response on this issue.
  - California applies a benefit-to-cost (BC) ratio that is calculated using the total project utility over cost. The cost is calculated based on the square footage of the bridge deck. Calculating the BC ratio ensures the equitable comparison of bridges of various sizes.

  - New York stated that repair and replacement costs do not directly influence the state's vulnerability assessment.
  - Michigan has developed a bridge asset management program that analyzes the optimal "mix of fixes." The program encompasses replacement, rehabilitation, and preventive maintenance projects. The program determines how much money should be dedicated to each of these tasks. For example, Michigan's program consists of 22 percent preventive maintenance, 30 percent rehabilitation, and 48 percent replacement projects. This approach has slowed the bridge deterioration rate while allowing the state Transportation Department to make progress towards achieving bridge condition goals.
  - Minnesota indicated that replacement costs are not considered.
  - Virginia had no response on this issue.

- ***What flexibility exists within the states' Risk Assessment to account for regional or site specific cost differences?***
  - Florida indicated that Districts have control over both the maintenance of structures and the costs associated with repairs.
  - Wisconsin is currently considering the use of regional cost factors to normalize costs across the state.
  - California maintains an extensive database of costs by region. Costs are derived from advance-planning studies.
  - New York stated that regional offices review the statewide prioritization list and set priorities for structures within individual regions.
  - Michigan stated that there is considerable flexibility within the system to account for costs. Bridge projects are selected by TSCs and region bridge engineers.
  - Minnesota currently uses a single cost system statewide. The current system does not account for regional cost variations.
  - Virginia stated that a network-level cost estimate is calculated. Project managers subsequently provide detailed cost estimates.

- ***How are you prioritizing structure maintenance/replacement needs based on the Risk Assessment data? What latitude is permitted in adjusting the prioritization? How often is a reprioritization of assets conducted?***
  - Florida had no response on this issue.
  - Wisconsin maintenance personnel play an integral part in the decision-making process during the prioritization of maintenance work.
  - California stated that structures are prioritized during the preliminary screening process. A team of senior engineers within CALTrans refines the list based upon knowledge of the structures within each member's assigned region.
  - New York updates its prioritizations every two years, at a minimum, but updates may be performed more frequently, if required. Vulnerability is evaluated by central office only. All information is maintained in a database that can be accessed at any time.
  - Michigan uses its bridge strategic plan and is reviewed during the annual five- year call for projects.
  - Minnesota performs an initial run with a spreadsheet that implements the decision matrix workflow. The results are given to the regional offices who adjust the list based on local knowledge.
  - Virginia is very flexible regarding reprioritization of the six-year plan. The initial list is provided to each District for reprioritization based on engineers' intimate knowledge of local structures.

- ***In what ways is your state utilizing the findings of the Risk Assessment data?***
    - Florida had no response on this issue.
    - Wisconsin uses the data to program its bridges.
    - California uses the data to program its bridges.
    - New York uses the data to program its bridges.
    - Michigan uses the data to program its bridges and stated that all decisions are based upon its bridge strategic plan, as directed by the annual five-year call for projects.
    - Minnesota uses a matrix of conditions to evaluate state bridge rehabilitation, replacement, or preservation needs.
    - Virginia uses the data to program its bridges.

- ***Does your state utilize PONTIS? Does your Risk Assessment include element level data?***
    - Florida indicated that inspections are conducted using both NBI and Pontis.
    - Wisconsin has developed a proprietary element-level coding manual and web-based system in lieu of Pontis. The system is used for workflow, deterioration, and rating score.
    - California uses Pontis and uses element-level data for risk assessment.
    - New York has its own proprietary element-level system.
    - Michigan is just beginning to use Pontis and currently only provides a report each year to the regional bridge engineers. Michigan also uses internal programs that assist in project selection and bridge network management.
    - Virginia stated that Pontis and element-level data have been used since the early 1990s to determine needs.

- ***In what way has your state customized the PONTIS system in regards to deterioration of specific structure types?***
    - Florida has added movable bridges, changed condition-state language, deck (coding for top and bottom) not using soffit as smart flag unless condition is severe, prestressed decks, pile jackets, additional load data, and miscellaneous applets for extracting information.
    - Wisconsin had no response on this issue.
    - California stated that Pontis is able to predict deterioration. It is the only commercially available tool capable of performing that function. However, since Pontis uses a least-cost solution, CALTrans has developed external tools that determine life cycle costs based on data from Pontis.
    - New York does not currently use Pontis to predict the deterioration of specific structure types.
    - Michigan has modified some AASHTO CoRe elements and has developed agency rules.
    - Minnesota has added some smart flags for specific items and also has worked on revising the deterioration curves because it believes that the existing curves do not accurately model observed deterioration within the state.
    - Virginia has extensively modified Pontis through the addition of smart flags, core elements, deterioration curves, and cost models.

- ***Does the DOT currently have or are they working on an Asset Management Program? If so, how long has this program been in place? Please describe or provide documentation discussing the key features of the program.***
    - Florida had no response on this issue.
    - Wisconsin had no response on this issue.
    - California does not have a centralized asset program. Individual risk assessment system results are compiled manually to create the prioritization list.

    - New York does not currently have an asset management program. The state does have a bridge programming worksheet and is currently evaluating Pontis' asset management capabilities.
    - Michigan has had an asset management system for nine years. Michigan has set Department goals for preserving and improving the condition of freeway and non-freeway bridges. The state Transportation Department has developed computer programs to monitor bridge condition in accordance with these goals. The Department has developed a program called Bridge Condition Forecast System (BCFS) that forecasts bridge condition based upon deck area and number of bridges in each NBI condition-state, cost to do replacement, rehab, and PM projects, inflation, budget, transition probabilities (bridge deterioration), and project selection strategy. This is all performed within the five-year call for projects. As part of the process the central office establishes policy, develops strategy, and provides guidance for the seven regions.
    - Minnesota uses a three-part approach to asset management: 1) Program structure replacements. 2) Preventative maintenance (replacement of expansion joints and sealing of decks). 3) Reactive maintenance.
    - Virginia utilizes Pontis for asset management.

- ***What challenges where encountered during implementation of your Asset Management Program?***
    - Florida had no response on this issue.
    - Wisconsin had no response on this issue.
    - California had no response on this issue.
    - New York had no response on this issue.
    - Michigan stated that development of its strategic plan and an ideal "mix of fixes" was easier than implementation. Michigan stated that it was a challenge to show the benefit of preventative maintenance (PM) and to keep focused on bridge preservation needs. Securing FHWA agreement with project selections was also a significant challenge.
    - Minnesota had no response on this issue.
    - Virginia had no response on this issue.

- ***What software tools are used as part of the Asset Management Program? Does your Asset Management Program utilize Geographic Information System data?***
    - Florida had no response on this issue.
    - Wisconsin uses GIS for oversize-overweight routing, emergency management, hydraulics (flood-prone structures), and lane closures, and also uses Google for mapping and reporting.
    - California uses GIS to spatially locate inventoried structures and consolidates maintenance tasks based on the locations of the proposed projects.
    - New York stated that GIS is used to manage permitting, trace routes, and assess bridge needs along the routes.
    - Michigan indicated that it currently uses the following software tools: Pontis, BCFS, Possible Projects, Michigan Bridge Reporting System (MBRS), and TRAMS 9 (Transportation Asset Management System).   TRAMS 9 uses GIS data. TRAMS 9 generates lists and maps of many roadway and bridge features, including features of structurally deficient or functionally obsolete bridges. Information provided includes traffic data and pavement condition data. MBRS is an Internet-based system that generates standard reports on bridges such as poor bridges, scour-critical bridges, and programmed bridges. The system can also perform ad-hoc queries of the bridge database.
    - Minnesota stated that GIS is used to display results from programming decisions. The technology is primarily used to enable non-engineers to visualize the locations of programmed structures.

  - Virginia developed the Roadway Network System using GIS software. It is linked to the Pontis database to locate all bridges within the state's system.

- ***Does your Asset Management Program contain a specific Risk Assessment Module?***
  - Florida had no response on this issue.
  - Wisconsin had no response on this issue.
  - California uses multiple individual modules and combines the results to determine prioritization.
  - New York had no response on this issue.
  - Michigan stated that its asset management program does not currently contain a specific risk assessment module.
  - Minnesota stated that its asset management program does not currently contain a specific risk assessment module.
  - Virginia stated that risk assessment is part of its asset management program but not integral with the software.

- ***Does this program cover the states entire bridge inventory?***
  - Florida had no response on this issue.
  - Wisconsin uses various independent systems to maintain an inventory of 9,000 state- and locally owned structures, several hundred of which are SD bridges at the state level. Wisconsin inventories all structures with span lengths greater than five feet.
  - California's program covers 13,000 state-owned structures.
  - New York's program covers 17,400 state-owned bridges.
  - Michigan's program covers all structures in the state, but to different degrees. Local agency bridges are managed by the bridge owners, but many of the same tools are available to them.
  - Minnesota stated that only 3,500 of the state's 13,000 bridges are covered by the state system.
  - Virginia stated that all of the state's 19,400 bridges are covered by the state system.

Task 3, Recommendations for Risk Management Strategy

Executive Summary

This report provides recommendations to improve the Pennsylvania Department of Transportation's (PennDOT) risk assessment program based on an analysis of relevant research performed in Task 1 and evaluation of the results from a survey of PennDOT Districts and a survey of other state transportation agencies, commissioned in Task 2.

The following recommendations are divided into three action-item categories. The first category, Quick-Strike Items, focuses on enhancements that can be performed without significant research or development. The second category, Medium-Range Goals, encompasses improvements that can be implemented with limited effort. The final category, Long-Range Goals, involves changes that constitute major revisions to PennDOT's existing system and require research and development.

Quick-Strike Items

- Reproduce the existing flowcharts using BMS2 notation.
- Divide the existing worksheets into sections and create multiple worksheets; add a worksheet to enable the user to retrieve all of the data for a single bridge in a compact, concise report (See Figure 3.2.2.2-1).

Medium-Range Goals

- To discern trends among a structure's risk assessment scores and evaluate the effectiveness of risk assessment scoring, create a new table within BMS2 that is to be populated by the risk assessment database, based on the results of each prioritization. This table will facilitate the retrieval of legacy data. The risk assessment database should automatically retrieve data on Transportation Improvement Program (TIP) project bridges from the Multimodal Project Management System (MPMS) database.
- Revise the weighting of risk conditions for the aggregate and structurally deficient risk. The proposed weights require a sensitivity analysis to determine the effect on the system.
- Select the problematic bridge details (e.g., rocker bearings, non-composite adjacent box beams, and precast bridge barriers) that should be identified within the BMS2 framework and used in the state's risk assessment process. The bridges and structures that incorporate problematic details would be assigned an "importance factor."
- Use load capacity and observed scour rating instead of structural condition and waterway adequacy to calculate a bridge's structural deficiency risk score.
- To mitigate potential errors, automate the transfer of data between the risk assessment database and the cost spreadsheet via an Open-Database Connection (ODBC).

Long-Range Goals

- Create a preservation priority list and develop additional coding items to address preservation needs. The preservation score would be calculated for each structure.
- In conjunction with PennDOT's current element-level inspection procedures, implement element-level risk assessment using the Pontis framework.

1.0 Introduction

This report summarizes the effort to identify and recommend strategies and measures to enhance PennDOT's existing risk management system. The strategies outlined represent the culmination of the review and analysis of existing research, performed in Task 1, and the evaluation of risk management survey responses from Districts within PennDOT and from other state transportation agencies that currently have some form of risk assessment program, performed in Task 2.

2.0 Overview of Current System

PennDOT's current risk assessment program is used to establish risk levels for bridge types and structures within the Department's inventory and measures to mitigate risks. The program was developed to use data available within the Department's existing Bridge Management System (BMS). The system relies upon several focus areas within BMS that include physical condition, load capacity, scour, impact damage/overheight vehicles, and fatigue. Risk levels are identified as high, medium, or minor based on the condition ratings established under National Bridge Inventory (NBI) guidelines, which are presented in the following table:

Table 2.1 – Risk Level

Risk Level	Condition Rating
High Risk	4 or less
Medium Risk	5
Minor Risk	6 or greater

Risk levels are further influenced by the Business Plan Network (BPN) classification of the roadway. The BPN consists of four classifications. Two pertain to structures located on the National Highway System (NHS) and two pertain to structures located on non-NHS routes, as shown in Table 2.2.

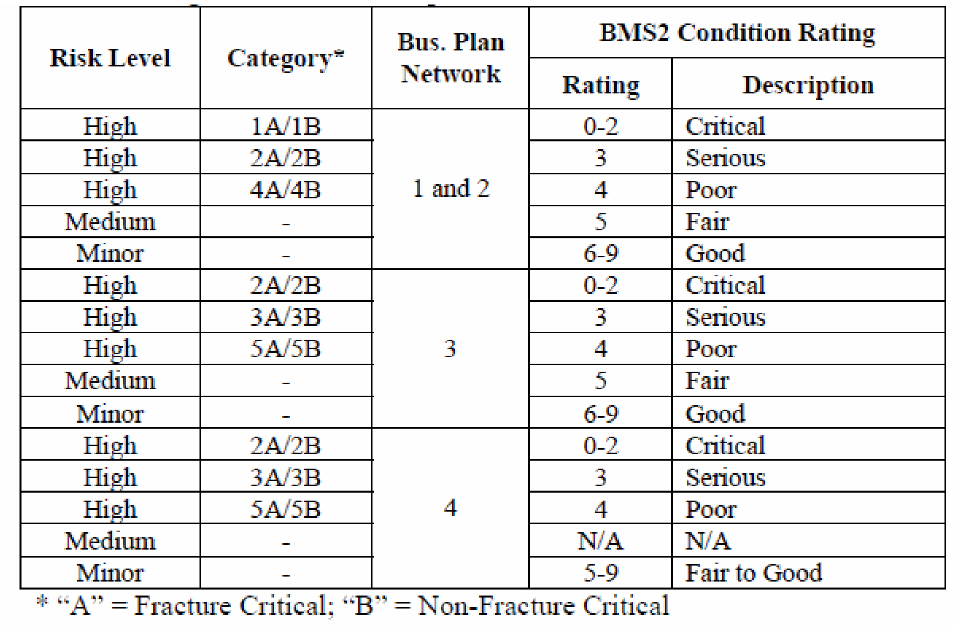
Table 2.2 – Business Plan Network

Roadway Classification	BPN
NHS - Interstate + Ramps	1
Other NHS	2
Non-NHS, ADT ≥ 2000	3
Non-NHS, ADT < 2000	4

NHS = National Highway System
ADT = Average Daily Traffic

The condition ratings, in conjunction with the BPN, are used to determine the risk level and category of each risk factor (please refer to Table 2.3).

Table 2.3 – Example Risk Condition Table For Selection of Risk Level

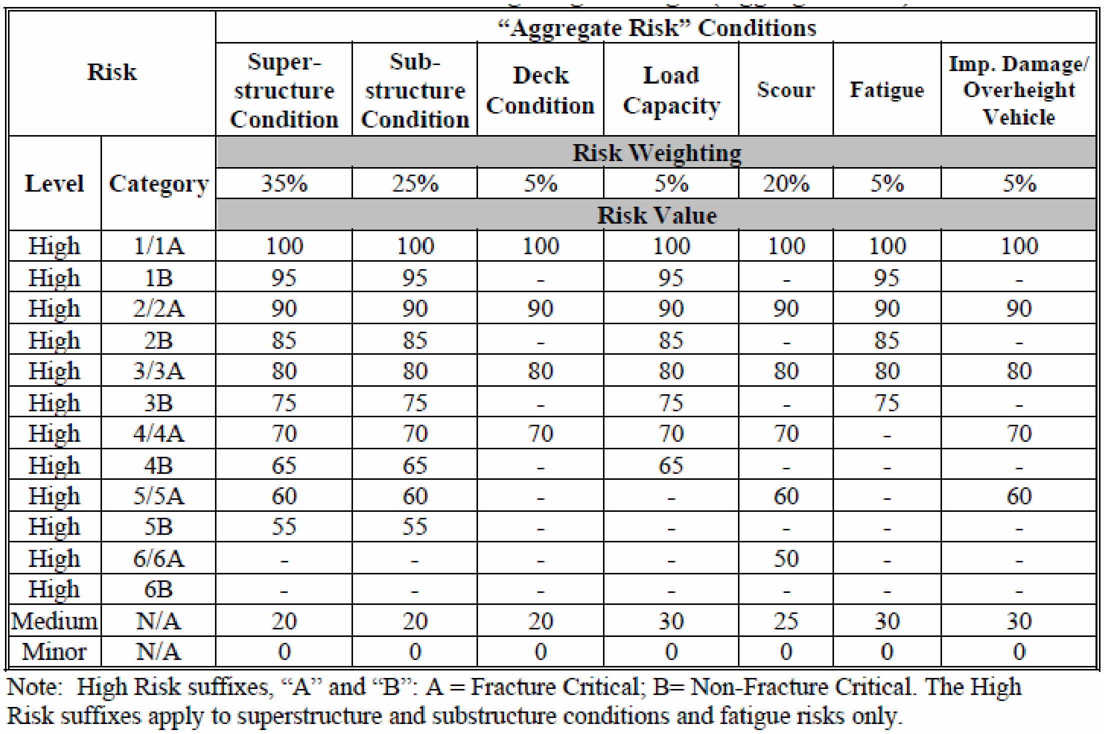


Risk Level	Category*	Bus. Plan Network	BMS2 Condition Rating	
			Rating	Description
High	1A/1B	1 and 2	0-2	Critical
High	2A/2B		3	Serious
High	4A/4B		4	Poor
Medium	-		5	Fair
Minor	-		6-9	Good
High	2A/2B	3	0-2	Critical
High	3A/3B		3	Serious
High	5A/5B		4	Poor
Medium	-		5	Fair
Minor	-		6-9	Good
High	2A/2B	4	0-2	Critical
High	3A/3B		3	Serious
High	5A/5B		4	Poor
Medium	-		N/A	N/A
Minor	-		5-9	Fair to Good

* "A" = Fracture Critical; "B" = Non-Fracture Critical

The risk level and category are then used to determine the numerical risk score, as shown in Table 2.4:

Table 2.4 – Numerical Risk Values and Weighting – Bridges (Aggregate Risk)

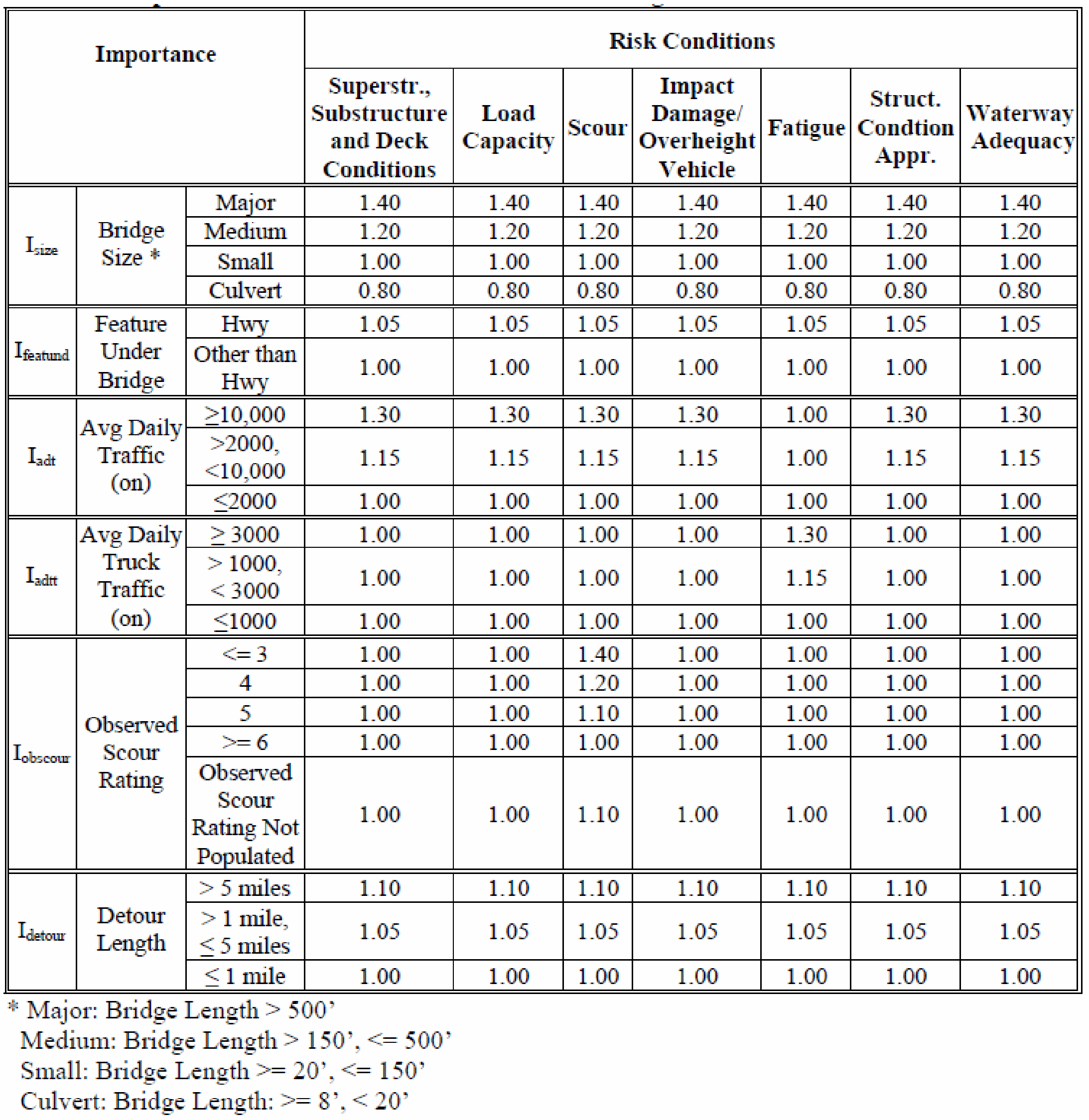


Risk		"Aggregate Risk" Conditions						
		Super-structure Condition	Sub-structure Condition	Deck Condition	Load Capacity	Scour	Fatigue	Imp. Damage/ Overheight Vehicle
Level	Category	Risk Weighting						
		35%	25%	5%	5%	20%	5%	5%
		Risk Value						
High	1/1A	100	100	100	100	100	100	100
High	1B	95	95	-	95	-	95	-
High	2/2A	90	90	90	90	90	90	90
High	2B	85	85	-	85	-	85	-
High	3/3A	80	80	80	80	80	80	80
High	3B	75	75	-	75	-	75	-
High	4/4A	70	70	70	70	70	-	70
High	4B	65	65	-	65	-	-	-
High	5/5A	60	60	-	-	60	-	60
High	5B	55	55	-	-	-	-	-
High	6/6A	-	-	-	-	50	-	-
High	6B	-	-	-	-	-	-	-
Medium	N/A	20	20	20	30	25	30	30
Minor	N/A	0	0	0	0	0	0	0

Note: High Risk suffixes, "A" and "B": A = Fracture Critical; B= Non-Fracture Critical. The High Risk suffixes apply to superstructure and substructure conditions and fatigue risks only.

Importance factors are determined based on specific criteria pertaining to the structure. Items such as size of the bridge, features under the bridge, ADT or ADTT, observed scour, and length of detour are all used to calculate the importance factors. Certain importance factors are limited to a specific risk condition (e.g., ADT and ADTT are specific to the fatigue risk condition; observed scour is specific to the scour risk condition). The importance factors are listed in Table 2.5.

Table 2.5 – Importance Factors for Risk Conditions - Bridges



Importance			**Risk Conditions**						
			Superstr., Substructure and Deck Conditions	**Load Capacity**	**Scour**	**Impact Damage/ Overheight Vehicle**	**Fatigue**	**Struct. Condtion Appr.**	**Waterway Adequacy**
I_{size}	Bridge Size *	Major	1.40	1.40	1.40	1.40	1.40	1.40	1.40
		Medium	1.20	1.20	1.20	1.20	1.20	1.20	1.20
		Small	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Culvert	0.80	0.80	0.80	0.80	0.80	0.80	0.80
$I_{featund}$	Feature Under Bridge	Hwy	1.05	1.05	1.05	1.05	1.05	1.05	1.05
		Other than Hwy	1.00	1.00	1.00	1.00	1.00	1.00	1.00
I_{adt}	Avg Daily Traffic (on)	≥10,000	1.30	1.30	1.30	1.30	1.00	1.30	1.30
		>2000, <10,000	1.15	1.15	1.15	1.15	1.00	1.15	1.15
		≤2000	1.00	1.00	1.00	1.00	1.00	1.00	1.00
I_{adtt}	Avg Daily Truck Traffic (on)	≥ 3000	1.00	1.00	1.00	1.00	1.30	1.00	1.00
		> 1000, < 3000	1.00	1.00	1.00	1.00	1.15	1.00	1.00
		≤1000	1.00	1.00	1.00	1.00	1.00	1.00	1.00
$I_{obscour}$	Observed Scour Rating	<= 3	1.00	1.00	1.40	1.00	1.00	1.00	1.00
		4	1.00	1.00	1.20	1.00	1.00	1.00	1.00
		5	1.00	1.00	1.10	1.00	1.00	1.00	1.00
		>= 6	1.00	1.00	1.00	1.00	1.00	1.00	1.00
		Observed Scour Rating Not Populated	1.00	1.00	1.10	1.00	1.00	1.00	1.00
I_{detour}	Detour Length	> 5 miles	1.10	1.10	1.10	1.10	1.10	1.10	1.10
		> 1 mile, ≤ 5 miles	1.05	1.05	1.05	1.05	1.05	1.05	1.05
		≤ 1 mile	1.00	1.00	1.00	1.00	1.00	1.00	1.00

* Major: Bridge Length > 500'
Medium: Bridge Length > 150', <= 500'
Small: Bridge Length >= 20', <= 150'
Culvert: Bridge Length: >= 8', < 20'

Risk is processed and evaluated using two separate methods. The first method involves calculating an aggregate risk score that includes all focus areas. The second method involves calculating a structurally deficient risk score that reflects only risk components associated with structural deficiency. The risk level and category are used to determine the numerical risk values for each method. The summation of the weighted risk values times the importance factors represents the risk assessment score for the structure.

The risk assessment scores are calculated within the risk database. Structured Query Language (SQL) is used to directly access pertinent values from BMS and Visual Basic macros to calculate the risk scores.

The risk scores are then exported to a Microsoft Excel spreadsheet that sorts the bridges based on score and calculates the costs associated with replacement. The spreadsheet also allows for District manipulation of the priority list based on intimate knowledge of local projects. After the District has completed its prioritization, the secondary priority list is stored in conjunction with the initial list for future reference.

3.0 Recommendations

A two-pronged approach was used to identify and research improvements to the existing system.

- **Task 1 – Literature Search.** Task 1 consisted of conducting a literature search to garner information on global trends and developments in risk assessment processes. The information aided in the development of relevant questions for Task 2.
- **Task 2 – Research Survey.** Task 2 involved surveying the individual PennDOT Districts and various state transportation agencies throughout the nation. The PennDOT District surveys solicited feedback on specific aspects of the Department's existing system. In contrast, the state surveys gathered details of state risk assessment systems nationwide to identify select program elements for potential inclusion in Pennsylvania's existing system.

Information gathered through the surveys was processed and refined into recommendations. The recommendations have been divided into three categories: process, software, and element-level implementation of risk assessment.

3.1 Process

The process recommendations are grouped into a single category that includes proposed changes and improvements to the methodology of PennDOT's current risk assessment system.

3.1.1 Proposed Risk Factors

The comprehensiveness and ultimate value of a risk assessment program lies in its ability to evaluate all relevant risk factors affecting a structure. During the course of this project, several risk factors were identified for potential inclusion in the existing risk assessment program. These factors are discussed in the following subsections.

3.1.1.1 Utilities Supported by Structures

To assess the risk potential of structures that support utilities, it would be necessary to collect and prioritize additional data. Currently, no relevant information exists within the BMS framework to evaluate the characteristics of utilities carried by structures; therefore, factors such as pipe diameter, material transported, and population affected would be difficult to quantify.

Based on the research from this report, it is recommended that utilities be excluded from the initial prioritization within the risk assessment program. If utilities are to be considered in risk assessment, it would be at the District level, based on engineers' knowledge of local structures, and would be accounted for during the reprioritization. This methodology parallels that of several state agencies.

3.1.1.2 Proposed Data Collection for Problematic Details

As a result of experience, several states indicated that specific design details pose higher levels of risk than others. Pennsylvania has encountered several problematic bridge details (e.g., rocker bearings, non-composite adjacent box beams, precast bridge barriers, and through-truss end posts) that should be identified within the BMS2 framework and used in the state's risk assessment process. These items should be assigned an importance factor solely on the basis of their presence. However, additional information for through-truss end posts will be required to establish applicability as a problematic detail importance factor. Items such as the alignment of the approach roadway and the presence of protective measures also must be considered. The importance factor would only be applied to the risk condition pertaining to the applicable problematic detail (e.g., rocker bearings to superstructure, precast barriers to deck).

3.1.1.3 *Seismic Considerations*

Seismic risk assessment procedures vary greatly across the country and reflect the seismic zone in which each state is located. For example, California has a very comprehensive program that incorporates approximately 30 separate categories for evaluation. In contrast, Michigan, Wisconsin, and Virginia have no seismic risk assessment procedures because they are located within zones of low seismic risk.

Seismic risk in Pennsylvania is typically a factor in the design of new bridges within the eastern portion of the state. Specific details, such as rocker bearings, represent a potential “weak link” in regions. Consideration of rocker bearings as part of the risk assessment has been outlined in Section 3.1.1.2. Research conducted for PennDOT by The Pennsylvania State University and Drexel University revealed that if normal reinforcement detailing were performed for older bridges, these bridges would meet the anticipated seismic demand. Considering this research, no further evaluation of seismic factors should be included in structural risk assessment within Pennsylvania.

3.1.1.4 *Service-Sensitive Facilities*

Certain structures are vital to the conveyance of emergency equipment and personnel. None of the states surveyed considered service-sensitive facilities in initial risk assessment prioritization. However, New York, Michigan, and Virginia allow these factors to be considered at the District or regional level during the review and re-prioritization process. Other states, such as California, stated that generally service-sensitive facilities are adequately accounted for by ADT or ADTT. Research and survey results indicate that there is no method for quantifying the importance of a structure’s proximity to a service-sensitive facility. Furthermore, the impact is only relevant during the implementation of maintenance and rehabilitation work, when traffic control procedures are required.

Pennsylvania already accounts for ADT and ADTT through the Business Plan Network (BPN) number, and the Districts currently have control over the final prioritization. Consequently, the impact on service-sensitive facilities can be regulated based on District Engineers' intimate knowledge of local structures and environs. Hence, it is not recommended that any additional factors or categories for service-sensitive facilities be implemented at this time.

3.1.2 *Proposed Adjustments to Weights of Risk Factors*

PennDOT currently assigns weighting factors to individual components of its risk assessment program to vary emphasis on risk factors. The weighted risk factors are used to calculate the cumulative risk score, which aids in project prioritization. The District survey results include requests for specific modifications to the weights to more precisely quantify the overall risk to a structure. The proposed weights must be verified through a sensitivity analysis to determine their effect on the system. The following two subsections propose revisions to the weighting percentages.

3.1.2.1 *Aggregate Risk*

Aggregate risk is a global assessment of all relevant focus areas. One function of the District surveys was to solicit feedback, based on experience, with regard to the individual weights currently applied within the existing system. District survey results were generally consistent with respect to weighting adjustments. The recommended revised weights are presented below.

	Current	Proposed
Superstructure Condition	35%	30%
Substructure Condition	25%	20%
Deck Condition	5%	10%
Load Capacity	5%	10%
Scour	20%	15%
Fatigue	5%	5%
Impact Damage / Over Height Vehicle	5%	10%

3.1.2.2 *Structurally Deficient Risk*

Structurally deficient (SD) risk is a specific assessment of data associated only with structurally deficient components. As noted previously, one function of the District survey was to solicit feedback, based on experience, with regard to the individual weights currently applied within the existing system. District survey results varied with respect to weighting adjustments for structurally deficient components only. Therefore, the results were analyzed to determine District preferences based on general consensus. The recommended revised weights are presented below.

	Current	Proposed
Superstructure Condition	40%	35%
Substructure Condition	30%	25%
Deck Condition	20%	25%
Structural Condition Appraisal	0%	0%
Waterway Adequacy	0%	0%
Load Capacity	5%	5%
Scour	5%	10%

3.1.3 *Proposed Adjustments to Risk Conditions*

3.1.3.1 *Structurally Deficient Appraisal Risk*

The structural condition appraisal rating is an overall rating based on the condition ratings for superstructure, substructure, and load capacity. Inclusion of this item is redundant because the superstructure and substructure are already accounted for, as individual risk items, in the total risk score. Risks are better identified using load capacity to calculate the structurally deficient risk score. It is recommended to replace structural condition appraisal rating with load capacity to derive the structurally deficient risk score.

3.1.3.2 *Waterway Adequacy Appraisal Risk*

The waterway adequacy appraisal rating is an assessment of the capability of a structure to handle flood flows. It accounts for overtopping frequency and the traffic delays associated with overtopping. This factor does not adequately address the susceptibility to scour. Threats are better identified using the observed scour rating to calculate the structurally deficient risk score. It is recommended to replace the waterway adequacy appraisal rating with the observed scour rating to derive the structurally deficient risk score.

3.1.4 *Low-ADT Routes with Critically Deficient Structures*

The Districts indicated that too much focus on average daily traffic (ADT) may de-emphasize lower ADT routes where most SD bridges are located. The current relationship between BPN and risk level category tends to diminish the importance of deficiencies with respect to low-ADT routes.

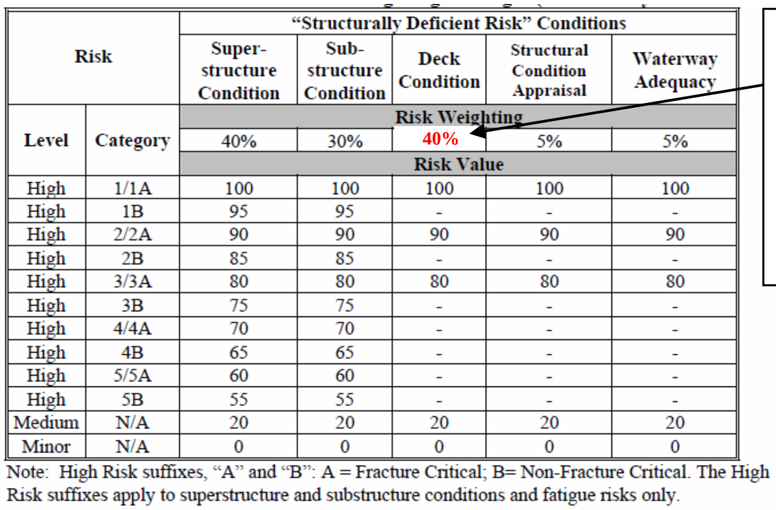
It is recommended that a percentage increase be factored into the final risk score for structures with a BPN of three or four (i.e., non-NHS routes) and with two or more critical deficiency ratings (0-2 for BMS2 Condition Rating) for any of the aggregate risk factors. A sensitivity analysis is required to determine an accurate percentage of increase to ensure that structures with higher BPN numbers are not over- or undervalued.

3.1.5 *Critical Rating Risk Surcharge*

In the current system, greater emphasis, as reflected by increased risk weighting values, is placed on the superstructure than the substructure and deck because experience shows that superstructure condition typically determines rehabilitation and replacement needs. However, when a substructure or deck is in critical condition (0-2 for BMS2 Condition Rating), the current system assigns a lesser weight, which de-emphasizes the importance of the numerical risk score.

To mitigate the de-emphasis of critical conditions, it is recommended that when a critical rating exists, the system should increase the risk condition weighting to equal that of the superstructure. This default increase would only be applied to substructures and/or decks when a critical rating is detected and would apply to all BPN categories. Table 2.6 presents an example of a default increase for a critical deck condition. This methodology applies to both the aggregate and structurally deficient risk scores.

Table 2.6: Numerical Risk Values and Weighting – Bridges (Structurally Deficient Risk)



Risk		"Structurally Deficient Risk" Conditions				
		Super-structure Condition	Sub-structure Condition	Deck Condition	Structural Condition Appraisal	Waterway Adequacy
		Risk Weighting				
Level	Category	40%	30%	40%	5%	5%
		Risk Value				
High	1/1A	100	100	100	100	100
High	1B	95	95	-	-	-
High	2/2A	90	90	90	90	90
High	2B	85	85	-	-	-
High	3/3A	80	80	80	80	80
High	3B	75	75	-	-	-
High	4/4A	70	70	-	-	-
High	4B	65	65	-	-	-
High	5/5A	60	60	-	-	-
High	5B	55	55	-	-	-
Medium	N/A	20	20	20	20	20
Minor	N/A	0	0	0	0	0

Note: High Risk suffixes, "A" and "B": A = Fracture Critical; B= Non-Fracture Critical. The High Risk suffixes apply to superstructure and substructure conditions and fatigue risks only.

If a critical rating (0-2 for BMS2 Condition Rating) was found for a deck, the risk weighting would be increased from 20% to 40% due to the critical condition of the component.

3.1.6 *Exclusion of Transportation Improvement Program Projects from Priority List*

The Transportation Improvement Program (TIP) projects are currently included in the priority lists developed during the risk assessment process. TIP bridges are currently listed in the Multimodal Project Management System (MPMS) database and may be manually removed from the priority list.

The risk assessment database should be modified to automatically retrieve the list of TIP bridges from the MPMS database. This modification would facilitate the exclusion of TIP bridges from the priority list and also allow for the creation of a secondary list consisting of only TIP bridges. The list of TIP bridges could be further refined to identify if a project is in the first, second, or third four-year period of planning.

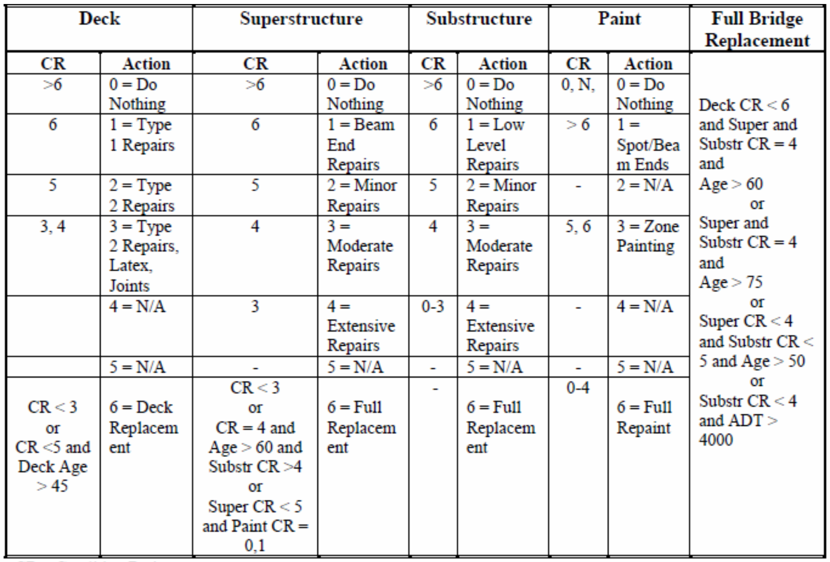
3.1.7 *Preservation Activity Identification and Prioritization*

The Districts identified a need within the state for specifying preservation activities within the existing risk assessment program. Currently, preservation items are assigned a risk level within the risk assessment database based on correlated data because BMS2 does not currently identify the condition of the items. The risk levels are provided as information only and are not used further in the system.

Implementation of element-level inspection items for bearings, expansion joints, and bearing areas would efficiently and effectively assess preservation items. Pontis does not currently address bearing areas and would require modification prior to implementation to include this item.

To facilitate the creation of a preservation priority list, it is recommended that preservation activities be assigned individual weights and risk values. Preservation items to be considered include the presence of deck expansion joints, bearing area deterioration, deck condition, bearing condition, paint condition, and scour. Each preservation item score would be calculated and summed for each structure. The risk assessment spreadsheet could then be used to sort the structures based on preservation scores to create a priority list. The spreadsheet would exclude structures from the list that already require partial or total replacement. Criteria for the replacement of components are outlined in Table 3.1: Scope of Work for Bridges in this risk assessment report.

Table 3.1 – Scopes of Work for Bridge Preservation



Deck		Superstructure		Substructure		Paint		Full Bridge Replacement
CR	Action	CR	Action	CR	Action	CR	Action	
>6	0 = Do Nothing	>6	0 = Do Nothing	>6	0 = Do Nothing	0, N,	0 = Do Nothing	Deck CR < 6 and Super and Substr CR = 4 and Age > 60 or Super and Substr CR = 4 and Age > 75 or Super CR < 4 and Substr CR < 5 and Age > 50 or Substr CR < 4 and ADT > 4000
6	1 = Type 1 Repairs	6	1 = Beam End Repairs	6	1 = Low Level Repairs	> 6	1 = Spot/Beam Ends	
5	2 = Type 2 Repairs	5	2 = Minor Repairs	5	2 = Minor Repairs	-	2 = N/A	
3, 4	3 = Type 2 Repairs, Latex, Joints	4	3 = Moderate Repairs	4	3 = Moderate Repairs	5, 6	3 = Zone Painting	
	4 = N/A	3	4 = Extensive Repairs	0-3	4 = Extensive Repairs	-	4 = N/A	
	5 = N/A	-	5 = N/A	-	5 = N/A	-	5 = N/A	
CR < 3 or CR <5 and Deck Age > 45	6 = Deck Replacement	CR < 3 or CR = 4 and Age > 60 and Substr CR >4 or Super CR < 5 and Paint CR = 0,1	6 = Full Replacement	-	6 = Full Replacement	0-4	6 = Full Repaint	

CR – Condition Rating

3.1.8 *Documentation Improvements*

The risk assessment flowcharts currently use old BMS nomenclature. Reproduction of existing flowcharts using BMS2 notation is recommended.

3.2 *Software*

The software recommendations are grouped into a single category that includes proposed changes and improvements to the implemented software used by the current risk assessment system.

3.2.1 *Risk Assessment Database Software*

3.2.1.1 *Legacy Prioritization Data*

To discern trends in and assess the effectiveness of the risk assessment scores for a structure, Districts have requested the ability to retrieve legacy data for each iteration of the prioritization. Therefore, it is recommended that a new table be created within BMS2 that would be populated by the risk assessment database based on the results of each prioritization. This table would facilitate the retrieval of legacy data.

3.2.1.2 *Independent District Prioritization*

Districts have indicated a need to unofficially process the risk assessment database outside of the official two-year cycle. This capability would allow the Districts to refine their prioritization based on the most current inspection data. Therefore, it is recommended that a version of the risk assessment database be created that would facilitate the retrieval of District-specific structure data from BMS2, through SQL commands, for processing. The results of these unofficial risk assessment runs would be available to the Districts and also to central office.

3.2.2 *Risk Assessment Cost Spreadsheet*

Currently, the data from the risk assessment database is hard input into the cost valuation spreadsheet. This step introduces the potential for errors in data transfer and may result in erroneous risk assessment scores. To mitigate the potential for error, it is recommended to automate the transfer of data between the risk assessment database and the cost spreadsheet using an Open-Database Connection (ODBC).

3.2.2.1 *Divide Spreadsheet into Sections across Tabs*

The existing spreadsheet is essentially a large flat file of data. Upon extensive review of the sorting process, it is recommended that the spreadsheet be divided into sections; each section would constitute a new worksheet. The sections would consist of the following:

- **Input.** This sheet would include all structure identification information and input values relevant to calculating the risk assessment score and costs.
- **Risk Assessment Score.** This sheet would include structure identification information and relevant data from the input sheet, as well as all relevant intermediate information pertaining to the risk assessment score calculation.
- **Cost Sheet.** This sheet would include structure identification information and relevant data from the input sheet, as well as all relevant intermediate information pertaining to the cost calculation.

The revision described above would provide a more focused view of the values across multiple worksheets.

3.2.2.2 *Create Individual Bridge View Tab*

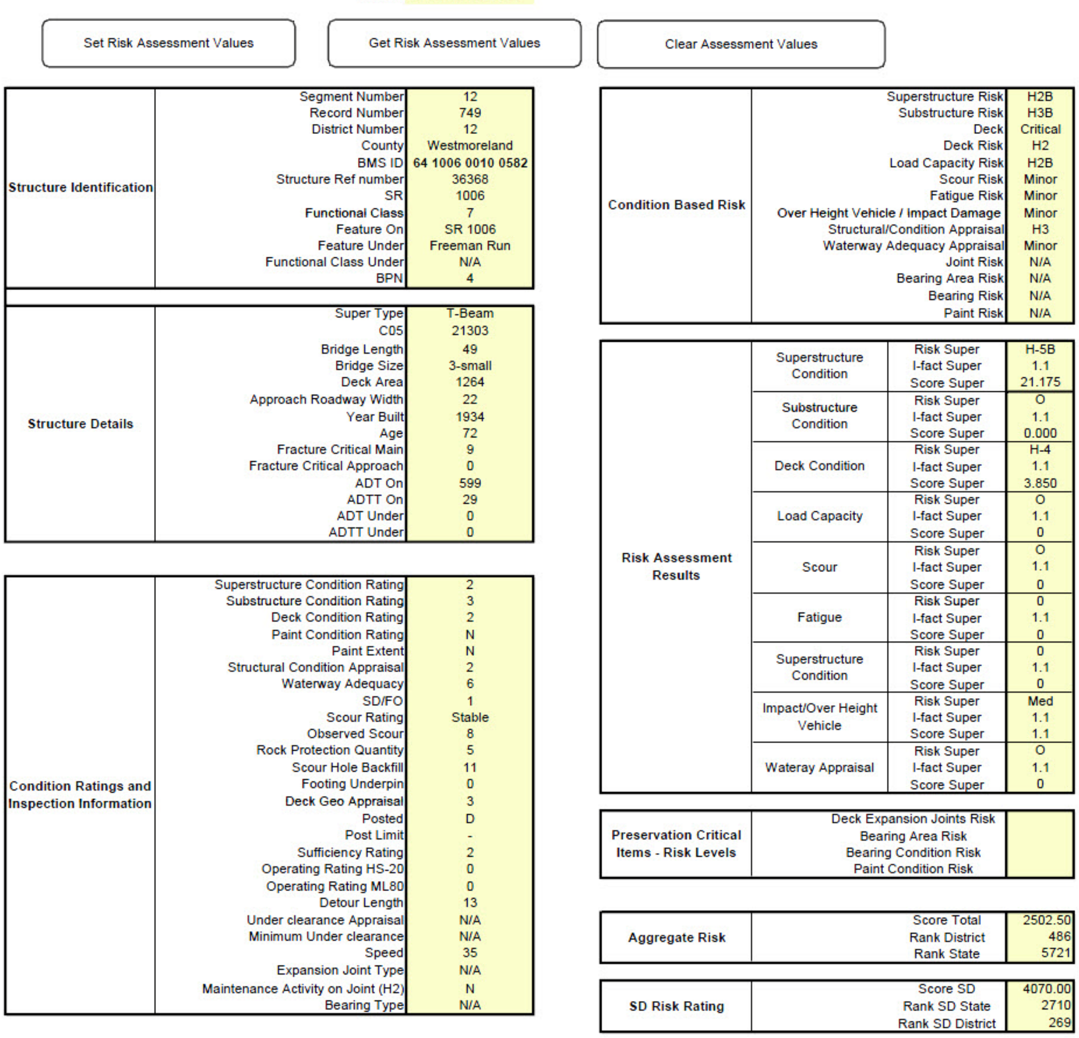
The current spreadsheet only allows users to view bridge information in a tabular format that is 185 columns in length. A new worksheet should be added to the program that would allow the user to retrieve all of the data for a single bridge in a compact, concise report. Visual Basic for Applications macros could be used that would allow the user to perform the following functions:

- Retrieve all data for a bridge based on the BRKEY.
- Edit validated user input in the column view (no calculated data would be affected).
- Save changed data in the column view back to the original tabular location.

This revision would simplify the review and manipulation of all data for a specific bridge. Figure 3.2.2.2-1 shows a potential mock-up of an option for the new Individual Bridge View. The mock-up is just a proof-of-concept example. The final sheet could be tailored to match the Internet forms (I-forms) currently used by the Department.

Figure 3.2.2.2-1
Individual Bridge View Tab Example

The user would enter the BMS ID number at the top of the sheet and then hit a button to extract the data from the main sheet. The user could then edit input and transfer the modified data back to the main sheet.



BMS ID 64 1006 0010 0582

Structure Identification	Segment Number	12
	Record Number	749
	District Number	12
	County	Westmoreland
	BMS ID	**64 1006 0010 0582**
	Structure Ref number	36368
	SR	1006
	Functional Class	7
	Feature On	SR 1006
	Feature Under	Freeman Run
	Functional Class Under	N/A
	BPN	4

Structure Details	Super Type	T-Beam
	C05	21303
	Bridge Length	49
	Bridge Size	3-small
	Deck Area	1264
	Approach Roadway Width	22
	Year Built	1934
	Age	72
	Fracture Critical Main	9
	Fracture Critical Approach	0
	ADT On	599
	ADTT On	29
	ADT Under	0
	ADTT Under	0

Condition Ratings and Inspection Information	Superstructure Condition Rating	2
	Substructure Condition Rating	3
	Deck Condition Rating	2
	Paint Condition Rating	N
	Paint Extent	N
	Structural Condition Appraisal	2
	Waterway Adequacy	6
	SD/FO	1
	Scour Rating	Stable
	Observed Scour	8
	Rock Protection Quantity	5
	Scour Hole Backfill	11
	Footing Underpin	0
	Deck Geo Appraisal	3
	Posted	D
	Post Limit	-
	Sufficiency Rating	2
	Operating Rating HS-20	0
	Operating Rating ML80	0
	Detour Length	13
	Under clearance Appraisal	N/A
	Minimum Under clearance	N/A
	Speed	35
	Expansion Joint Type	N/A
	Maintenance Activity on Joint (H2)	N
	Bearing Type	N/A

Condition Based Risk	Superstructure Risk	H2B
	Substructure Risk	H3B
	Deck	Critical
	Deck Risk	H2
	Load Capacity Risk	H2B
	Scour Risk	Minor
	Fatigue Risk	Minor
	Over Height Vehicle / Impact Damage	Minor
	Structural/Condition Appraisal	H3
	Waterway Adequacy Appraisal	Minor
	Joint Risk	N/A
	Bearing Area Risk	N/A
	Bearing Risk	N/A
	Paint Risk	N/A

Risk Assessment Results	Superstructure Condition	Risk Super	H-5B
		I-fact Super	1.1
		Score Super	21.175
	Substructure Condition	Risk Super	O
		I-fact Super	1.1
		Score Super	0.000
	Deck Condition	Risk Super	H-4
		I-fact Super	1.1
		Score Super	3.850
	Load Capacity	Risk Super	O
		I-fact Super	1.1
		Score Super	0
	Scour	Risk Super	O
		I-fact Super	1.1
		Score Super	0
	Fatigue	Risk Super	0
		I-fact Super	1.1
		Score Super	0
	Superstructure Condition	Risk Super	0
		I-fact Super	1.1
		Score Super	0
	Impact/Over Height Vehicle	Risk Super	Med
		I-fact Super	1.1
		Score Super	1.1
	Wateray Appraisal	Risk Super	O
		I-fact Super	1.1
		Score Super	0

Preservation Critical Items - Risk Levels	Deck Expansion Joints Risk	
	Bearing Area Risk	
	Bearing Condition Risk	
	Paint Condition Risk	

Aggregate Risk	Score Total	2502.50
	Rank District	486
	Rank State	5721

SD Risk Rating	Score SD	4070.00
	Rank SD State	2710
	Rank SD District	269

3.3 *Element Level Implementation of Risk Assessment*

3.3.1 *Long-Term Element-Level Risk*

As PennDOT expands its coverage of element-level inspections, the opportunity will arise to develop a more refined risk analysis. Traditional bridge condition ratings on the 0-9 scale combine considerations of type, severity, and extent of deterioration, which lowers their correlation with risk. The type of deterioration, such as cracking versus spalling, can be very significant in the assessment. Severity of deterioration, such as section loss versus surface rust, is also significant. The extent of deterioration, though important, is a less significant indicator of risk than the other two factors.

Inspections that follow the *AASHTO Guide for Commonly Recognized (CoRe) Structural Elements* (AASHTO CoRe Element Guide) clearly differentiate among type, severity, and extent of deterioration. In particular, "smart flags" in the AASHTO CoRe Element Guide are used to record the incidence of cracking, section loss, pack rust, settlement, and scour, which are highly associated with risk. In addition, the worst-level criterion of most element condition-states is used to identify section loss or strength loss due to ordinary corrosion or material deterioration. This condition of advanced deterioration is associated with elevated risk, while less severe condition-states are not.

While the current version of the AASHTO CoRe Element Guide is very helpful in the assessment of risk, future versions will help even more. Revisions now under development are likely to provide finer resolution of the deterioration of steel superstructure elements, separate from consideration of the coating system. The level of detail for the assessment of deck condition is especially likely to increase, providing data useful for the assessment of risk for deck pop-outs and major spalls that, if unaddressed, could expose road users to hazardous conditions.

The first two subsections below provide useful background information, while the remaining subsections provide recommendations.

3.3.1.1 *Element Risk in Context*

Element-level risk must be considered in the full context of the performance measures that are useful for bridge management. Element-level risk quantifies the possibility of sudden structural damage that could result in loss of function or harm to persons or property.

When highly deteriorated conditions are evident, agencies will typically apply operational measures, such as limiting traffic, to avoid harm to people or property. This response shifts the problem to one of mobility, but does not diminish the seriousness of the underlying condition.

Similarly, risk is not the only driver of maintenance tasks for bridge elements. In general, corrective action for corrosion, spalling, and paint damage is much less expensive when the element is in good condition, before risk from deterioration becomes a factor.

Even if a substantial percentage of the inventory is in a condition of non-zero risk, it is considered best practice to take a multiyear approach to mitigation. This may involve planning according to the four-year term of elected officials or the ten-year term typical of capital programs. Under either scenario, the goal is to maximize the condition of assets or minimize risk for a given level of funding. The optimal approach involves reserving a portion of the funding to maintain structures that are in relatively good condition, thus keeping a large number of structures out of the risk category with a relatively small amount of money. One of the primary purposes of a bridge management system is to quantify how much money should be dedicated to bridge repair and rehabilitation and to identify the best opportunities for strategic preventive maintenance. A worst-first prioritization regimen that focuses only on the highest-risk structures will require far more money over the long term to demonstrate progress. This fact is evidenced by the unrelenting deterioration of bridges in the inventory in general, under traffic and environmental conditions. Each bridge replaced because of structurally deficient or risk is likely to be offset by two structures newly identified as deficient, unless the pattern of constant deterioration is interrupted by strategic preventative action.

3.3.1.2 *Risk Management Framework*

For element-level conditions, the collection of condition-states and smart-flag data, according to the AASHTO CoRe Element Guide, constitutes the risk assessment. As in other areas of risk, quantification is facilitated by dividing the assessment into three components:

- Likelihood of an extreme event
- Consequences of an extreme event to the structure
- Impact of structural damage to the facility’s mission and to life and property

Table 1 lists the element condition-states that are related to risk in the AASHTO CoRe Element Guide. This table shows how the identification of risk factors in the CoRe elements is related to the three components of risk.

Table 3.3.2.1 - Risk Implications of Element Condition-States

Observed condition associated with risk	Likelihood of extreme event	Consequences to structure	Impact on mission, life, and property
Concrete decks – Currently, there is no indication of risk, but this is likely to change in the next revision of the *AASHTO CoRe Element Guide*	Passage of a heavy truck or onset of a freeze-thaw cycle that causes fracture of a weakened section of deck.	A portion of the deck disintegrates into a pothole or punch-through.	The damaged portion of deck is dangerous or unusable, causing collisions, property damage, and/or congestion. The safety of motorists on roadways under the structure may be jeopardized by falling concrete.
Timber decks, superstructure, and substructure elements, condition-state 4 – "Deterioration is advanced. Decay, insect infestation, splits, cracks, or crushing has produced loss of strength or deflection that affects the serviceability of the bridge."	Passage of a heavy truck may cause sudden fracture.	A primary structural element loses its load-bearing capacity.	A vehicle may collide with a damaged portion of the structure or with another vehicle, causing damage or injury.
Steel decks, condition-state 5 – "Corrosion is advanced. Numerous connectors have failed. Section loss and/or connectivity is sufficient to warrant analysis to ascertain the impact on the ultimate strength and/or serviceability of either the element or the bridge."	Passage of a heavy truck may cause sudden fracture.	A portion of the deck grid breaks away.	A vehicle may collide with a damaged portion of the structure or with another vehicle, causing damage or injury.
Unpainted steel superstructure and substructure elements, condition-state 4 – "Section loss or other deterioration is sufficient to warrant analysis for strength and/or serviceability of either the element or the bridge."	Sudden fracture due to loading cycles or plastic deformation of a weakened section.	Loss of load-bearing capacity and possible misalignment of part of the road surface.	Loads can no longer be carried without causing further damage. Deformation may cause vehicular collisions, resulting in damage or injury.
Painted steel superstructure and substructure elements, condition-state 5 – "Corrosion has caused section loss and is sufficient to warrant structural analysis to ascertain the impact on the ultimate strength and/or serviceability of either the element or the bridge."	Sudden fracture due to loading cycles, or plastic deformation of a weakened section.	Loss of load-bearing capacity and possible misalignment of part of the road surface.	Loads can no longer be carried without causing further damage. Deformation may cause vehicular collisions, resulting in damage or injury.
Concrete superstructure and substructure elements, condition-state 4 – "Delaminations, spalls, and corrosion of non-prestressed	Routine heavy water flow, seismic events, or the passage of heavy trucks could trigger	Movement may cause loss of bearing support, movement of bearings beyond design limits, or	Movement of the road surface could render the bridge hazardous to vehicles or

Observed condition associated with risk	Likelihood of extreme event	Consequences to structure	Impact on mission, life, and property
reinforcement are prevalent. There may also be exposure and deterioration of the prestress system (manifested by loss of bond, broken strands or wire, failed anchorages, etc.). There is sufficient concern to warrant an analysis to ascertain the impact on the strength and/or serviceability of either the element or the bridge.”	movement in the weakened superstructure or substructure.	displacement of the road surface.	impassable.
Elastomeric bearings, condition-state 3 – “Deterioration is advanced. Shear deformations may be excessive. Top and bottom surfaces may no longer be parallel. Loss of bearing may be imminent.”	Substructure settlement or normal movement due to loading or temperature changes could cause a loss of bearing support.	Loss of support could cause displacement of the road surface.	Movement of the road surface could render the bridge hazardous to vehicles or impassable.
Movable bearings, condition-state 3 – “There is advanced corrosion with section loss. There may be loss of section of the supporting member sufficient to warrant supplemental supports or load restrictions. Bearing alignment may be beyond tolerable limits. Shear keys may have failed. The lubrication system, if any, may have failed.”	Similar to previous	Similar to previous	Similar to previous
Enclosed or concealed bearings, condition-state 3 – “Vertical and/or horizontal offsets are significant, indicating bearing failures. There may be significant vertical movement under traffic. Cracking of the support members may be significant. There may be significant reduction of bearing due to superstructure shortening.”	Similar to previous	Similar to previous	Similar to previous
Fixed bearings, condition-state 3 – “There is advanced corrosion with section loss. There may be loss of section of the supporting member sufficient to warrant supplemental supports or load restrictions. Shear keys may have failed.”	Similar to previous	Similar to previous	Similar to previous
Pot bearings, condition-state 3 – “Corrosion is advanced. Bearing alignment and load-carrying capacity may be beyond limits. Shear keys and lubrication system, if any, may have failed.	Similar to previous	Similar to previous	Similar to previous

Observed condition associated with risk	Likelihood of extreme event	Consequences to structure	Impact on mission, life, and property
Elastomer may be actively extruding from the device.”			
Disk bearings, condition-state 3 – “Corrosion is advanced. Bearing alignment and load-carrying capacity may be beyond limits. Shear keys and the lubrication system, if any, may have failed.”	Similar to previous	Similar to previous	Similar to previous
Approach slabs, condition-state 4 – “The slab is broken or rocks under traffic loads. Settlement is excessive and cannot be corrected without increasing the size of the slab.”	Movement or collapse of the road surface under passage of a heavy truck.	Uneven or hazardous surface.	The damaged portion of the surface is dangerous or unusable, causing collisions, property damage, and/or congestion.
Steel fatigue smart flag, condition-state 3 – “Fatigue damage exists that warrants analysis of the element to ascertain the serviceability of the element or the bridge.”	Normal loading cycles or passage of a heavy truck could cause sudden fracture.	Loss of load-bearing capacity and possible catastrophic or plastic movement under additional loading.	Movement of the road surface could render the bridge hazardous to vehicles or impassable. On fracture-critical bridges, potential severe property damage, injury, and/or loss of life.
Pack rust smart flag, condition-state 4 – “Rusting between plates has caused serious distress to the connection, which warrants analysis of the bridge to ascertain the impact on the serviceability of the bridge. Some rivets or other connectors may have popped or are no longer effective.”	Normal loading cycles or passage of a heavy truck could cause sudden fracture of connectors.	Loss of load-bearing capacity, or at worst, a chain reaction of connector failures that causes complete loss of support and collapse of the structure.	Potential severe property damage, injury, and/or loss of life.
Settlement smart flag, condition-state 3 – “Settlement or rotation of the bridge supporting elements is significant enough to warrant analysis of the bridge.”	Storm event, minor seismicity, or underground movement could cause displacement of the substructure.	Superstructure and deck components could be displaced. Bearings could lose support.	Movement of the road surface could render the bridge hazardous to vehicles or impassable.
Scour smart flag, condition-state 3 – “Scour is significant enough to warrant analysis of the structure.”	Storm event, minor seismicity, or underground movement could cause displacement of the substructure.	Superstructure and deck components could be displaced. Bearings could lose support.	Movement of the road surface could render the bridge hazardous to vehicles or impassable.
Traffic impact smart flag, condition-state 3 – “Impact has occurred and the strength of the member is impaired. Analysis is warranted to ascertain the serviceability of the bridge.”	Sudden fracture due to loading cycles or plastic deformation of weakened section.	Loss of load-bearing capacity and possible misalignment of part of the road surface. Possible shedding of structure material	Loads can no longer be carried without causing further damage. Deformation may cause vehicular collisions, resulting in damage or

Observed condition associated with risk	Likelihood of extreme event	Consequences to structure	Impact on mission, life, and property
		onto a roadway below.	injury.
Section loss smart flag, condition-state 4 – “Section loss has affected the load-carrying capacity or serviceability of the bridge.”	Sudden fracture due to loading cycles or plastic deformation of weakened section.	Loss of load-bearing capacity and possible misalignment of part of the road surface.	Loads can no longer be carried without causing further damage. Deformation may cause vehicular collisions, resulting in damage or injury.

A risk management framework does not have to quantify all three components of risk separately for each vulnerable element. The state of the practice is not yet sufficiently advanced. However, the risk management strategy should recognize and respond to all three. For example:

- When deteriorated element conditions are observed, operational measures may be applied to minimize the likelihood of a triggering event, usually the passage of a heavy truck. Thus, weight limits may be enforced. Imposing weight limits has direct cost impacts – to agency imposing and to road users, who are inconvenienced by the loss of mobility. Both of these costs are readily quantifiable using available tools.
- Remedial measures, such as strengthening, shoring, and the addition of redundant members, may protect a structure from damage in case of a triggering event. These measures typically do not provide complete protection. Moreover, they must be funded, and they may exacerbate the negative public reaction to aging transportation infrastructure in the community. Slope protection to mitigate scour may limit structure damage in the event of a major storm.
- Operational measures, such as limiting the number of lanes or closing a structure completely, can reduce the public's exposure to hazards caused by structure damage in case of a triggering event. The placement of metal plates over weakened sections of deck, alone or in combination with the placement of netting or timber blocks under the deck, may reduce danger to the public.

None of these measures respond to the root cause of elevated risk, which is the deteriorated condition of bridge elements. Therefore, the risk management strategy must also contain the necessary components of programmed activity to avoid or remedy a deteriorated condition. These components are as follows:

- Warrants for application of specific remedial treatments, including preventative maintenance, repairs, rehabilitation, and replacement. This effort includes the estimation of risk as a function of element condition.
- Procedures for estimating the cost of treatments.
- Procedures for estimating the effectiveness of treatments in improving conditions and eliminating specific types of risk.
- A method for routinely calculating the risk associated with element deterioration and smart flags, for identifying and evaluating potential agency responses, and for prioritizing corrective action.

The most practical way to implement an efficient risk management strategy for element deterioration is to build on the existing functionality of Pontis. Pontis already has automated features for forecasting element deterioration that also address the extent of each of the condition-states in Table 3.3.2.1 for ordinary elements. Functionality for modeling smart flags is to be added in the release of Pontis 5.2.

Currently in Pontis, the likelihood of adverse impact is modeled by the element failure probability and cost. However, this feature is to be eliminated in Pontis 5.2 in favor of a more comprehensive risk management approach. For future compatibility and to make the PennDOT framework more durable, it is recommended that a likelihood probability be estimated at the element category (deck, superstructure, substructure, etc.) level. This breakdown provides a sufficient level of detail for this analysis in the near term. Quantitative values can be estimated using an expert elicitation process that parallels PennDOT's approach in other parts of the risk strategy to date.

For simplicity, consequences to the structure are assumed to be quantified by the replacement cost of the affected element. This approach ignores non-programmed operational strategies but should be a reasonably accurate measure of the programmable implications of advanced deterioration.

Consequences to mission, life, and property are modeled as the effect on road users, using the same model that Pontis uses for functional deficiencies. This model estimates detour distance and time, using National Bridge Inventory data and published estimates of detour costs for users. All consequences are expressed as the result of operational measures to limit traffic or close the bridge. In other words, it is assumed that all safety-related consequences are converted to mobility consequences by operational policy.

Considering these basic quantitative inputs, the following sections address how each component of risk management can be handled.

3.3.1.3 *Warrants*

Preservation warrants are expressed in Pontis in the form of feasible actions associated with each possible condition-state. For preventive maintenance planning, this remains the best approach. A similar scheme, with somewhat greater agency flexibility, will remain in place in Pontis 5.2.

For the response to advanced deterioration, the warrants for action would be expressed as the product of the likelihood of event times the consequences to the structure. Bridges above a threshold value on this scale would be considered for programmed corrective action. The warrant measure (WM) would be normalized to a scale of 0-100, where 100 has the lowest risk:

$$WM = 100 - \frac{\sum_e L_e PW_e R_e Q_e}{\sum_e R_e Q_e} \times 100$$

Where:

L_e = likelihood of adverse impact for element e (from element’s category)

PW_e = probability of being in the worst condition-state for element e, either taken directly from the most recent inspection, or forecasted for a future year using the Pontis deterioration model

R_e = replacement unit cost for element e

Q_e = quantity of element e on the structure

This equation is calculated over all elements that comprise the structure and are associated with risk conditions, as indicated in Table 3.3.2.1. The alert reader will notice that this computation is closely related to the health index formula, except that it is calculated only for risk-related elements and only for the worst condition-state and includes smart flags.
The threshold value of this criterion to implement mitigation action will be determined through expert judgment and may vary by type of action.

Smart flags by definition lack replacement costs, yet they are very important in a risk analysis. It is recommended that each smart flag in use by PennDOT be associated with a group of elements. For example, the pack rust smart flag would be associated with all truss elements.

This relationship will be formalized in the proposed approach for the next revision of AASHTO's CoRe Element Guide. On a given bridge, the replacement cost for the above formula would be calculated as the sum of replacement costs of all associated elements that comprise the bridge.

Elements associated with fracture criticality, specifically trusses, disproportionately affect risk. These should be given added weight, by a factor determined from expert judgment. This fracture criticality factor may be varied in a sensitivity analysis to determine the effect on program composition.

3.3.1.4 *Cost Estimation*

Existing PennDOT tools and data for cost estimation should be used for programmed risk reduction actions warranted according to the procedure in the preceding section. Estimates are intended to be suitable for program planning on a multiyear timeframe and not for design or letting.

3.3.1.5 *Effectiveness*

Programmed corrective actions are distinct from emergency measures, such as shoring or temporary strengthening of a structure. The latter may be only partially effective in removing the element risk and do not address the root cause, which is advanced deterioration. Programmed actions should improve the condition of the structure and eliminate all immediate risk. Typically, these actions include replacement, rehabilitation, and permanent strengthening. Thus, all element risks should be reduced to zero.

However, PennDOT may desire to address temporary corrective measures. The framework allows for this possibility by enabling the improvement of the risk warrant measure to a point above the warrant threshold but below the perfectly risk-free condition. In this case, the resulting performance level would need to be estimated through expert judgment.

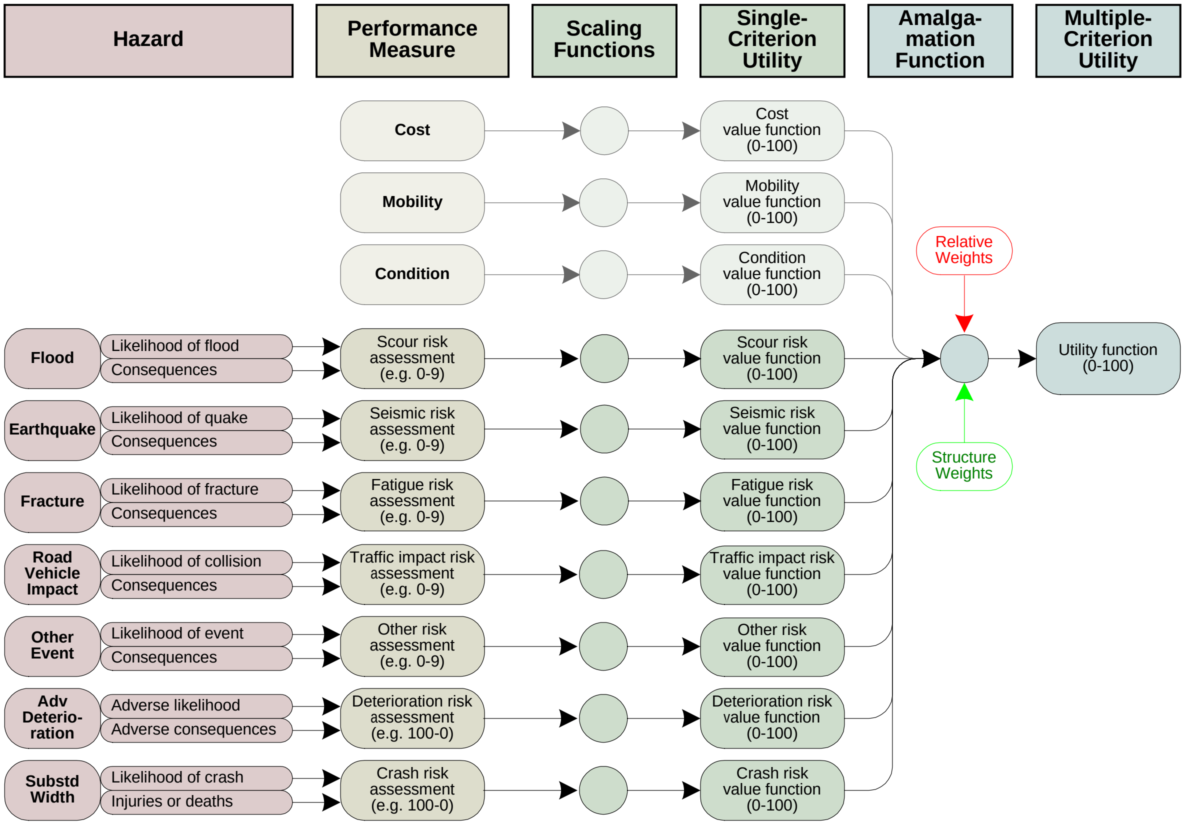
3.3.1.6 *Priority Setting*

Element risk can be used by itself or in combination with other performance measures for the priority-setting of bridge investments. It is recommended that the priority-setting measure be calculated in the same manner as proposed for Pontis 5.2, using the principles of utility theory. This method is simple enough to fit into the same spreadsheet framework as the rest of the analysis and is upwardly compatible for future migration to Pontis 5.2. Thus, the results developed now will not have to be discarded later. As depicted in Figure 1, the basic steps are as follows:

- Computation of each performance measure, with and without an action being taken. Agencies can use different scales for different measures, to fit their normal practice.
- Transformation of each measure to a standard, bounded scale. This process, called scaling, produces a "value function" or single-criterion utility function.
- Amalgamation of measures, using a weighting scheme, resulting in a utility function. Weights are applied within each structure to reflect the relative importance of performance measures and across structures to reflect the importance of each structure in the transportation network.

The basic risk performance measure for advanced deterioration is the same warrant measure defined above, including the handling indicated for smart flags and fracture-critical elements.

Figure 3.3.1.6-1 Framework for Priority Setting



A value function can be derived by asking a panel of experts structured questions about their preference between changes in levels of the performance criterion.

STEP 0: Set V(HI=0) = 0 and — Value function is zero when performance is zero, which is the highest risk level

V(HI=100) = 100 — Value function is 100 when performance is 100, when there is no risk at all

STEP 1: Find X50 for which V(X50) = 50

Find X50 such that you are equally satisfied with

– an improvement of performance from 0 to X50

– an improvement of performance from X50 to 100

You decide that X50 = 70. Value function is 50 when performance is 70

STEP 2: Find X25 for which V(X25) = 25

Find X25 such that you are equally satisfied with

– an improvement of performance from 0 to X25

– an improvement of performance from X25 to X50

You decide that X25 = 40. Value function is 25 when performance is 40

STEP 3: Find X75 for which V(X75) = 75

Find X75 such that you are equally satisfied with

– an improvement of performance from X50 to X75

– an improvement of performance from X75 to 100

You decide that X75 = 90. Value function is 75 when performance is 90

STEP 4: Consistency Check

Are you equally satisfied with

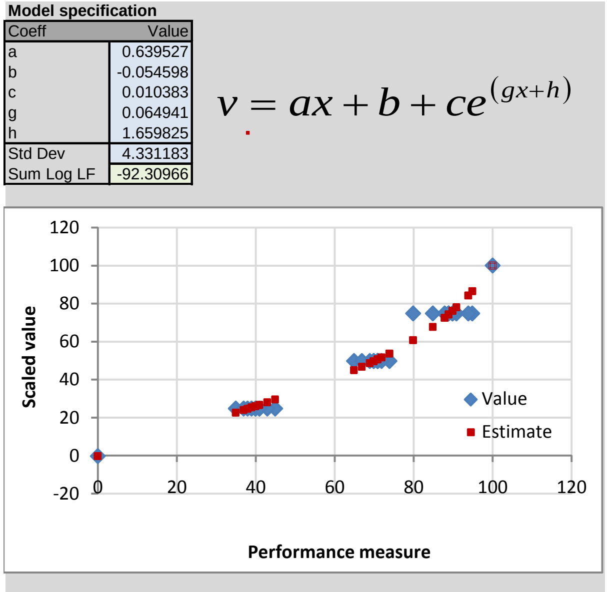
– an improvement of performance from X25 to X50

– an improvement of performance from X50 to X75

If not, make adjustments to X25, X50, or X75

One way of converting the data to a value function is to average the responses to each question and then make a piecewise linear equation. A better way is to use all the raw data points in a regression model. This exercise will typically produce smooth but non-linear result, as shown in Figure 3.3.1.6-2 below.

Figure 3.3.1.6-2 Exponential Scaling Function Concave Upward



Model specification

Coeff	Value
a	0.639527
b	-0.054598
c	0.010383
g	0.064941
h	1.659825
Std Dev	4.331183
Sum Log LF	-92.30966

$$v = ax + b + ce^{(gx+h)}$$

It is proposed that the parameters of this model be developed as a part of the development of the proposed new spreadsheet tool to assist in the risk management process. Similar models are likely to be needed for other performance measures, as every performance measure must be placed on a uniform scale before a utility function can be applied for priority-setting.

After the performance measure is scaled, the benefit of a risk mitigation project is readily computed as the difference in performance between the existing situation and the improved situation. Because of the uniform scale, this difference will be equally meaningful for any value of the existing or improved measure.

To prioritize bridges using one or more performance measures, it is necessary to introduce the cost of the work and weight the benefits according to the importance of each bridge relative to the inventory as a whole. This approach is called "structure weighting." For element risk, the weights reflect the two types of consequences: consequences to the structure are represented by the structure replacement cost, and impact on the public is represented by detour user cost. This approach is consistent again with converting safety-related risks to mobility consequences because of operational policies.

When additional performance measures are included, such as additional risk factors or condition or life cycle cost, each measure can have its own structure weight. It is also necessary to introduce a weight to reflect the relative importance of one performance measure in relation to the others. This importance weighting is typically derived by asking a panel of decision-makers to estimate the weights directly and averaging their responses. The weights are later adjusted during use of the tool to ensure that forecast performance outcomes reflect policy goals.

The prioritization criterion PC is thus calculated as follows:

$$PC_{sp} = \frac{\sum_{m} SV_{pm} RW_m SW_{sm}}{C_p \sum_{m} RW_m} \times 100$$

Where: SV_{pm} = scaled value of performance measure m for project p. For element risk, this is the warrant measure (WM) as calculated earlier, processed by the scaling function as in Figure 2 to place it on a uniform scale. It is expressed as the improvement in performance if the project is implemented, rather than doing nothing. Other performance measures will have their own raw performance measures and scaling functions for each project.

RW_m = relative weight of performance measure m to all other performance measures to be considered. Conventionally, the sum of relative weights is 1.0, but its attainment is not strictly required because the formula normalizes the result.

SW_{pm} = structure weight for project p and performance measure m. For element risk, the structure weight is calculated as the sum of the replacement cost and detour user cost, to reflect consequences to the structure and consequences to road users, respectively. See further information below.

C_p = estimated cost of the project.

Because the numerator of this formula is expressed as the difference in utility between taking the proposed action and doing nothing, and the denominator has a total project cost, the formula can be recognized as a standardized benefit-cost ratio.

The structure weight for element risk would be computed by using the replacement cost of the structure to represent maximum consequences to the structure. To represent maximum consequences to the road user, it is assumed that the structure would be closed, and all vehicles would be detoured to the bypass route as used for NBI item 19. The structure weight is:

$$SW = R + Dur \times ADT \times BL \times (CV + CT / Speed)$$

Where: R = replacement cost of the structure, in dollars.
Dur = typical duration of a forced bridge replacement project, in days.
ADT = average daily traffic on the bridge, NBI item 29.
BL = bypass length, in km, NBI item 19.
CV = vehicle operating cost per km, from the literature.
CT = travel time cost per hour, from the literature.
$Speed$ = speed on the detour route. If available, this may be bridge-specific; otherwise a default value by functional class is typically used.

Replacement cost for this purpose is typically a simple function of deck area. However, a more refined value may be used if it is available for a given structure. It is not necessary to expend much effort to refine the parameters dur, CV, CT, and speed, as long as they are applied consistently for all projects. The user cost weight merely escalates the priority of bridges that either carry a high traffic volume or whose closure necessitates a lengthy detour.

3.3.1.7 *Implementation Strategy*

The methodology presented here for element risk relies on NBI data and element inspection data. Only one element-level inspection is required for each bridge. Thus, as PennDOT broadens the implementation of its element inspection process, the method can be applied immediately. The method should be stable through future releases of Pontis according to current plans.

It is recommended that the method be implemented using a spreadsheet model as an extension to the spreadsheet functionality proposed for the rest of the risk analysis. The spreadsheet would access existing PennDOT databases to obtain the necessary data.
It is assumed that existing cost estimation procedures, as implemented by PennDOT in Microsoft Excel spreadsheets, would be interfaced with this method to estimate the cost of risk mitigation actions. Once Pontis is populated with element-level preservation cost data, it will be possible to use such data in the analysis. However, that information is not required for the risk model as proposed.

After PennDOT develops its Pontis deterioration models, it will be possible to perform the risk analysis in a multiyear timeframe, forecasting new element risk projects as structures deteriorate. This exercise would be extremely valuable to help the Department anticipate and quantify the volume of new needs that are likely to arise. As indicated earlier in this section, a viable long-term risk reduction strategy requires interrupting the deterioration cycle: correcting problems to diminish existing risks and also preventing the degradation of additional structures to reduce future risk. The strategic aspect of a risk reduction strategy is anticipating future needs and intercepting them at the most opportune time, which is typically well before the public is exposed to any elevated risk.

Pontis 5.2 will use the same Markovian deterioration models as Pontis 4.4, so there is no need to change strategy or delay implementation as a result of the upcoming system enhancements. All data developed for the proposed methodology and stored in Pontis 4.4 will remain available and useful in Pontis 5.2 under current system design plans.

4.0 *Summary of Recommendations*

This report provides recommendations, based on research conducted as part of Tasks 1 and 2, for enhancements to the current PennDOT risk assessment program. The recommendations in the preceding sections were organized according to relevance to the existing risk assessment program (i.e., Process Recommendations, Software Recommendations, and Element-Level Recommendations).

The recommendations, which represent a plan of action, are divided into three categories based on the level of effort required for implementation. The first category, Quick-Strike Items, consists of implementation initiatives that can be accomplished without research or development. The second category, Medium-Range Goals, can be implemented with limited levels of research and development. The final category, Long-Range Goals, consists of goals that constitute major revisions to the existing system and require advanced levels of research and development. Category components are as follows:

Quick-Strike Items

- The risk assessment flowcharts currently use old Bridge Management System (BMS) nomenclature. The existing flowcharts should be reproduced using the new BMS2 nomenclature.
- The existing spreadsheet is essentially a large flat file of data. Extensive review of the sorting process indicates that it would be possible to divide the spreadsheet into sections; each section would consist of a new worksheet.
- The current spreadsheet only allows a user to view bridge information in a tabular format that is 185 columns in length. A new worksheet can be added to the program to enable the user to retrieve all of the data for a single bridge in a compact, concise report (See Figure 3.2.2.2-1).

Medium-Range Goals

- To discern trends among a structure's risk assessment scores and evaluate the effectiveness of risk assessment scoring, Districts have requested the ability to retrieve legacy data for each iteration of the prioritization. Therefore, a new table should be created within BMS2 that would be populated by the risk assessment database based on the results of each prioritization. This table would facilitate the retrieval of legacy data.
- The risk assessment database should be modified to automatically retrieve the list of Transportation Improvement Program (TIP) bridges from the Multimodal Project Management System (MPMS) database. This would not only facilitate exclusion of TIP bridges from the priority list, but also allow for the creation of a secondary list consisting of only TIP bridges. The list of TIP bridges could be further refined to identify if a project is in the first, second, or third four-year period of planning.
- Revise weighting of risk conditions of the aggregate and structurally deficient risk assessments. The revised weights, presented in this report, are assumptions based on general trends resulting from the District survey conducted in Task 2. The proposed weights will require verification through a sensitivity analysis to determine the effect on the system.
- Pennsylvania has encountered several problematic bridge details (e.g., rocker bearings, non-composite adjacent box beams, and precast bridge barriers) that should be identified within the BMS2 framework and used in the state's risk assessment process. These items would be assigned an importance factor based solely on their presence.
- Load capacity and observed scour rating are better assessments of risk compared to the structural condition and waterway adequacy appraisal ratings currently used to assess structurally deficient risk scores. Load capacity and observed scour rating should be used to calculate the structurally deficient risk score.
- The current relationship between Business Plan Network (BPN) and risk-level categories tends to diminish the importance of deficiencies with respect to low-ADT routes. A percentage increase should be factored into the final risk score for structures with a BPN of three or four (i.e., non-NHS

routes) and with two or more critical deficiency ratings (0-2 for BMS2 Condition Rating) for any of the aggregate risk factors. A sensitivity analysis would be required to determine an accurate percentage of increase to ensure that structures with a higher BPN number are not over- or undervalued.

- To mitigate the de-emphasis of critical conditions, when a critical rating exists, the system should increase the risk condition weighting to equal that of the superstructure. This default increase would only be applied to substructures and/or decks when a critical rating is detected. This methodology applies to both the aggregate and structurally deficient risk scores.
- Automation of the transfer of data between the risk assessment database and the cost spreadsheet using an Open-Database Connection (ODBC) will mitigate potential errors.

Long-Range Goals

- To facilitate the creation of a preservation priority list, preservation activities should be assigned individual weights and risk values. Each preservation item score would be calculated and summed for each structure. The risk assessment spreadsheet could then be used to sort the structures, based on preservation scores, to create a priority list.
- In conjunction with PennDOT's current initiative of implementing element-level inspection procedures, a strategy for the implementation of element-level risk assessment using the Pontis framework is recommended. The Pontis framework should be customized, through the addition of smart flags and core elements, to meet Pennsylvania's infrastructure needs.

Appendix A:
District Survey Questionnaire

Baker

pennsylvania
DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey For District Bridge Engineers

PennDOT District No.___

Interview Information
Date:
Time:
DOT Staff:

Baker Staff:

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

1. The following additional data items **should be** considered as factors in the risk assessment of a bridge:

	Strongly agree		Neutral		Strongly disagree
a. Utilities supported by a bridge	1	2	3	4	5
b. Nearby service sensitive facilities such as hospitals	1	2	3	4	5
c. Nearby heavy users such as manufacturers	1	2	3	4	5
d. Accident history at the bridge location	1	2	3	4	5
e. Seismic risk	1	2	3	4	5
2. The Business Plan route number designation is sufficient to address service volumes at a bridge site.	1	2	3	4	5
3. Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site.	1	2	3	4	5

4. The existing considerations are shown for the “Aggregate Risk Score” along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
35%	Superstructure Condition	1	2	3	4	5
25%	Substructure Condition	1	2	3	4	5
5%	Deck Condition	1	2	3	4	5
5%	Load Capacity	1	2	3	4	5
20%	Scour	1	2	3	4	5
5%	Fatigue	1	2	3	4	5
5%	Impact Damage / Over Height Vehicle	1	2	3	4	5

5. The following new consideration may become part of the “Aggregate Risk Score” depending on District input. Indicate your opinion regarding the **proposed magnitude** of weighting factors shown.

		Strongly agree		Neutral		Strongly disagree
5%	Utilities supported by a bridge	1	2	3	4	5
5%	Nearby service sensitive facilities	1	2	3	4	5
5%	Nearby heavy users	1	2	3	4	5
5%	Accident history	1	2	3	4	5
5%	Seismic risk	1	2	3	4	5

		Strongly agree		Neutral		Strongly disagree
6.	The existing considerations are shown for the “Structurally Deficient Risk Score” along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.					
40%	Superstructure Condition	1	2	3	4	5
30%	Substructure Condition	1	2	3	4	5
20%	Deck Condition	1	2	3	4	5
5%	Structural Condition Appraisal	1	2	3	4	5
5%	Waterway Adequacy	1	2	3	4	5
7.	Risk assessment training would benefit District staff.	1	2	3	4	5
8.	The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors.	1	2	3	4	5
9.	The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration.	1	2	3	4	5

Thank You!

Appendix B:
District Survey Results

Baker

pennsylvania
DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey For District Bridge Engineers

PennDOT District D1-0

Interview Information
Date: January 15, 2009
Time: 2:15 – 2:45 PM
DOT Staff:
Bill Koller & Mark Bredl
Baker Staff:
Ray Hartle & Mary Rosick

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

	Strongly agree		Neutral		Strongly disagree
1. The following additional data items **<u>should be</u>** considered as factors in the risk assessment of a bridge:					
a. Utilities supported by a bridge NA for the District's region	1	2	3	4	[✓ 5]
b. Nearby service sensitive facilities such as hospitals NA for the District's region	1	2	3	4	[✓ 5]
c. Nearby heavy users such as manufacturers NA for the District's region	1	2	3	4	[✓ 5]
d. Accident history at the bridge location NA for the District's region	1	2	3	4	[✓ 5]
e. Seismic risk NA for the District's region	1	2	3	4	[✓ 5]
2. The Business Plan route number designation is sufficient to address service volumes at a bridge site.	[✓ 1]	2	3	4	5
3. Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site.	1	2	[✓ 3]	4	5

4. The existing considerations are shown for the "Aggregate Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
35%	Superstructure Condition	1	2	[✓ 3]	4	5
25%	Substructure Condition	1	2	[✓ 3]	4	5
5%	Deck Condition	1	2	[✓ 3]	4	5
5%	Load Capacity	1	2	[✓ 3]	4	5
20%	Scour	1	2	[✓ 3]	4	5
5%	Fatigue	1	2	[✓ 3]	4	5
5%	Impact Damage / Over Height Vehicle	1	2	[✓ 3]	4	5

5. The following new consideration may become part of the "Aggregate Risk Score" depending on District input. Indicate your opinion regarding the **proposed magnitude** of weighting factors shown.

		Strongly agree		Neutral		Strongly disagree
5%	Utilities supported by a bridge	1	2	3	4	[✓ 5]
Lower – Re. Question #1						
5%	Nearby service sensitive facilities	1	2	3	4	[✓ 5]
Lower – Re. Question #1						
5%	Nearby heavy users	1	2	3	4	[✓ 5]
Lower – Re. Question #1						
5%	Accident history	1	2	3	4	[✓ 5]
Lower – Re. Question #1						
5%	Seismic risk	1	2	3	4	[✓ 5]
Lower – Re. Question #1						

Notes:

1. There is a perception that CO believes the wrong bridges are being programmed.
2. With Act 44, bond money and the Economic Stimulus Package, Legislators add top priority to the TIP and bridge replacement resulting in a shortage of preservation projects.
3. District 1-0 has advanced maintenance force capabilities and the TIP needs to include projects that support them.

		Strongly agree		Neutral		Strongly disagree
6.	The existing considerations are shown for the "Structurally Deficient Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.					
	40% Superstructure Condition	1	[✓ 2]	3	4	5
	30% Substructure Condition	1	[✓ 2]	3	4	5
	20% Deck Condition	1	[✓ 2]	3	4	5
	5% Structural Condition Appraisal	1	[✓ 2]	3	4	5
	5% Waterway Adequacy	1	[✓ 2]	3	4	5
7.	Risk assessment training would benefit District staff.	1	2	3	4	[✓ 5]
8.	The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors. Depends on the timing.	1	[✓ 2]	3	4	5
9.	The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration.	[✓ 1]	2	3	4	5

Thank You!

Baker

pennsylvania
DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey For District Bridge Engineers

PennDOT District D2-0

Interview Information
Date: January 14, 2009
Time: 10:30 – 11:17 AM
DOT Staff:
George Prestash
Baker Staff:
Ray Hartle & Mary Rosick

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

	Strongly agree		Neutral		Strongly disagree
1. The following additional data items **should be** considered as factors in the risk assessment of a bridge:					
a. Utilities supported by a bridge Ordinary water and gas lines typical.	1	2	3	[✓ 4]	5
b. Nearby service sensitive facilities such as hospitals	1	[✓ 2]	3	4	5
c. Nearby heavy users such as manufacturers	1	[✓ 2]	3	4	5
d. Accident history at the bridge location More of a safety issue, would not necessarily take action on a bridge - like replacement, would take other action. Depends on the cause of the accident.	1	2	3	[✓ 4]	5
e. Seismic risk Even though they are not all in a seismic zone, feel it could be important.	1	[✓ 2]	3	4	5
2. The Business Plan route number designation is sufficient to address service volumes at a bridge site. Not enough information just because it is a business plan route.	1	2	3	[✓ 4]	5
3. Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site.	1	[✓ 2]	3	4	5

4. The existing considerations are shown for the "Aggregate Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
35%	Superstructure Condition	1	2	3	[✓ 4]	5
Decrease to 30%						
25%	Substructure Condition	[✓ 1]	2	3	4	5
5%	Deck Condition	1	2	3	[✓ 4]	5
Increase to 10%						
5%	Load Capacity	1	2	3	[✓ 4]	5
Increase to 10%						
20%	Scour	1	2	3	[✓ 4]	5
Decrease to 15%						
5%	Fatigue	1	2	[✓ 3]	4	5
5%	Impact Damage / Over Height Vehicle	1	2	[✓ 3]	4	5

5. The following new consideration may become part of the "Aggregate Risk Score" depending on District input. Indicate your opinion regarding the **proposed magnitude** of weighting factors shown.

		Strongly agree		Neutral		Strongly disagree
5%	Utilities supported by a bridge	1	2	3	[✓ 4]	5
5%	Nearby service sensitive facilities	1	[✓ 2]	3	4	5
5%	Nearby heavy users	1	[✓ 2]	3	4	5
5%	Accident history	1	2	3	[✓ 4]	5
5%	Seismic risk	1	2	[✓ 3]	4	5

Notes:

1. The new tool should retain the ability to customize reports using various formatting changes and color coding the data.
2. Run the new tool against the final (reprioritized) recommendations list from the districts.
3. Live list update using BMS2 would be useful when responding to CO requests.
4. Updated lists should identify bridges on the current TIP
5. Updated lists should identify candidates for preservation activities
6. Old risk assessment lists should be archived for future review and comparison.

	Strongly agree		Neutral		Strongly disagree
6. The existing considerations are shown for the "Structurally Deficient Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **<u>magnitude</u>** of the weighting factors.					
40% Superstructure Condition	1	[✓ 2]	3	4	5
30% Substructure Condition	1	[✓ 2]	3	4	5
20% Deck Condition	1	[✓ 2]	3	4	5
5% Structural Condition Appraisal	1	[✓ 2]	3	4	5
5% Waterway Adequacy	1	[✓ 2]	3	4	5
7. Risk assessment training would benefit District staff. Only If a new tool other than the spreadsheet, Don't need inner workings, just methods to extract data.	1	[✓ 2]	3	[✓ 4]	5
8. The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors. Would help when able, depending on when needed and the level of effort.	1	2	[✓ 3]	4	5
9. The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration.	1	[✓ 2]	3	4	5

General discussion was had regarding the use of the spreadsheet and not wanting to get rid of it. Having all the information available in a spreadsheet is very useful and you don't need to always do queries to a database for the information. For any future application, consideration should be given for making it easy for the districts to continue to pick information that they would like to see and manipulating it outside of the application. The District agreed that having the information queried directly from BMS2 would be very valuable.

Suggest don't get rid of risk assessment that is there now. This could help for going back to see how we did things in the past and revalidate information.

Thank You!

Baker

pennsylvania
DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey For District Bridge Engineers

PennDOT District D3-0

Interview Information
Date: January 15, 2009
Time: 11:00 – 11:30 AM
DOT Staff:
Gary Williams
Baker Staff:
Ray Hartle

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

	Strongly agree		Neutral		Strongly disagree
1. The following additional data items **<u>should be</u>** considered as factors in the risk assessment of a bridge:					
a. Utilities supported by a bridge Non-Issue in the District 3-0 region	1	2	3	4	[✓ 5]
b. Nearby service sensitive facilities such as hospitals Non-Issue in the District 3-0 region	1	2	3	4	[✓ 5]
c. Nearby heavy users such as manufacturers Non-Issue in the District 3-0 region	1	2	3	4	[✓ 5]
d. Accident history at the bridge location Must know cause	1	[✓ 2]	3	4	5
e. Seismic risk No risk	1	2	3	4	[✓ 5]
2. The Business Plan route number designation is sufficient to address service volumes at a bridge site.	[✓ 1]	2	3	4	5
3. Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site.	1	2	3	[✓ 4]	5

4. The existing considerations are shown for the “Aggregate Risk Score” along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
35%	Superstructure Condition	1	[✓ 2]	3	4	5
25%	Substructure Condition	1	[✓ 2]	3	4	5
5%	Deck Condition	1	[✓ 2]	3	4	5
5%	Load Capacity	1	[✓ 2]	3	4	5
Should be higher						
20%	Scour	1	[✓ 2]	3	4	5
5%	Fatigue	1	[✓ 2]	3	4	5
5%	Impact Damage / Over Height Vehicle	1	[✓ 2]	3	4	5

5. The following new consideration may become part of the “Aggregate Risk Score” depending on District input. Indicate your opinion regarding the **proposed magnitude** of weighting factors shown.

		Strongly agree		Neutral		Strongly disagree
5%	Utilities supported by a bridge	[✓ 1]	2	3	4	5
5%	Nearby service sensitive facilities	[✓ 1]	2	3	4	5
5%	Nearby heavy users	[✓ 1]	2	3	4	5
5%	Accident history	1	[✓ 2]	3	4	5
Should be higher						
5%	Seismic risk	[✓ 1]	2	3	4	5

Notes:

1. Bridges already on the TIP from prior assessments should not be included in the assessment update.
2. Bridge type should be a factor. I.E. Pinned connected trusses are problematic in the District.
3. Bridges with precast parapet installations need to be addressed.
4. Bridges with integral deck such as slab bridges are typically prioritized too high because defects are double counted in the rating of Deck and Superstructure.

6. The existing considerations are shown for the “Structurally Deficient Risk Score” along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
40%	Superstructure Condition	1	[✓ 2]	3	4	5
30%	Substructure Condition	1	[✓ 2]	3	4	5
20%	Deck Condition	1	[✓ 2]	3	4	5
5%	Structural Condition Appraisal	1	[✓ 2]	3	4	5
5%	Waterway Adequacy	1	[✓ 2]	3	4	5

7. Risk assessment training would benefit District staff. 1 2 3 4 [✓ 5]
A good user manual would be sufficient, or a brief 1-2 hour presentation at a Bridge Engineer’s meeting.

8. The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors. 1 2 [✓ 3] 4 5
Depends on timing.

9. The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration. [✓ 1] 2 3 4 5

Thank You!

Baker

pennsylvania
DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey For District Bridge Engineers

PennDOT District D4-0

Interview Information
Date: January 30, 2009
Time: NA –Mail In
DOT Staff:
Harold Hill
Baker Staff:
NA

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

	Strongly agree		Neutral		Strongly disagree
1. The following additional data items **<u>should be</u>** considered as factors in the risk assessment of a bridge:					
a. Utilities supported by a bridge	1	2	3	[✓ 4]	5
b. Nearby service sensitive facilities such as hospitals	[✓ 1]	2	3	4	5
c. Nearby heavy users such as manufacturers	1	2	[✓ 3]	4	5
d. Accident history at the bridge location	1	[✓ 2]	3	4	5
e. Seismic risk	1	2	3	[✓ 4]	5
2. The Business Plan route number designation is sufficient to address service volumes at a bridge site.	1	2	3	4	[✓ 5]
3. Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site.	[✓ 1]	2	3	4	5

4. The existing considerations are shown for the "Aggregate Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
35%	Superstructure Condition	[✓ 1]	2	3	4	5
25%	Substructure Condition	[✓ 1]	2	3	4	5
5%	Deck Condition	[✓ 1]	2	3	4	5
5%	Load Capacity	[✓ 1]	2	3	4	5
20%	Scour	[✓ 1]	2	3	4	5
5%	Fatigue	[✓ 1]	2	3	4	5
5%	Impact Damage / Over Height Vehicle	[✓ 1]	2	3	4	5

5. The following new consideration may become part of the "Aggregate Risk Score" depending on District input. Indicate your opinion regarding the **proposed magnitude** of weighting factors shown.

		Strongly agree		Neutral		Strongly disagree
5%	Utilities supported by a bridge	1	2	3	4	[✓ 5]
5%	Nearby service sensitive facilities	[✓ 1]	2	3	4	5
5%	Nearby heavy users	1	2	3	4	[✓ 5]
5%	Accident history	1	2	3	4	[✓ 5]
5%	Seismic risk	1	2	3	4	[✓ 5]

6. The existing considerations are shown for the "Structurally Deficient Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **<u>magnitude</u>** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
40%	Superstructure Condition	[✓ 1]	2	3	4	5
30%	Substructure Condition	[✓ 1]	2	3	4	5
20%	Deck Condition	[✓ 1]	2	3	4	5
5%	Structural Condition Appraisal	[✓ 1]	2	3	4	5
5%	Waterway Adequacy	[✓ 1]	2	3	4	5

7. Risk assessment training would benefit District staff.	[✓ 1]	2	3	4	5
8. The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors.	1	2	3	4	[✓ 5]
9. The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration.	1	2	3	4	[✓ 5]

Thank You!

Note:

Harold sent in his response electronically via a scanned copy of the completed questionnaire. No comments were provided.

Baker

pennsylvania
DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey For District Bridge Engineers

PennDOT District D5-0

Interview Information
Date: January 29, 2009
Time: 3:00 – 3:45 PM
DOT Staff:
Karl Kroboth & Kamlesh Ashar
Baker Staff:
Ray Hartle

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

1. The following additional data items **should be** considered as factors in the risk assessment of a bridge:

	Strongly agree		Neutral		Strongly disagree
a. Utilities supported by a bridge	1	2	[✓ 3]	4	5
b. Nearby service sensitive facilities such as hospitals	1	[✓ 2]	3	4	5
c. Nearby heavy users such as manufacturers	1	[✓ 2]	3	4	5
d. Accident history at the bridge location	[✓ 1]	2	3	4	5
e. Seismic risk	[✓ 1]	2	3	4	5

2. The Business Plan route number designation is sufficient to address service volumes at a bridge site. 1 2 3 4 [✓ 5]

3. Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site. [✓ 1] 2 3 4 5

4. The existing considerations are shown for the "Aggregate Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

	Strongly agree		Neutral		Strongly disagree
35% Superstructure Condition 30% recommended	1	2	3	[✓ 4]	5
25% Substructure Condition 20% recommended	1	2	3	[✓ 4]	5
5% Deck Condition 10% recommended	1	2	3	[✓ 4]	5
5% Load Capacity 10% recommended	1	2	3	[✓ 4]	5
20% Scour 15% recommended	1	2	3	[✓ 4]	5
5% Fatigue	[✓ 1]	2	3	4	5
5% Impact Damage / Over Height Vehicle 10% recommended	1	2	3	[✓ 4]	5

5. The following new consideration may become part of the "Aggregate Risk Score" depending on District input. Indicate your opinion regarding the **proposed magnitude** of weighting factors shown.

	Strongly agree		Neutral		Strongly disagree
5% Utilities supported by a bridge	1	[✓ 2]	3	4	5
5% Nearby service sensitive facilities	1	[✓ 2]	3	4	5
5% Nearby heavy users	1	[✓ 2]	3	4	5
5% Accident history Higher recommended	1	2	3	[✓ 4]	5
5% Seismic risk Higher recommended	1	2	3	[✓ 4]	5

6. The existing considerations are shown for the "Structurally Deficient Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **<u>magnitude</u>** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
40%	Superstructure Condition	[✓ 1]	2	3	4	5
30%	Substructure Condition	[✓ 1]	2	3	4	5
20%	Deck Condition	1	[✓ 2]	3	4	5
5%	Structural Condition Appraisal	[✓ 1]	2	3	4	5
Inventory Rating should be stand alone						
5%	Waterway Adequacy	[✓ 1]	2	3	4	5

7. Risk assessment training would benefit District staff. [✓ 1] 2 3 4 5
Likes regional training. More than DBE would attend.

8. The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors. 1 2 3 4 [✓ 5]
Short on staff.

9. The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration. 1 [✓ 2] 3 4 5
Need some priority within the District

Thank You!

Notes:

1. The District recommended the following additional spreadsheet columns: Year Built / Bridge Type / Date of last Load Rating / Inspection Date / CoRe Elements
2. The Risk Spreadsheet should operate on Real Time data, linking to BMS2 and MPMS.
3. Costs should be updated routinely and tailored to each District.

Baker

pennsylvania
DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey For District Bridge Engineers

PennDOT District D6-0

Interview Information
Date: January 28, 2009
Time: 1:00 – 2:00 PM
DOT Staff:
Peter Berg
Baker Staff:
Ray Hartle

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

1. The following additional data items **should be** considered as factors in the risk assessment of a bridge:

	Strongly agree		Neutral		Strongly disagree
a. Utilities supported by a bridge	1	2	3	[✓ 4]	5
b. Nearby service sensitive facilities such as hospitals	1	2	3	[✓ 4]	5
c. Nearby heavy users such as manufacturers Super loads and permit vehicles are a concern	1	[✓ 2]	3	4	5
d. Accident history at the bridge location	1	2	3	[✓ 4]	5
e. Seismic risk	1	2	3	[✓ 4]	5

2. The Business Plan route number designation is sufficient to address service volumes at a bridge site.	1	2	3	[✓ 4]	5
3. Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site.	1	[✓ 2]	3	4	5

4. The existing considerations are shown for the "Aggregate Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
35%	Superstructure Condition	1	2	3	[✓ 4]	5
25% recommended						
25%	Substructure Condition	1	[✓ 2]	3	4	5
Super / Sub / Deck could equally put a bridge at risk						
5%	Deck Condition	1	2	3	[✓ 4]	5
25% recommended						
5%	Load Capacity	1	[✓ 2]	3	4	5
20%	Scour	1	2	[✓ 3]	4	5
5%	Fatigue	1	[✓ 2]	3	4	5
5%	Impact Damage / Over Height Vehicle	1	[✓ 2]	3	4	5

5. The following new consideration may become part of the "Aggregate Risk Score" depending on District input. Indicate your opinion regarding the **proposed magnitude** of weighting factors shown.

		Strongly agree		Neutral		Strongly disagree
5%	Utilities supported by a bridge	1	[✓ 2]	3	4	5
5%	Nearby service sensitive facilities	1	[✓ 2]	3	4	5
5%	Nearby heavy users	1	2	3	[✓ 4]	5
10% recommended						
5%	Accident history	1	[✓ 2]	3	4	5
5%	Seismic risk	1	[✓ 2]	3	4	5

	Strongly agree		Neutral		Strongly disagree
6. The existing considerations are shown for the "Structurally Deficient Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **<u>magnitude</u>** of the weighting factors.					
40% Superstructure Condition	1	2	3	[✓ 4]	5
Super / Sub / Deck should have equal weight					
30% Substructure Condition	1	[✓ 2]	3	4	5
20% Deck Condition	1	2	3	[✓ 4]	5
Super / Sub / Deck should have equal weight					
5% Structural Condition Appraisal	1	2	3	[✓ 4]	5
Should consider only Inventory Rating					
5% Waterway Adequacy	1	2	3	[✓ 4]	5
Maybe switch this item with Scour in Aggregate Risk					
7. Risk assessment training would benefit District staff.	[✓ 1]	2	3	4	5
Should also have support staff at CO					
8. The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors.	1	2	[✓ 3]	4	5
Very busy and short staffed					
9. The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration.	1	2	[✓ 3]	4	5

Thank You!

Notes:

1. Added risk considerations may dilute the decision making process to effectively group bridge projects based on deficiencies.
2. It would be ideal to have individual priorities for individual projects
3. The SD Risk score should use only SD items and not functional considerations such as waterway appraisal.

Baker

pennsylvania
DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey For District Bridge Engineers

Interview Information
Date: January 30, 2009
Time: 10:30 – 11:15 AM
DOT Staff:
Harivadan Parikh / Ray Ebersole
Baker Staff:
Ray Hartle

PennDOT District D8-0

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

		Strongly agree		Neutral		Strongly disagree
1.	The following additional data items **<u>should be</u>** considered as factors in the risk assessment of a bridge:					
	a. Utilities supported by a bridge Not critical	1	2	3	[✓ 4]	5
	b. Nearby service sensitive facilities such as hospitals Not considered in programming	1	2	3	4	[✓ 5]
	c. Nearby heavy users such as manufacturers Not considered in programming	1	2	3	4	[✓ 5]
	d. Accident history at the bridge location	1	2	[✓ 3]	4	5
	e. Seismic risk Feel strongly that a, b, and c could be rolled into one consideration and the District should assign a factor	1	[✓ 2]	3	4	5
2.	The Business Plan route number designation is sufficient to address service volumes at a bridge site.	1	[✓ 2]	3	4	5
3.	Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site. May not be needed if 1c. is done	1	[✓ 2]	3	4	5

4. The existing considerations are shown for the "Aggregate Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
35%	Superstructure Condition	[✓ 1]	2	3	4	5
25%	Substructure Condition	[✓ 1]	2	3	4	5
5%	Deck Condition	[✓ 1]	2	3	4	5
5%	Load Capacity	[✓ 1]	2	3	4	5
20%	Scour	1	2	3	[✓ 4]	5
Lower. Not happy with existing scour definition						
5%	Fatigue	1	2	3	[✓ 4]	5
Not a true assessment of bridge performance. Should be Fracture Critical instead.						
5%	Impact Damage / Over Height Vehicle	1	2	3	[✓ 4]	5
HIgher						

5. The following new consideration may become part of the "Aggregate Risk Score" depending on District input. Indicate your opinion regarding the **proposed magnitude** of weighting factors shown.

		Strongly agree		Neutral		Strongly disagree
5%	Utilities supported by a bridge	1	2	[✓ 3]	4	5
5%	Nearby service sensitive facilities	1	2	[✓ 3]	4	5
5%	Nearby heavy users	1	2	[✓ 3]	4	5
5%	Accident history	1	2	[✓ 3]	4	5
5%	Seismic risk	1	2	[✓ 3]	4	5

6. The existing considerations are shown for the “Structurally Deficient Risk Score” along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

	Strongly agree		Neutral		Strongly disagree
40% Superstructure Condition	[✓ 1]	2	3	4	5
30% Substructure Condition	[✓ 1]	2	3	4	5
20% Deck Condition	[✓ 1]	2	3	4	5
5% Structural Condition Appraisal	[✓ 1]	2	3	4	5
5% Waterway Adequacy	[✓ 1]	2	3	4	5
7. Risk assessment training would benefit District staff.	[✓ 1]	2	3	4	5
8. The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors.	1	[✓ 2]	3	4	5
9. The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration.	1	[✓ 2]	3	4	5

Thank You!

Notes:

1. Other factors that are not part of the risk assessment that the District has to consider include:
    a. Cost vs. Budget
    b. Political pressure
2. Having access to the old replacement ranking would be useful

Baker

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DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey For District Bridge Engineers

PennDOT District D9-0

Interview Information
Date: January 12, 2009
Time: 3:00 PM – 3:30 PM
DOT Staff: Ralph DeStefano, Lance Eckenrode
Baker Staff: Ray Hartle, Mary Rosick, Tom Ryan

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

1. The following additional data items **should be** considered as factors in the risk assessment of a bridge:

	Strongly agree		Neutral		Strongly disagree
a. Utilities supported by a bridge Mostly local structures. Would have to be something extraordinary like a major conduit line for it to matter. Not usually an issue.	1	2	[✓ 3]	4	5
b. Nearby service sensitive facilities such as hospitals	1	2	3	[✓ 4]	5
c. Nearby heavy users such as manufacturers Tied in with ADT and/or ADTT so maybe don't need separate information.	1	2	3	[✓ 4]	5
d. Accident history at the bridge location Not location specific. For instance, a smaller structure on a stretch it is hard to draw a conclusion that the accident is related to the structure.	1	2	3	4	[✓ 5]
e. Seismic risk	1	2	3	4	[✓ 5]

2. The Business Plan route number designation is sufficient to address service volumes at a bridge site. 1 2 3 [✓ 4] 5
Less of an impact than actual ADT. OK for Interstates mainlines. Need something better for Ramp volumes so they get recognized with a much lower weight.

3. Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site. 1 [✓ 2] 3 4 5
Would like to see ultra high or ultra low values.

4. The existing considerations are shown for the "Aggregate Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.
Not much attention paid to Aggregate Score.

Strongly agree — Neutral — Strongly disagree

35% Superstructure Condition [✓ 1] 2 3 4 5

25% Substructure Condition [✓ 1] 2 3 4 5

5% Deck Condition [✓ 1] 2 3 4 5

5% Load Capacity [✓ 1] 2 3 4 5

20% Scour [✓ 1] 2 3 4 5
One of Brian Thompson's bigger concerns

5% Fatigue [✓ 1] 2 3 4 5

5% Impact Damage / Over Height Vehicle [✓ 1] 2 3 4 5

5. The following new consideration may become part of the "Aggregate Risk Score" depending on District input. Indicate your opinion regarding the **proposed magnitude** of weighting factors shown.

Strongly agree — Neutral — Strongly disagree

5% Utilities supported by a bridge 1 [✓ 2] 3 4 5

5% Nearby service sensitive facilities 1 [✓ 2] 3 4 5

5% Nearby heavy users 1 [✓ 2] 3 4 5

5% Accident history 1 [✓ 2] 3 4 5

5% Seismic risk 1 2 3 4 [✓ 5]
Using map would suffice.

6. The existing considerations are shown for the "Structurally Deficient Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
40%	Superstructure Condition	[✓ 1]	2	3	4	5
30%	Substructure Condition	[✓ 1]	2	3	4	5
20%	Deck Condition	[✓ 1]	2	3	4	5
5%	Structural Condition Appraisal	[✓ 1]	2	3	4	5
5%	Waterway Adequacy	[✓ 1]	2	3	4	5

7. Risk assessment training would benefit District staff. 1 [✓ 2] 3 4 5
Depends on how good the training is.

8. The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors. 1 2 [✓ 3] 4 5
Based on timing.

9. The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration. [✓ 1] 2 3 4 5

Notes

1. The new strategy should have built-in costs that are District specific.
2. Add general user defined considerations and importance factors in BMS2 at the District level to denote special importance issues. This would be better than adjusting the ranking after the assessment is run.
3. The assessment/ priority list is something the District can take to the Planning organization as proof of need.
4. Cost is another issue because each District has different costs.
5. Suggest building District specific cost factors into BMS2 somehow so that every time the assessment is run, customization for District costs would not be necessary.
6. RHartle did advise the District that Central Office would like to keep away from specific district customization to maintain a statewide standard of prioritization.

Thank You!

Baker

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DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey
For
District Bridge Engineers

PennDOT District D10-0

Interview Information
Date: January 12, 2009
Time: 11:00 – 12:00 AM
DOT Staff:
Jim Andrews
Baker Staff:
Ray Hartle

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

	Strongly agree		Neutral		Strongly disagree
1. The following additional data items **<u>should be</u>** considered as factors in the risk assessment of a bridge:					
a. Utilities supported by a bridge	1	2	3	[✓ 4]	5
Rural districts, so not a lot that have utilities					
b. Nearby service sensitive facilities such as hospitals	1	[✓ 2]	3	4	5
c. Nearby heavy users such as manufacturers	1	[✓ 2]	3	4	5
d. Accident history at the bridge location	[✓ 1]	2	3	4	5
e. Seismic risk	1	2	3	[✓ 4]	5
2. The Business Plan route number designation is sufficient to address service volumes at a bridge site.	1	2	3	4	[✓ 5]
Could be inaccuate as far as traffic counts go.					
3. Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site.	1	[✓ 2]	3	4	5
ADTT is not a big concern.					

4. The existing considerations are shown for the "Aggregate Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

	Strongly agree		Neutral		Strongly disagree
35% Superstructure Condition	1	2	3	[✓ 4]	5
Should be lower					
25% Substructure Condition	1	[✓ 2]	3	4	5
OK					
5% Deck Condition	1	2	3	[✓ 4]	5
Should be higher					
5% Load Capacity	1	2	3	[✓ 4]	5
Should be higher					
20% Scour	1	2	3	[✓ 4]	5
Should be lower					
5% Fatigue	1	[✓ 2]	3	4	5
OK					
5% Impact Damage / Over Height Vehicle	1	[✓ 2]	3	4	5
OK					

5. The following new consideration may become part of the "Aggregate Risk Score" depending on District input. Indicate your opinion regarding the **proposed magnitude** of weighting factors shown.

	Strongly agree		Neutral		Strongly disagree
5% Utilities supported by a bridge	1	[✓ 2]	3	4	5
OK					
5% Nearby service sensitive facilities	1	2	[✓ 3]	4	5
OK, maybe up a little, but not real high					
5% Nearby heavy users	1	2	[✓ 3]	4	5
OK, maybe up a little, but not real high					
5% Accident history	1	2	3	[✓ 4]	5
Should be higher					
5% Seismic risk	1	2	3	4	[✓ 5]
Should be lower					

	Strongly agree		Neutral		Strongly disagree
6. The existing considerations are shown for the "Structurally Deficient Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.					
40% Superstructure Condition Should be lower	1	2	3	[✓ 4]	5
30% Substructure Condition Could be lower	1	2	[✓ 3]	4	5
20% Deck Condition Could be higher	1	2	3	[✓ 4]	5
5% Structural Condition Appraisal OK	1	2	[✓ 3]	4	5
5% Waterway Adequacy OK	1	2	[✓ 3]	4	5
7. Risk assessment training would benefit District staff. Would be limited staff, Jim, Tom and Rich - maybe just the three of them, they do all the programming.	1	[✓ 2]	3	4	5
8. The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors. No. Will not be able to assist.	1	2	3	4	[✓ 5]
9. The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration.	[✓ 1]	2	3	4	5

Thank You!

Baker

pennsylvania
DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey For District Bridge Engineers

PennDOT District D11-0

Interview Information
Date: January 16, 2009
Time: 10:45 – 11:15 AM
DOT Staff:
Lou Ruzzi & Jason Zang
Baker Staff:
Ray Hartle & Tom Ryan

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

	Strongly agree		Neutral		Strongly disagree
1. The following additional data items **<u>should be</u>** considered as factors in the risk assessment of a bridge:					
a. Utilities supported by a bridge More of an issue during design	1	2	3	[✓ 4]	5
b. Nearby service sensitive facilities such as hospitals	1	[✓ 2]	3	4	5
c. Nearby heavy users such as manufacturers	1	[✓ 2]	3	4	5
d. Accident history at the bridge location	1	[✓ 2]	3	4	5
e. Seismic risk Not a problem in D-11	1	2	3	4	[✓ 5]
2. The Business Plan route number designation is sufficient to address service volumes at a bridge site.	1	[✓ 2]	3	4	5
3. Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site. Too much focus may de-emphasize lower ADT routes which are where most SD bridges are located.	1	[✓ 2]	3	4	5

4. The existing considerations are shown for the “Aggregate Risk Score” along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.

		Strongly agree		Neutral		Strongly disagree
35%	Superstructure Condition	1	[✓ 2]	3	4	5
25%	Substructure Condition	1	[✓ 2]	3	4	5
5%	Deck Condition	1	2	3	[✓ 4]	5
Consider 10% - More need to do deck replacements						
5%	Load Capacity	1	2	3	[✓ 4]	5
Consider 10% - Just as important as scour						
20%	Scour	1	2	3	[✓ 4]	5
Should be lower - consider 10%						
5%	Fatigue	1	2	[✓ 3]	4	5
5%	Impact Damage / Over Height Vehicle	1	[✓ 2]	3	4	5

5. The following new consideration may become part of the “Aggregate Risk Score” depending on District input. Indicate your opinion regarding the **proposed magnitude** of weighting factors shown.

		Strongly agree		Neutral		Strongly disagree
5%	Utilities supported by a bridge	1	2	3	[✓ 4]	5
5%	Nearby service sensitive facilities	1	[✓ 2]	3	4	5
5%	Nearby heavy users	1	[✓ 2]	3	4	5
5%	Accident history	1	[✓ 2]	3	4	5
5%	Seismic risk	1	2	3	[✓ 4]	5

	Strongly agree		Neutral		Strongly disagree
6. The existing considerations are shown for the "Structurally Deficient Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **magnitude** of the weighting factors.					
40% Superstructure Condition	1	[✓ 2]	3	4	5
30% Substructure Condition Consider 20%	1	2	3	[✓ 4]	5
20% Deck Condition Consider 30%	1	2	3	[✓ 4]	5
5% Structural Condition Appraisal	1	2	[✓ 3]	4	5
5% Waterway Adequacy	1	2	[✓ 3]	4	5
7. Risk assessment training would benefit District staff. Webinar and Manual would suffice	1	2	[✓ 3]	4	5
8. The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors. Depends on how much time would be required and when this support would be needed.	1	2	[✓ 3]	4	5
9. The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration.	1	2	[✓ 3]	4	5

Thank You!

Notes:

1. This risk assessment should be one of the tools to program work. Easiest projects to do quickly are those that do not involve Right-of-Way such as deck rehabs, painting, etc.
2. Agrees with proposed plan that provides a separate list of updated TIP bridges and coordinates the TIP list with list of remaining system bridges prioritized based on Risk Assessment.
3. Baker noted that the Risk Assessment list is scheduled to be updated in April.

Baker

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DEPARTMENT OF TRANSPORTATION

Risk Management Strategy Survey For District Bridge Engineers

PennDOT District D12-0

Interview Information
Date: January 23, 2009
Time: 1:30 – 2:15 PM
DOT Staff:
Don Herbert & Steve Hoyer
Baker Staff:
Ray Hartle

Instructions:

Thank you for your participation. This survey is being conducted as part of Research Project No. 070802 - **Risk Management Strategy for Bridges and Structures**. Your opinion on the statements below will play a significant role in determining the direction of the project team as development of the Department's updated risk management strategy takes place. Please review each statement in preparation for your phone interview and mark your answer. ***Your answers and comments will be documented by the interviewer.*** The opinion key for all statements is a simple scale of 1 to 5, with 1 meaning you strongly agree and 5 meaning you strongly disagree. Your answers should reflect your experience at the District level.

1. The following additional data items **<u>should be</u>** considered as factors in the risk assessment of a bridge:

	Strongly agree		Neutral		Strongly disagree
a. Utilities supported by a bridge	1	2	[✓ 3]	4	5
Almost a 4. Not a big factor. Mostly a nuisance					
b. Nearby service sensitive facilities such as hospitals	[✓ 1]	2	3	4	5
c. Nearby heavy users such as manufacturers	[✓ 1]	2	3	4	5
d. Accident history at the bridge location	1	[✓ 2]	3	4	5
Important but not considered often.					
e. Seismic risk	1	2	[✓ 3]	4	5

2. The Business Plan route number designation is sufficient to address service volumes at a bridge site. 1 2 3 [✓ 4] 5

3. Consideration of ADT and/or ADTT counts in a more detailed fashion is a better way to address service volumes at a bridge site. 1 [✓ 2] 3 4 5

4. The existing considerations are shown for the “Aggregate Risk Score” along with the currently assigned weighting factor. Indicate your opinion regarding the **<u>magnitude</u>** of the weighting factors.

	Strongly agree		Neutral		Strongly disagree
35% Superstructure Condition	1	[✓ 2]	3	4	5
Should be highest but could be slightly lower					
25% Substructure Condition	1	2	3	[✓ 4]	5
Could be lowered					
5% Deck Condition	[✓ 1]	2	3	4	5
5% Load Capacity	1	2	3	[✓ 4]	5
Should be higher					
20% Scour	1	2	[✓ 3]	4	5
OK as is. Frequency should not affect weighting.					
5% Fatigue	1	2	[✓ 3]	4	5
5% Impact Damage / Over Height Vehicle	1	2	[✓ 3]	4	5

5. The following new consideration may become part of the “Aggregate Risk Score” depending on District input. Indicate your opinion regarding the **<u>proposed magnitude</u>** of weighting factors shown.

	Strongly agree		Neutral		Strongly disagree
5% Utilities supported by a bridge	1	2	3	[✓ 4]	5
Should be 0%					
5% Nearby service sensitive facilities	1	[✓ 2]	3	4	5
5% Nearby heavy users	1	[✓ 2]	3	4	5
5% Accident history	1	2	[✓ 3]	4	5
5% Seismic risk	1	2	[✓ 3]	4	5

Notes:

1. There is a general concern that adding factors will dilute the weight of key concerns like super and sub condition, and load capacity.
2. Spreadsheet is a great tool, matches the Districts programming approach, and is being used as is. However, it is very cumbersome and wastes a lot of time navigating through the data.
3. Interface of a new programming tool with BMS and MMS is desirable.
4. SH Suggested the new interface provide a lead off list of standard queries for various project types such as, PM, painting, and rehab, entitled “What do you want to do?” Each query would have a “customize” option so Districts could tune up the query criteria for the standard items included or add/subtract query items to suit their need.

	Strongly agree		Neutral		Strongly disagree
6. The existing considerations are shown for the "Structurally Deficient Risk Score" along with the currently assigned weighting factor. Indicate your opinion regarding the **<u>magnitude</u>** of the weighting factors.					
40% Superstructure Condition	1	[✓ 2]	3	4	5
30% Substructure Condition	1	[✓ 2]	3	4	5
20% Deck Condition	1	[✓ 2]	3	4	5
Integral decks of slabs and T-beam bridges are not a double dipping issue. Supers Are bad too.					
5% Structural Condition Appraisal	1	[✓ 2]	3	4	5
5% Waterway Adequacy	1	[✓ 2]	3	4	5
7. Risk assessment training would benefit District staff.	1	[✓ 2]	3	4	5
If new processes are involved. Limited staff would participate.					
8. The District is willing to provide support staff to assist the project team in retrospect evaluations of existing sample bridges to help calibrate risk assessment weighting factors.	1	2	3	[✓ 4]	5
Too busy to participate					
9. The AASHTO seismic risk map is sufficient to weight potential seismic activity as a risk consideration.	1	[✓ 2]	3	4	5

Thank You!

Appendix C:
State Survey Questionnaire

Risk Management Strategy Questionnaire
For
State Bridge Engineers

Name of State

(State Contact Name
Street Address
Telephone No.
E-mail address)

1) Does your state have a Risk Assessment for structures based on bridge safety inspection data?

2) Does your state have a Risk Assessment for structures for seismic vulnerability? Scour? Coastal/hurricane? Other?

3) Are any of the following items a factor in the states' Risk Assessment? If so, how are they used in calculating the risk?

- Superstructure rating
- Substructure rating
- Deck rating
- Culvert rating
- Load Capacity (Operating Rating Loads)
- Scour vulnerability (NBI item 113 Scour Critical Bridges)
- Clearance data
- Structural Condition Appraisal
- Waterway Adequacy Appraisal
- ADT/ADTT
- Size
- Detour Length
- Seismic vulnerability
- Vehicular impact
- Accident history at the bridge location
- Fatigue and Fracture (NBI item 92 Critical Feature Inspection)
- State specific bridge types or details
- Service sensitive facilities such as hospitals, heavy users and manufacturers near a bridge
- Vulnerability of terrorist attacks
- Permit routes, for overweight/oversized vehicles
- Utilities supported by structure

Risk Management Strategy Questionnaire

4) Based on experience with events regarding failures, what data would be worthwhile to use in aiding your Risk Assessment?

5) Are external influences (i.e. stakeholder views, user costs, public opinion, economic factors…) considered in the states' Risk Assessment? If so, how are they considered?

6) How do repair and replacement costs influence the states' Risk Assessment?

7) What flexibility exists within the states' Risk Assessment to account for regional or site specific cost differences?

8) How are you prioritizing structure maintenance/replacement needs based on the Risk Assessment data? What latitude is permitted in adjusting the prioritization? How often is a reprioritization of assets conducted?

9) In what ways is your state utilizing the findings of the Risk Assessment data?

10) Does your state utilize PONTIS? Does your Risk Assessment include element level data?

11) In what way has your state customized the PONTIS system in regards to deterioration of specific structure types?

Asset Management

12) Does the DOT currently have or are they working on an Asset Management Program? If so, how long has this program been in place? Please describe or provide documentation discussing the key features of the program.

13) What challenges where encountered during implementation of your Asset Management Program?

14) What software tools are used as part of the Asset Management Program? Does your Asset Management Program utilize Geographic Information System data?
For items such as:

- Detour routes
- Proximity to emergency facilities
- Proximity to fault lines
- Proximity to flood prone waterways

15) Does your Asset Management Program contain a specific Risk Assessment Module?

16) Does this program cover the states entire bridge inventory?

Standard follow up questions

After each question the responder will be queried in detail as to why or how each item has been treated or considered in their state. Specific questions will be formulated based on the responses received to the survey. Follow up questions and responses will be documented.

Appendix D:
State Survey Results

Risk Management Strategy Questionnaire
For
State Bridge Engineers

VIRGINIA

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Observations: Virginia has a prioritization system to determine bridge funding. The system considers 10 factors with associated weights on a fractional scale from 0 to 1. A summation of these weighted factors is calculated to determine the highest priority structures. Virginia maintains 19,400 structures on the statewide system with approximately 1,650 of them being SD.

1) Does your state have a Risk Assessment for structures based on bridge safety inspection data? Virginia has a prioritization tool to determine bridge funding. They are developing a score based system.

2) Does your state have a Risk Assessment for structures for seismic vulnerability? Scour? Coastal/hurricane? Other? No seismic or coastal/hurricane considerations are implemented. Virginia does however consider scour as one of the 10 factors.

3) Are any of the following items a factor in the states' Risk Assessment? If so, how are they used in calculating the risk?
   - Superstructure rating
   - Substructure rating
   - Deck rating
   - Culvert rating

   General condition ratings are one of the 10 factors considered in the prioritization. The least rating obtained from these 4 items, are used in the assessment

   - Load Capacity (Operating Rating Loads) - Virginia considers Load Capacity in their prioritization.
   - Scour vulnerability (NBI item 113 Scour Critical Bridges) - Virginia considers scour in their prioritization.
   - Clearance data - Only used for long range planning, not a factor in initial prioritization
   - Structural Condition Appraisal – Considered to determine deficiency
   - Waterway Adequacy Appraisal – Considered to determine deficiency
   - ADT/ADTT - Virginia considers ADT/ ADTT in their prioritization.
   - Size - Virginia considers deck size in their prioritization.

Risk Management Strategy Questionnaire

- Detour Length - Virginia considers detour length as one of the 10 factors in their prioritization
- Seismic vulnerability – Not considered
- Vehicular impact - Only used for long range planning, not a factor in initial prioritization
- Accident history at the bridge location - Only used for long range planning, not a factor in initial prioritization
- Fatigue and Fracture (NBI item 92 Critical Feature Inspection) - Virginia considers fatigue and fracture as one of the 10 factors in their prioritization
- State specific bridge types or details – None considered
- Service sensitive facilities such as hospitals, heavy users and manufacturers near a bridge - Not a factor in initial prioritization, can be considered on the district level.
- Vulnerability of terrorist attacks - Virginia does not consider terrorist attack in their prioritization.
- Permit routes, for overweight/oversized vehicles - Virginia does not consider permit routes in their prioritization.
- Utilities supported by structure - Virginia does not consider utilities on structures in their prioritization.

4) Based on experience with events regarding failures, what data would be worthwhile to use in aiding your Risk Assessment? Not Applicable

5) Are external influences (i.e. stakeholder views, user costs, public opinion, economic factors…) considered in the states' Risk Assessment? If so, how are they considered? When developing 6 year plan, they solicit feedback from the public. Plan goes to the Commonwealth Transportation Board (CTB) ,which consists government officials and business leaders , who determines final project selection.

6) How do repair and replacement costs influence the states' Risk Assessment?

7) What flexibility exists within the states' Risk Assessment to account for regional or site specific cost differences? A network level cost estimate is calculated. Then project mangers provide detailed cost estimate.

8) How are you prioritizing structure maintenance/replacement needs based on the Risk Assessment data? What latitude is permitted in adjusting the prioritization? How often is a reprioritization of assets conducted? Virginia provides lots of flexibility to reprioritize the 6 year plan. The initial list is provided to each district for reprioritization based on intimate local knowledge of structures.

9) In what ways is your state utilizing the findings of the Risk Assessment data?

Risk Management Strategy Questionnaire

10) Does your state utilize PONTIS? Does your Risk Assessment include element level data? PONTIS and element level data have been used since the early 90's to determine needs.

11) In what way has your state customized the PONTIS system in regards to deterioration of specific structure types? Virginia has extensively modified PONTIS with the addition of smart flags, core elements, deterioration curves and cost models.

Asset Management

12) Does the DOT currently have or are they working on an Asset Management Program? If so, how long has this program been in place? Please describe or provide documentation discussing the key features of the program.
Yes, PONTIS is used for asset management.

13) What challenges where encountered during implementation of your Asset Management Program?
Not applicable

14) What software tools are used as part of the Asset Management Program? Does your Asset Management Program utilize Geographic Information System data?
For items such as:
    - Detour routes
    - Proximity to emergency facilities
    - Proximity to fault lines
    - Proximity to flood prone waterways

    Virginia developed the Roadway Network System using GIS software. It is linked into the PONTIS database to locate all bridges within the states system.

15) Does your Asset Management Program contain a specific Risk Assessment Module?
Risk Assessment is part of the program but not integral with the software.

16) Does this program cover the states entire bridge inventory?

Standard follow up questions

After each question the responder will be queried in detail as to why or how each item has been treated or considered in their state. Specific questions will be formulated based on the responses received to the survey. Follow up questions and responses will be documented.

Risk Management Strategy Questionnaire
For
State Bridge Engineers

MINNESOTA

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State Bridge Engineer
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Observations: Minnesota does not use a probabilistic approach with their risk assessment system. The state utilizes a matrix of conditions to evaluate the rehabilitation, replacement or preservations needs for bridges in the state. An initial prioritized list is generated and provided to the regional offices. The regional offices restructure and reprioritize the list based on intimate knowledge of the structures in the region. Minnesota has 3600 bridges on the state system with 105 being SD. There are also 9,500 local bridges which are not handled by the state system.

1) Does your state have a Risk Assessment for structures based on bridge safety inspection data?
The state has an assessment system that utilizes a decision based matrix to place structures into categories for work type.

2) Does your state have a Risk Assessment for structures for seismic vulnerability? Scour? Coastal/hurricane? Other?
Minnesota stated that scour is considered by the regional offices and is not part of the initial matrix based prioritization.

3) Are any of the following items a factor in the states' Risk Assessment? If so, how are they used in calculating the risk?
    - Superstructure rating Only considered for structurally deficient bridges
    - Substructure rating Only considered for structurally deficient bridges
    - Deck rating Deck condition is the primary factor, in the decision matrix, on which the level of preventative maintenance to be programmed is determined.
    - Culvert rating Only considered for structurally deficient bridges
    - Load Capacity (Operating Rating Loads) Looked at on the regional level, but not considered in the matrix.
    - Scour vulnerability (NBI item 113 Scour Critical Bridges) Looked at on the regional level, but not considered in the matrix.
    - Clearance data Not considered

Risk Management Strategy Questionnaire

- Structural Condition Appraisal Looked at on the regional level, but not considered in the matrix.
- Waterway Adequacy Appraisal Looked at on the regional level, but not considered in the matrix.
- ADT/ADTT is considered in the decision matrix.
- Size Not considered
- Detour Length Not considered
- Seismic vulnerability Not considered
- Vehicular impact Looked at on the regional level, but not considered in the matrix.
- Accident history at the bridge location Looked at on the regional level, but not considered in the matrix.
- Fatigue and Fracture (NBI item 92 Critical Feature Inspection) Looked at on the regional level, but not considered in the matrix.
- State specific bridge types or details Overlay types and rebar protection
- Service sensitive facilities such as hospitals, heavy users and manufacturers near a bridge Not considered
- Vulnerability of terrorist attacks Preformed assessment in 2002 and developed a list of 15 bridges having the highest ADTs and therefore highest risk to terrorist attack. However no replacements are scheduled based on risk of terrorist attack.
- Permit routes, for overweight/oversized vehicles Not considered
- Utilities supported by structure Not considered

4) Based on experience with events regarding failures, what data would be worthwhile to use in aiding your Risk Assessment? 2 girder systems with fatigue prone details and fracture critical details

5) Are external influences (i.e. stakeholder views, user costs, public opinion, economic factors…) considered in the states' Risk Assessment? If so, how are they considered? External influence is entirely at the regional level. Expansion projects are undertaken where the existing structure is in good condition but the cost to replace is cheaper than the cost to widen.

6) How do repair and replacement costs influence the states' Risk Assessment?

7) What flexibility exists within the states' Risk Assessment to account for regional or site specific cost differences? The state currently uses a single cost system state wide. There is no accounting for regional cost variations in the current system.

8) How are you prioritizing structure maintenance/replacement needs based on the Risk Assessment data? What latitude is permitted in adjusting the prioritization? How often is a reprioritization of assets conducted? Initial run is performed with a spreadsheet that implements the decision matrix workflow. The results are then given to the regional offices who adjust the list based on local knowledge.

9) In what ways is your state utilizing the findings of the Risk Assessment data?
The state utilizes a matrix of conditions to evaluate the rehabilitation, replacement or preservations needs for bridges in the state

10) Does your state utilize PONTIS? Does your Risk Assessment include element level data? Minnesota utilizes PONTIS to store bridge inspection data.

11) In what way has your state customized the PONTIS system in regards to deterioration of specific structure types?
Minnesota has added some Smart Flags for specific items. They have also worked on revising the deterioration curves as the feel the existing curves do not accurate model observed deterioration within the state.

Asset Management

12) Does the DOT currently have or are they working on an Asset Management Program? If so, how long has this program been in place? Please describe or provide documentation discussing the key features of the program.
Minnesota uses a 3 part approach to asset management. 1) Program structure replacements 2) Preventative maintenance work (replace expansion joints and seal decks) 3) Reactive maintenance.

13) What challenges where encountered during implementation of your Asset Management Program?
N/A

14) What software tools are used as part of the Asset Management Program? Does your Asset Management Program utilize Geographic Information System data?
For items such as:

- Detour routes
- Proximity to emergency facilities
- Proximity to fault lines
- Proximity to flood prone waterways

GIS is used to display results from programming decisions Primarily for non-engineers to visualize locations of programmed structures.

15) Does your Asset Management Program contain a specific Risk Assessment Module?

16) Does this program cover the states entire bridge inventory? No, only 3500 of the state’s 13,000 bridges is covered by the state system.

<u>Standard follow up questions</u>

Risk Management Strategy Questionnaire

After each question the responder will be queried in detail as to why or how each item has been treated or considered in their state. Specific questions will be formulated based on the responses received to the survey. Follow up questions and responses will be documented.

Risk Management Strategy Questionnaire
For
State Bridge Engineers

NEW YORK

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Observations: New York has 17,400 bridges in the state, 7,500 of which are local. 30% of the bridges are SD which is comparable to the percentage of SD bridges in Pennsylvania. Although New York's inventory is comparable to Pennsylvania, the risk assessment program is not as comprehensive. New York has several modules to assess vulnerability but does not combine the results of each module to generate a overall risk score.

1) Does your state have a Risk Assessment for structures based on bridge safety inspection data?
   Vulnerability assessment - not probability based.

2) Does your state have a Risk Assessment for structures for seismic vulnerability? Scour? Coastal/hurricane? Other?
   Vulnerability assessments are conducted for the following categories: Scour, Seismic, Overload, Steel Details, Concrete Details and Collision.

3) Are any of the following items a factor in the states' Risk Assessment? If so, how are they used in calculating the risk?

   New York bridge ratings are conducted using both NBI Ratings and element level ratings established by New York. The NBI ratings are only performed to comply with federal coding guidelines.

   - Superstructure rating
   - Substructure rating
   - Deck rating
   - Culvert rating
   - Load Capacity (Operating Rating Loads)
   - Scour vulnerability (NBI item 113 Scour Critical Bridges)
   - Clearance data – Used in the collision vulnerability assessment
   - Structural Condition Appraisal
   - Waterway Adequacy Appraisal – Used in the hydraulic (scour) vulnerability module
   - ADT/ADTT is used in the vulnerability assessment modules like fatigue life and steel details.
   - Size

- Detour Length
- Seismic vulnerability
- Vehicular impact – Yes, considered in collision vulnerability module.
- Accident history at the bridge location - only considered at the regional level. Not centralized.
- Fatigue and Fracture (NBI item 92 Critical Feature Inspection)
- State specific bridge types or details - No
- Service sensitive facilities such as hospitals, heavy users and manufacturers near a bridge – not part of the automatic vulnerability assessment. However, Is considered on the regional level when programming structures.
- Vulnerability of terrorist attacks – considered for new structures and signature structures within the state. This equates to approximately 1000 structures within New York.
- Permit routes, for overweight/oversized vehicles
- Utilities supported by structure – Not considered when programming a bridge.

4) Based on experience with events regarding failures, what data would be worthwhile to use in aiding your Risk Assessment? New York wants to implement more optimization capabilities (i.e. optimize assets and more efficiently obtain costs).

5) Are external influences (i.e. stakeholder views, user costs, public opinion, economic factors…) considered in the states' Risk Assessment? If so, how are they considered? Regions consider external influences when programming. Not a factor for the central office when performing statewide programming.

6) How do repair and replacement costs influence the states' Risk Assessment? Repair and replacement costs do not directly influence the state's vulnerability assessment.

7) What flexibility exists within the states' Risk Assessment to account for regional or site specific cost differences? Regions look at statewide prioritization list and set priorities for structures within their individual regions.

8) How are you prioritizing structure maintenance/replacement needs based on the Risk Assessment data? What latitude is permitted in adjusting the prioritization? How often is a reprioritization of assets conducted? 2 year program update cycle at a minimum. Vulnerability is run by central office only. Vulnerability is run in the interim daily or by regional office request. All information is available in a database which can be accessed at any time.

9) In what ways is your state utilizing the findings of the Risk Assessment data? To prioritize structure programming.

Risk Management Strategy Questionnaire

10) Does your state utilize PONTIS? Does your Risk Assessment include element level data?
No, state has proprietary element level system in place.

11) In what way has your state customized the PONTIS system in regards to deterioration of specific structure types? Not Applicable

Asset Management

12) Does the DOT currently have or are they working on an Asset Management Program? If so, how long has this program been in place? Please describe or provide documentation discussing the key features of the program. New York does not currently have an asset management program. The state does have a bridge programming worksheet and is currently evaluating the asset management capabilities in PONTIS.

13) What challenges where encountered during implementation of your Asset Management Program?

14) What software tools are used as part of the Asset Management Program? Does your Asset Management Program utilize Geographic Information System data?
For items such as:
    - Detour routes
    - Proximity to emergency facilities
    - Proximity to fault lines
    - Proximity to flood prone waterways

GIS is used to manage permitting, trace routes and assess bridge needs along the route.

15) Does your Asset Management Program contain a specific Risk Assessment Module?

16) Does this program cover the states entire bridge inventory?

Standard follow up questions

After each question the responder will be queried in detail as to why or how each item has been treated or considered in their state. Specific questions will be formulated based on the responses received to the survey. Follow up questions and responses will be documented.

Project Overview

Michael Baker Jr., Inc. (Baker) in conjunction with the Pennsylvania Department of Transportation (PennDOT) is currently exploring ways to improve and expand upon the Departments established risk assessment program. PennDOT's current risk assessment program was created to quantify risk potential, both structural and functional, on Department-owned bridge types and structures in order to establish measures for mitigation.

Research was conducted and it was determined that your state currently has some form of risk assessment program in place. The attached survey is a series of questions designed to aid in providing PennDOT with a better understanding of risk assessment programs implemented in other states and to utilize that knowledge in further developing and refining PennDOT's current risk assessment program.

Risk Management Strategy Questionnaire For State Bridge Engineers

FLORIDA

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Observations: Florida stated that less than 1% (approximately 60) of the state owned bridges are SD and less than 3% (approximately 300) of combined state and locally owned bridges are SD for state. The low percentage of SD bridges combined with Florida's adequate transportation funding inherently allows Florida to address rehabilitation/replacement of structures as needed.

1) Does your state have a Risk Assessment for structures based on bridge safety inspection data?
   No formal process currently in place.

2) Does your state have a Risk Assessment for structures for seismic vulnerability? Scour? Coastal/hurricane? Other?
   Currently in the process of developing a wave vulnerability program with the University of Florida.

3) Are any of the following items a factor in the states' Risk Assessment? If so, how are they used in calculating the risk?
   - Superstructure rating Equal weighting with substructure
   - Substructure rating Equal weighting with superstructure
   - Deck rating Not an issue due to lack of deicing chemicals or freeze/thaw cycles. Only considered if it is in poor condition
   - Culvert rating Yes
   - Load Capacity (Operating Rating Loads) Important for truck routing (permits). Currently use LRFR.
   - Scour vulnerability (NBI item 113 Scour Critical Bridges) Not a driving factor. Only if observed scour is severe.
   - Clearance data Yes for the turnpike and frequently impacted bridges.
   - Structural Condition Appraisal Not considered
   - Waterway Adequacy Appraisal Not considered

- ADT/ADTT Not used in prioritization for state bridges but is used for local bridges
- Size Not considered
- Detour Length Not considered (except for bridges going to the Keys)
- Seismic vulnerability Not considered
- Vehicular impact Barge impact is considered for navigable waterways
- Accident history at the bridge location Not considered
- Fatigue and Fracture (NBI item 92 Critical Feature Inspection) Only considered once fatigue problems are detected.
- State specific bridge types or details Not considered
- Service sensitive facilities such as hospitals, heavy users and manufacturers near a bridge Not considered
- Vulnerability of terrorist attacks Not considered
- Permit routes for overweight/oversized vehicles Not considered
- Utilities supported by structure Only considered for Keys bridges

4) Based on experience with events regarding failures, what data would be worthwhile to use in aiding your Risk Assessment?
No additional information provided.

5) Are external influences (i.e. stakeholder views, user costs, public opinion, economic factors…) considered in the states' Risk Assessment? If so, how are they considered?
Money comes out of district's pool of money. Not too much interference from legislative end. No problem with funding for bridge replacement. Public opinion regarding historic structures is considered.

6) How do repair and replacement costs influence the states' Risk Assessment?
Not considered

7) What flexibility exists within the states' Risk Assessment to account for regional or site specific cost differences?
Districts have control and decide on what repairs will be performed.

8) How are you prioritizing structure maintenance/replacement needs based on the Risk Assessment data? What latitude is permitted in adjusting the prioritization? How often is a reprioritization of assets conducted?
Not considered

9) In what ways is your state utilizing the findings of the Risk Assessment data?
Not considered

10) Does your state utilize PONTIS? Does your Risk Assessment include element level data?
Inspections conducted using NBI and PONTIS. Element level coding in place since 1998.

11) In what way has your state customized the PONTIS system in regards to deterioration of specific structure types?
Movable bridges, changed condition state language, Deck (coding for top and bottom) not using soffit as smart flag unless condition is severe., prestressed decks, pile jackets, additional load data, miscellaneous applets for extracting information.

Asset Management **DOES NOT HAVE AN ASSET MANAGEMENT PROGRAM**

12) Does the DOT currently have or are they working on an Asset Management Program? If so, how long has this program been in place? Please describe or provide documentation discussing the key features of the program.

13) What challenges where encountered during implementation of your Asset Management Program?

14) What software tools are used as part of the Asset Management Program? Does your Asset Management Program utilize Geographic Information System data?
For items such as:
    - Detour routes
    - Proximity to emergency facilities
    - Proximity to fault lines
    - Proximity to flood prone waterways

15) Does your Asset Management Program contain a specific Risk Assessment Module?

16) Does this program cover the states entire bridge inventory?

Standard follow up questions

After each question the responder will be queried in detail as to why or how each item has been treated or considered in their state. Specific questions will be formulated based on the responses received to the survey. Follow up questions and responses will be documented.

Project Overview

Michael Baker Jr., Inc. (Baker) in conjunction with the Pennsylvania Department of Transportation (PennDOT) is currently exploring ways to improve and expand upon the Departments established risk assessment program. PennDOT’s current risk assessment program was created to quantify risk potential, both structural and functional, on Department-owned bridge types and structures in order to establish measures for mitigation.

Research was conducted and it was determined that your state currently has some form of risk assessment program in place. The attached survey is a series of questions designed to aid in providing PennDOT with a better understanding of risk assessment programs implemented in other states and to utilize that knowledge in further developing and refining PennDOT’s current risk assessment program.

Risk Management Strategy Questionnaire
For
State Bridge Engineers

WISCONSIN

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Observations: Wisconsin, while not having a unified risk assessment program in place, have several independent programs established to evaluate risk assessment in individual categories. The DOT works closely with maintenance personnel when prioritizing rehabilitation projects statewide. Wisconsin has 5,000 state bridges, 9,000 including local with several hundred SD bridges on State Level. The state considers all spans over 5' in the risk assessment system.

1) Does your state have a Risk Assessment for structures based on bridge safety inspection data?
Have multiple independent assessment programs in the state. Scour / Flood zones, Load capacity, vulnerability assessment (terrorism)

2) Does your state have a Risk Assessment for structures for seismic vulnerability? Scour? Coastal/hurricane? Other?
No seismic or coastal conditions. However, barge impact for structures over Mississippi River is considered.

3) Are any of the following items a factor in the states' Risk Assessment? If so, how are they used in calculating the risk? All items are considered to some degree within the programs.

- Superstructure rating
- Substructure rating
- Deck rating
- Culvert rating
- Load Capacity (Operating Rating Loads) High priority
- Scour vulnerability (NBI item 113 Scour Critical Bridges)
- Clearance data High priority for frequent vehicular impacts
- Structural Condition Appraisal
- Waterway Adequacy Appraisal

  → Not good assessments when compared to scour and load capacity
- ADT/ADTT
- Size

- Detour Length
- Seismic vulnerability
- Vehicular impact High priority for frequent vehicular impacts – related to clearance data.
- Accident history at the bridge location
- Fatigue and Fracture (NBI item 92 Critical Feature Inspection) High weight – independent program

- State specific bridge types or details
- Service sensitive facilities such as hospitals, heavy users and manufacturers near a bridge
- Vulnerability of terrorist attacks 3-4 years ago identified approximately 75 bridges based on federal criteria.
- Permit routes for overweight/oversized vehicles
- Utilities supported by structure

4) Based on experience with events regarding failures, what data would be worthwhile to use in aiding your Risk Assessment? Traffic patterns of heavy users, ADT/ADTT

5) Are external influences (i.e. stakeholder views, user costs, public opinion, economic factors…) considered in the states' Risk Assessment? If so, how are they considered? Always have political influences and economics. Try to balance out external influences but safety always governs.

6) How do repair and replacement costs influence the states' Risk Assessment?

7) What flexibility exists within the states' Risk Assessment to account for regional or site specific cost differences?
Working on regional cost factor to adjust costs.

8) How are you prioritizing structure maintenance/replacement needs based on the Risk Assessment data? What latitude is permitted in adjusting the prioritization? How often is a reprioritization of assets conducted? Always, allow districts to reprioritize and have maintenance actively involved in the decision process.

9) In what ways is your state utilizing the findings of the Risk Assessment data?

10) Does your state utilize PONTIS? Does your Risk Assessment include element level data?
Do not use PONTIS but have developed own element level coding manual. Web based used for workflow, deterioration and rating score.

11) In what way has your state customized the PONTIS system in regards to deterioration of specific structure types?

Asset Management

12) Does the DOT currently have or are they working on an Asset Management Program? If so, how long has this program been in place? Please describe or provide documentation discussing the key features of the program.

13) What challenges where encountered during implementation of your Asset Management Program?

14) What software tools are used as part of the Asset Management Program? Does your Asset Management Program utilize Geographic Information System data?
For items such as:
- Detour routes
- Proximity to emergency facilities
- Proximity to fault lines
- Proximity to flood prone waterways

Use GIS for oversize / overweight routing, emergency management, hydraulics (flood prone structures), lane closures. Also uses Google for mapping and reporting.

15) Does your Asset Management Program contain a specific Risk Assessment Module?

16) Does this program cover the states entire bridge inventory?
5,000 state bridges, 9,000 including local. Several hundred SD bridges on State Level bridges Consider all spans over 5'.

Risk Management Strategy Questionnaire For State Bridge Engineers

CALIFORNIA

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Observations: California has an extensive risk assessment program. It is based on the use of multiobjective utility functions (weighting) which combine various components of risk into a singular quantified assessment. Factors such as the Bridge Health Index (BHI) , ADT, Detour Length, Bridge Barriers (Rails), Scour and Seismic Retrofit needs are used in the determination of the risk assessment score. It was stated that seismic and scour where the cause of most structure failures as receive the most weighting accordingly. California utilized the methodology outline in NCHRP 590 regarding the calculation of individual Risk weight . Inspections in California utilizes element level coding only. NBI ratings are no longer utilized.

Out of 13,000 stated owned bridges, 1620 are SD. 92% of bridges are concrete in the state (Only 1300 steel structures). Average age of bridges is around 47-48 years old. The majority of the climate is mild with the harsher areas in the mountains (sand and deicing compounds, freeze thaw cycles) and near the coast (heavy fogging within 5-10 miles of the coast.

1) Does your state have a Risk Assessment for structures based on bridge safety inspection data? Yes

2) Does your state have a Risk Assessment for structures for seismic vulnerability? Scour? Coastal/hurricane? Other? Have individual seismic and scour programs.

3) Are any of the following items a factor in the states' Risk Assessment? If so, how are they used in calculating the risk?
    - Superstructure rating
    - Substructure rating
    - Deck rating
    - Culvert rating

    Element level ratings are used and weighted based on the methodology outlined in NCHRP 590.

    - Load Capacity (Operating Rating Loads)
      Incorporated as part of Strengthening under Mobility Needs which is 1 of 5 utility components needed to calculate the risk score.

Risk Management Strategy Questionnaire

- Scour vulnerability (NBI item 113 Scour Critical Bridges)
  Is included as a utility component for the risk score.

- Clearance data
  Incorporated as part of Raising under Mobility Needs which is 1 of 5 utility components needed to calculate the risk score.

- Structural Condition Appraisal
  Are not used as part of the assessment

- Waterway Adequacy Appraisal
  Are not used as part of the assessment

- ADT/ADTT
  ADT is a factor within 3 utility components when calculating the risk score. It is used in:
  1. Rehabilitation and Replacement Needs
  2. Scour Needs
  3. Seismic Retrofit Needs

- Size
  No

- Detour Length
  Yes

- Seismic vulnerability
  California handles seismic considerations with an internal program. Seismic program is comprised of over 30 individual parameters such as details, soil types, bearing types, distance to fault lines and peak rock accelerations. Bearings other than neoprene and sliding plate are considered high risk.

- Vehicular impact
  Is only considered on deck and is used for Bridge Rail Upgrade Needs, which is one of the 5 utility components. Approach roadway alignment and speed are also considered.

- Accident history at the bridge location
  Is not considered in the initial risk score, but is used for final prioritization. They indicated that accident history would be considered if they would have an adequate database of information.

Risk Management Strategy Questionnaire

- Fatigue and Fracture (NBI item 92 Critical Feature Inspection)
  Fatigue is incorporated in the calculation of the BHI. Information is taken from element level smart flags for fatigue and pack rust.

- State specific bridge types or details
  Rails are problematic in the state. Particularly railings not meeting NCHRP 230 crash test standards. These include timber rails, steel tube rails and concrete picket rail. Also considered are rocker bearings and age of the bridge (older structure equal lack of confinement steel)

- Service sensitive facilities such as hospitals, heavy users and manufacturers near a bridge
  Not directly considered. CALTrans feels ADT covers these issues.

- Vulnerability of terrorist attacks
  Not part of risk assessment. Seismic typically controls over blast forces.

- Permit routes, for overweight/oversized vehicles
  Not considered

- Utilities supported by structure
  Not considered on initial screening process, but can be a factor during final prioritization and considered as part of seismic risk.

4) Based on experience with events regarding failures, what data would be worthwhile to use in aiding your Risk Assessment?
   More detailed seismic information.

5) Are external influences (i.e. stakeholder views, user costs, public opinion, economic factors…) considered in the states' Risk Assessment? If so, how are they considered?
   External influences include detour length and ADT. Analysis of the bridges overrides politics when performing the risk assessment.

6) How do repair and replacement costs influence the states' Risk Assessment?
   A Benefit to Cost ratio is calculated utilizing the Total Project Utility over the Cost. The Cost is calculated based on the square footage of deck. Calculating the B/C ratio allows the state to equally compare bridges of various sizes.

7) What flexibility exists within the states' Risk Assessment to account for regional or site specific cost differences?
   Costs come from advance planning studies. The state keeps an extensive database of costs by region.

Risk Management Strategy Questionnaire

8) How are you prioritizing structure maintenance/replacement needs based on the Risk Assessment data? What latitude is permitted in adjusting the prioritization? How often is a reprioritization of assets conducted?
Structures are prioritized during the preliminary screening process. A team of senior engineers within CALTrans refine the list based upon knowledge of structures within each members assigned region.

9) In what ways is your state utilizing the findings of the Risk Assessment data?
The data is used as part of the programming of bridges.

10) Does your state utilize PONTIS? Does your Risk Assessment include element level data?
Yes

11) In what way has your state customized the PONTIS system in regards to deterioration of specific structure types?
PONTIS is able to perform deterioration prediction. Only tool commercially available that can perform that function. However, since PONTIS utilized a least cost solution. CALTrans has developed external tools that determine life cycle costs based on data from PONTIS.

Asset Management

12) Does the DOT currently have or are they working on an Asset Management Program? If so, how long has this program been in place? Please describe or provide documentation discussing the key features of the program.
No centralized asset program in place. Individual system results are compiled manually.

13) What challenges where encountered during implementation of your Asset Management Program?

14) What software tools are used as part of the Asset Management Program? Does your Asset Management Program utilize Geographic Information System data?
For items such as:
- Detour routes
- Proximity to emergency facilities
- Proximity to fault lines
- Proximity to flood prone waterways

Use GIS for spatial location of inventoried structures, low index bridges, combine individual maintenance activates based on locations of proposed projects.

15) Does your Asset Management Program contain a specific Risk Assessment Module?

16) Does this program cover the states entire bridge inventory?
The program covers the state owned bridges.

Risk Management Strategy Questionnaire

Standard follow up questions

After each question the responder will be queried in detail as to why or how each item has been treated or considered in their state. Specific questions will be formulated based on the responses received to the survey. Follow up questions and responses will be documented.

Risk Management Strategy Questionnaire
For
State Bridge Engineers

TEXAS

Keith Ramsey
State Bridge Inspection Engineer
Texas Department of Transportation
125 E. 11th Street
Austin, TX 78701-2483
512-416-2250
kramsey@dot.state.tx.us

1) Does your state have a Risk Assessment for structures based on bridge safety inspection data?
Texas does not have a centralized risk assessment system. All districts act independently within the state to handle maintenance and replacement of district bridges. Out of 33,000 state owned bridges approximately 340 are SD.

2) Does your state have a Risk Assessment for structures for seismic vulnerability? Scour? Coastal/hurricane? Other?

3) Are any of the following items a factor in the states' Risk Assessment? If so, how are they used in calculating the risk?
    - Superstructure rating
    - Substructure rating
    - Deck rating
    - Culvert rating
    - Load Capacity (Operating Rating Loads)
    - Scour vulnerability (NBI item 113 Scour Critical Bridges)
    - Clearance data
    - Structural Condition Appraisal
    - Waterway Adequacy Appraisal
    - ADT/ADTT
    - Size
    - Detour Length
    - Seismic vulnerability
    - Vehicular impact
    - Accident history at the bridge location
    - Fatigue and Fracture (NBI item 92 Critical Feature Inspection)
    - State specific bridge types or details
    - Service sensitive facilities such as hospitals, heavy users and manufacturers near a bridge

Risk Management Strategy Questionnaire

  - Vulnerability of terrorist attacks
  - Permit routes, for overweight/oversized vehicles
  - Utilities supported by structure

4) Based on experience with events regarding failures, what data would be worthwhile to use in aiding your Risk Assessment?

5) Are external influences (i.e. stakeholder views, user costs, public opinion, economic factors…) considered in the states' Risk Assessment? If so, how are they considered?

6) How do repair and replacement costs influence the states' Risk Assessment?

7) What flexibility exists within the states' Risk Assessment to account for regional or site specific cost differences?

8) How are you prioritizing structure maintenance/replacement needs based on the Risk Assessment data? What latitude is permitted in adjusting the prioritization? How often is a reprioritization of assets conducted?

9) In what ways is your state utilizing the findings of the Risk Assessment data?

10) Does your state utilize PONTIS? Does your Risk Assessment include element level data?

11) In what way has your state customized the PONTIS system in regards to deterioration of specific structure types?

Asset Management

12) Does the DOT currently have or are they working on an Asset Management Program? If so, how long has this program been in place? Please describe or provide documentation discussing the key features of the program.

13) What challenges where encountered during implementation of your Asset Management Program?

14) What software tools are used as part of the Asset Management Program? Does your Asset Management Program utilize Geographic Information System data?
For items such as:
  - Detour routes
  - Proximity to emergency facilities
  - Proximity to fault lines
  - Proximity to flood prone waterways

15) Does your Asset Management Program contain a specific Risk Assessment Module?

Risk Management Strategy Questionnaire

16) Does this program cover the states entire bridge inventory?

Standard follow up questions

After each question the responder will be queried in detail as to why or how each item has been treated or considered in their state. Specific questions will be formulated based on the responses received to the survey. Follow up questions and responses will be documented.

Risk Management Strategy Questionnaire
For
State Bridge Engineers

MICHIGAN

Robert Kelley
Bridge Management Engineer
Michigan Department of Transportation
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Lansing, MI 48909
517-322-1398
kelleyr@michigan.gov

Observations: Michigan has a bridge strategic plan which incorporates both condition state ratings and deterioration rate assessments to determine costs for replacement, rehabilitation or preservation. There are 4500 NBIS and 6500 local bridges statewide. Of these bridges 12% are SD.

1) Does your state have a Risk Assessment for structures based on bridge safety inspection data? Michigan calls it bridge strategic plan or bridge asset management. Their emphasize is broader than "risk assessment" and they do little regarding analytical "risk" assessment. By improving the overall condition of their bridges while working towards eliminating all serious and critical bridges, they feel they are making their bridges safer and reducing risk, however, they do not have a formalized "risk" assessment. They also do more in-depth inspections with specialized engineer bridge inspectors on their fracture critical, complex and fatigue sensitive structures. They manage their complex and large deck area bridges centrally with a dedicated fund.

2) Does your state have a Risk Assessment for structures for seismic vulnerability? No Scour? They are beginning do to asset management of their scour critical bridges. This goes along with preparing action plans for their scour critical bridges. Coastal/hurricane? No Other?

3) Are any of the following items a factor in the states' Risk Assessment? If so, how are they used in calculating the risk?
    - Superstructure rating yes
    - Substructure rating yes
    - Deck rating yes
    - Culvert rating yes
    - Load Capacity (Operating Rating Loads) No. Their policy has always been to avoid posting bridges on their trunkline system. They strengthen them if needed.
    - Scour vulnerability (NBI item 113 Scour Critical Bridges) They are beginning utilize a new scour module.

- Clearance data They have agreements with the FHWA , which routes are exempt from raising when doing 4R work.
- Structural Condition Appraisal this is included in the assessments above
- Waterway Adequacy Appraisal no
- ADT/ADTT no, not directly
- Size yes, deck area is monitored and taken into consideration in the asset management program and they manage their large deck bridges in a special program
- Detour Length not directly
- Seismic vulnerability no. They are not in a significant seismic area
- Vehicular impact no, but since their freeway system was built at the very beginning of the NHS, many of the bridges in the Detroit metro area have substandard under-clearance. Michigan has developed policy as to what bridges need to meet the current standards when doing 4R work
- Accident history at the bridge location. No. Taken into consideration during design
- Fatigue and Fracture (NBI item 92 Critical Feature Inspection). Special in-depth inspections by qualified inspectors are done on these bridges. Michigan policy is to always maintain fracture critical bridge elements in good or fair condition.
- State specific bridge types or details no
- Service sensitive facilities such as hospitals, heavy users and manufacturers near a bridge no. this these types of decisions are handled by our Transportation Service Centers (TSCs) (Michigan is a decentralized state).
- Vulnerability of terrorist attacks no, but they do security assessments on long span authority managed bridges
- Permit routes, for overweight/oversized vehicles no
- Utilities supported by structure no

4) Based on experience with events regarding failures, what data would be worthwhile to use in aiding your Risk Assessment? Identifying problematic details such as link plates and rocker bearings.

5) Are external influences (i.e. stakeholder views, user costs, public opinion, economic factors…) considered in the states' Risk Assessment? If so, how are they considered? Yes, through a 5 year call for projects and MPO process

6) How do repair and replacement costs influence the states' Risk Assessment? Michigan has developed a bridge asset management program that analyzes the optimal "mix of fixes." This includes replacement, rehabilitation, and preventive maintenance projects. The program determines how much money should be put into each of these activities. For example, Michigan does 22% preventive maintenance, 30 percent rehabilitation, and 48% replacement projects. This has slowed the bridge deterioration rate while allowing the DOT to make progress towards bridge condition goals.

Risk Management Strategy Questionnaire

7) What flexibility exists within the states' Risk Assessment to account for regional or site specific cost differences? Lots. Bridge projects are picked by our TSCs and Region bridge engineers.

8) How are you prioritizing structure maintenance/replacement needs based on the Risk Assessment data? What latitude is permitted in adjusting the prioritization? How often is a reprioritization of assets conducted? All is done as described above and it is reviewed during Michigan's annual five year call for projects.

9) In what ways is your state utilizing the findings of the Risk Assessment data? All decisions are based upon the bridge strategic plan as directed by the annual five year call for projects.

10) Does your state utilize PONTIS? Yes Does your Risk Assessment include element level data? Yes. Michigan runs PONTIS and provides a report each year to the Region bridge engineers, however they are just getting PONTIS to the point of calibration where it is starting to give reasonable possible project selections. Much work still needs to be done here. Michigan also has internal programs that assist in project selection and bridge network management.

11) In what way has your state customized the PONTIS system in regards to deterioration of specific structure types? Michigan has modified some AASHTO CoRe elements, and have written agency rules.

Asset Management

12) Does the DOT currently have or are they working on an Asset Management Program? Yes If so, how long has this program been in place? 9 years Please describe or provide documentation discussing the key features of the program. Michigan has set department bridge goals preserving and improving the freeway and non-freeway bridge conditions. They have developed computer programs to monitor bridge condition in accordance to Department goals. They have developed a program called bridge Condition Forecast System (BCFS) that forecasts bridge condition based upon deck area and number of bridges in each NBI condition state, cost to do replacement, rehab, and PM projects, inflation, budget, transition probabilities (bridge deterioration), and project selection strategy. This is all done within the 5 year call for projects which provides policy, guidance, and strategy to each of the seven Regions.

13) What challenges where encountered during implementation of your Asset Management Program? It is easier to develop strategic plans and ideal mix of fixes than it is to implement the plans. It was a challenge to show the benefit of PM. It is a challenge to keep focused on bridge preservation needs. It was a big challenge to get the FHWA to agree to the project selections.

Risk Management Strategy Questionnaire

14) What software tools are used as part of the Asset Management Program? PONTIS, BCFS, Possible Projects, Michigan Bridge Reporting System (MBRS), TRAMS. Does your Asset Management Program utilize Geographic Information System data? TRAMS does. TRAMS 9 (Transportation Asset Management System) shows lists and maps of many road and bridge features, such a SD or FO bridges, traffic data, pavement condition data. MBRS is an internet based system for showing standard bridge reports such as poor bridges , scour critical bridges, bridges programmed. It can also do ad-hoc queries of the bridge data base.
For items such as:
    - Detour routes no
    - Proximity to emergency facilities no
    - Proximity to fault lines no
    - Proximity to flood prone waterways no

15) Does your Asset Management Program contain a specific Risk Assessment Module? no

16) Does this program cover the states entire bridge inventory? Yes, but to different degrees. Local agency bridges are managed by the bridge owners, but many of the same tools are available to them

Standard follow up questions

After each question the responder will be queried in detail as to why or how each item has been treated or considered in their state. Specific questions will be formulated based on the responses received to the survey. Follow up questions and responses will be documented.

Risk Management Strategy Questionnaire
For
State Bridge Engineers

IDAHO

Kathleen Slinger
Bridge Inspection Engineer
Idaho Department of Transportation
P.O. Box 7129
Boise, ID 83703
208-334-8407
kathleen.slinger@itd.idaho.gov

Observations: Idaho does not have a comprehensive risk assessment system. The only risk assessment type system that Idaho employs is a scour critical risk system.

1) Does your state have a Risk Assessment for structures based on bridge safety inspection data?

2) Does your state have a Risk Assessment for structures for seismic vulnerability? Scour? Coastal/hurricane? Other?

3) Are any of the following items a factor in the states' Risk Assessment? If so, how are they used in calculating the risk?
    - Superstructure rating
    - Substructure rating
    - Deck rating
    - Culvert rating
    - Load Capacity (Operating Rating Loads)
    - Scour vulnerability (NBI item 113 Scour Critical Bridges)
    - Clearance data
    - Structural Condition Appraisal
    - Waterway Adequacy Appraisal
    - ADT/ADTT
    - Size
    - Detour Length
    - Seismic vulnerability
    - Vehicular impact
    - Accident history at the bridge location
    - Fatigue and Fracture (NBI item 92 Critical Feature Inspection)
    - State specific bridge types or details
    - Service sensitive facilities such as hospitals, heavy users and manufacturers near a bridge

- Vulnerability of terrorist attacks
- Permit routes, for overweight/oversized vehicles
- Utilities supported by structure

4) Based on experience with events regarding failures, what data would be worthwhile to use in aiding your Risk Assessment?

5) Are external influences (i.e. stakeholder views, user costs, public opinion, economic factors…) considered in the states' Risk Assessment? If so, how are they considered?

6) How do repair and replacement costs influence the states' Risk Assessment?

7) What flexibility exists within the states' Risk Assessment to account for regional or site specific cost differences?

8) How are you prioritizing structure maintenance/replacement needs based on the Risk Assessment data? What latitude is permitted in adjusting the prioritization? How often is a reprioritization of assets conducted?

9) In what ways is your state utilizing the findings of the Risk Assessment data?

10) Does your state utilize PONTIS? Does your Risk Assessment include element level data?

11) In what way has your state customized the PONTIS system in regards to deterioration of specific structure types?

Asset Management

12) Does the DOT currently have or are they working on an Asset Management Program? If so, how long has this program been in place? Please describe or provide documentation discussing the key features of the program.

13) What challenges where encountered during implementation of your Asset Management Program?

14) What software tools are used as part of the Asset Management Program? Does your Asset Management Program utilize Geographic Information System data?
For items such as:
    - Detour routes
    - Proximity to emergency facilities
    - Proximity to fault lines
    - Proximity to flood prone waterways

15) Does your Asset Management Program contain a specific Risk Assessment Module?

16) Does this program cover the states entire bridge inventory?

Standard follow up questions

After each question the responder will be queried in detail as to why or how each item has been treated or considered in their state. Specific questions will be formulated based on the responses received to the survey. Follow up questions and responses will be documented.

Appendix E:
Impact Study of Risk Condition Weight Modifications

Appendix E – Impact Study of Risk Condition Weight Modifications

1.0 Introduction

The development of recommendations for the Task 3 report includes a review and analysis of the methodology behind the Bridge Risk Scoring system used in the Risk Assessment. One of the recommendations developed included adjustments to the weights used to calculate the Aggregate and Structurally Deficient Risk Score. This recommendation was the result of the District surveys conducted as part of Task 2. The Districts indicated a desire to adjust the weighting in some manner; however, the impact of these changes on the existing scores is not readily apparent. A system is required that would provide real-time feedback on changes made to the weights and how it would affect the entire range of risk scores.

In order to determine the impact of adjusting the risk factor weights, a study which calculates the score for every combination of risk factor condition rating was required. The study should provide a graphical representation of the scores for evaluation of trends in the data.

2.0 Assumptions

The study was created to determine the effects of adjusting the weights assigned to risk factors. To ensure only the changes observed in the score were related to weights, the consideration of importance factors was omitted by assuming all importance factors are equal to 1.0 for each case.

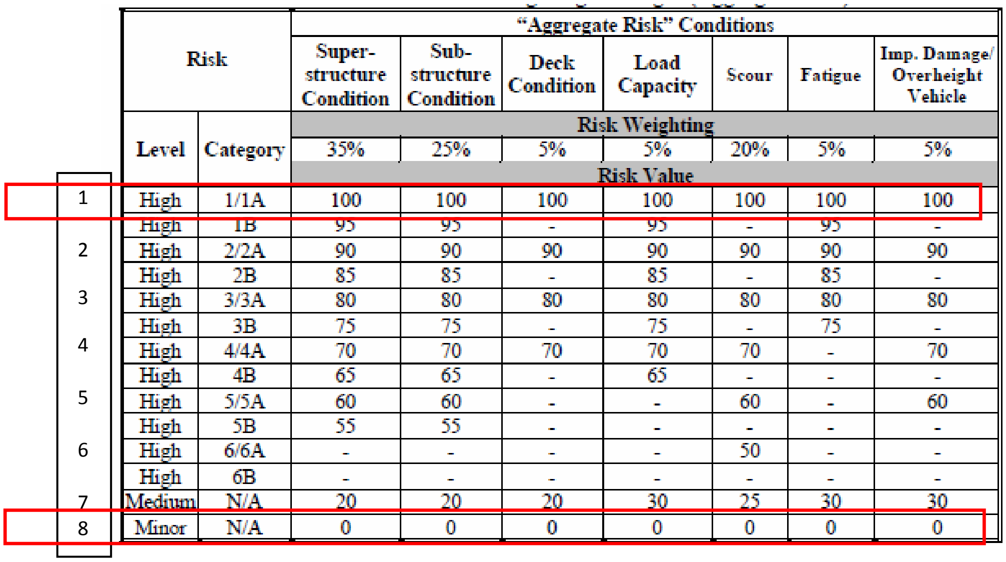
3.0 Data

Microsoft Excel was selected for this study due to the programs ability to manipulate tabular data and for producing various graphs for visual representation of data. Initially, the use of existing data from the Bridge Management System (BMS) was considered. However, it was determined that the data were not suited for testing changes in weights due to an inability to represent all possible combinations of condition ratings.

Since the BMS data does not provide a sufficient amount of rating combinations for global assessment, focus shifted to including every combination of condition rating within the study. However, the amount of data required was excessive (i.e. 2,097,152 lines of information for the Aggregate score and 16,807 for the Structurally Deficient score) and exceeded the limitations within Excel. This prompted the development of a simplified approach.

The methodology for the simplified approach was to test the extreme rating conditions in various combinations. The Table of Numerical Risk Values and Weighting for the Aggregate Score shows that the Risk value for each condition ranges from 0 to 100 depending on the Risk Category (i.e. Condition Rating). By checking only the best and worst ratings, the distance between the two points visually represents all the Risk Values for a Condition that fall within the range (See Figure 3.1). The same methodology was utilized to develop graphs for both the aggregate and structurally deficient risk scores. However, only the table for the Aggregate score is shown in Figure 3.1 for clarity.

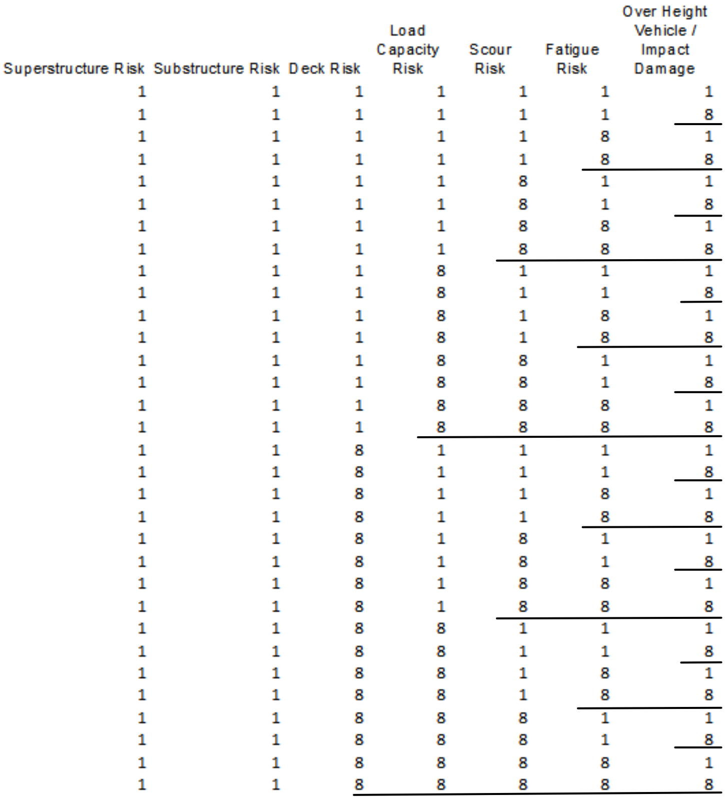
Figure 3.1 – Numerical Risk Values and Weighting – Aggregate Score



	Risk		"Aggregate Risk" Conditions						
			Super-structure Condition	Sub-structure Condition	Deck Condition	Load Capacity	Scour	Fatigue	Imp. Damage/ Overheight Vehicle
			Risk Weighting						
	Level	Category	35%	25%	5%	5%	20%	5%	5%
			Risk Value						
1	High	1/1A	100	100	100	100	100	100	100
	High	1B	95	95	-	95	-	95	-
2	High	2/2A	90	90	90	90	90	90	90
	High	2B	85	85	-	85	-	85	-
3	High	3/3A	80	80	80	80	80	80	80
	High	3B	75	75	-	75	-	75	-
4	High	4/4A	70	70	70	70	70	-	70
	High	4B	65	65	-	65	-	-	-
5	High	5/5A	60	60	-	-	60	-	60
	High	5B	55	55	-	-	-	-	-
6	High	6/6A	-	-	-	-	50	-	-
	High	6B	-	-	-	-	-	-	-
7	Medium	N/A	20	20	20	30	25	30	30
8	Minor	N/A	0	0	0	0	0	0	0

Figure 3.2 shows an excerpt of the rating combinations used to calculate the Aggregate risk score within the spreadsheet. The progression of iterations is delineated to highlight how the spreadsheet encompasses all combinations of best and worst ratings when calculating the risk score. Figure 3.2 only shows the delineation of five Risk Conditions as an example.

Figure 3.2 – Delineated Condition Rating Combinations



Superstructure Risk	Substructure Risk	Deck Risk	Load Capacity Risk	Scour Risk	Fatigue Risk	Over Height Vehicle / Impact Damage
1	1	1	1	1	1	1
1	1	1	1	1	1	8
1	1	1	1	1	8	1
1	1	1	1	1	8	8
1	1	1	1	8	1	1
1	1	1	1	8	1	8
1	1	1	1	8	8	1
1	1	1	1	8	8	8
1	1	1	8	1	1	1
1	1	1	8	1	1	8
1	1	1	8	1	8	1
1	1	1	8	1	8	8
1	1	1	8	8	1	1
1	1	1	8	8	1	8
1	1	1	8	8	8	1
1	1	1	8	8	8	8
1	1	8	1	1	1	1
1	1	8	1	1	1	8
1	1	8	1	1	8	1
1	1	8	1	1	8	8
1	1	8	1	8	1	1
1	1	8	1	8	1	8
1	1	8	1	8	8	1
1	1	8	1	8	8	8
1	1	8	8	1	1	1
1	1	8	8	1	1	8
1	1	8	8	1	8	1
1	1	8	8	1	8	8
1	1	8	8	8	1	1
1	1	8	8	8	1	8
1	1	8	8	8	8	1
1	1	8	8	8	8	8

The technique of only checking extreme conditions led to a significant data reduction (128 lines of information for the Aggregate score and 32 lines for the Structurally Deficient score.) without a loss of integrity to the study.

4.0 *Graphical Representation of System*

The calculated scores are then graphed in a line chart which shows the entire progression of the risk score from 0 to 10,000. Although actual risk scores can exceed 10,000 when importance factors are considered, they have been omitted as stated in Section 2. Figure 4.1 is a graphical representation of the Aggregate risk score based on the existing weights used in the current system. For the purposes of explanation, only the Aggregate risk based charts are shown in this section.

Figure 4.1 – Graphical Representation of Existing Aggregate Risk Scores

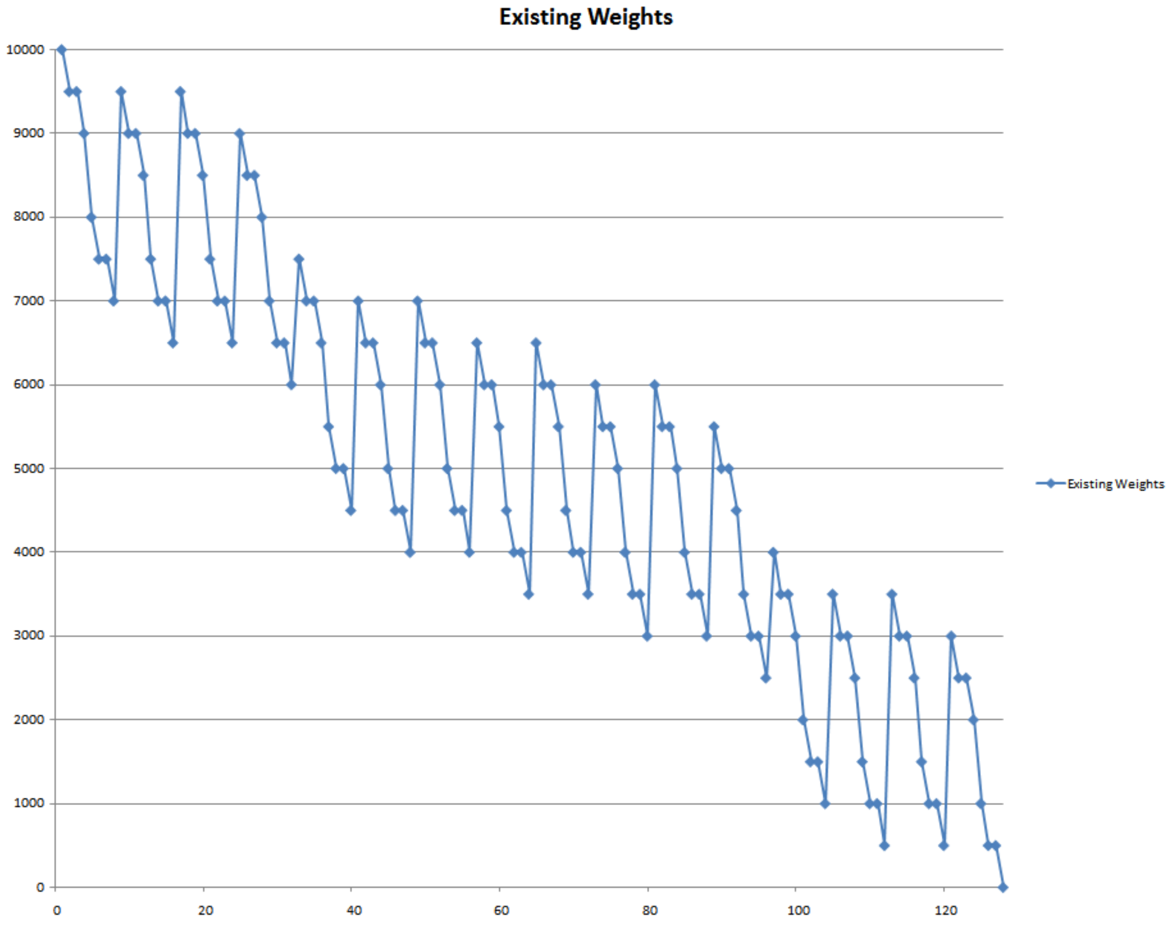
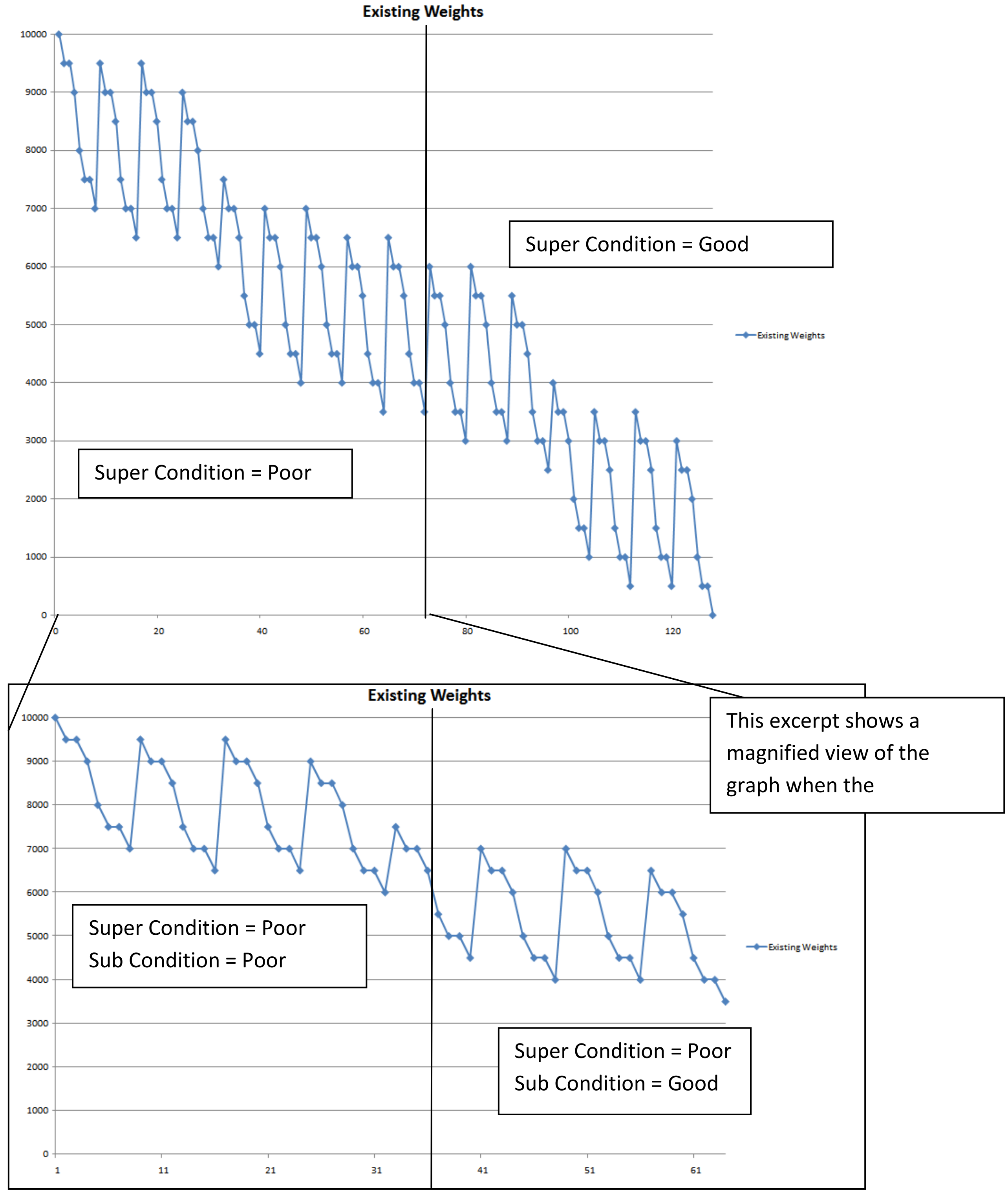


Figure 4.2 represents the influence that individual condition ratings have on the aggregate risk score. The breakdown has been limited to the superstructure and substructure risk conditions only but can be further refined to illustrate all seven risk conditions. For simplicity only one level is shown.

Figure 4.2 – Risk Condition / Condition Rating Relationship

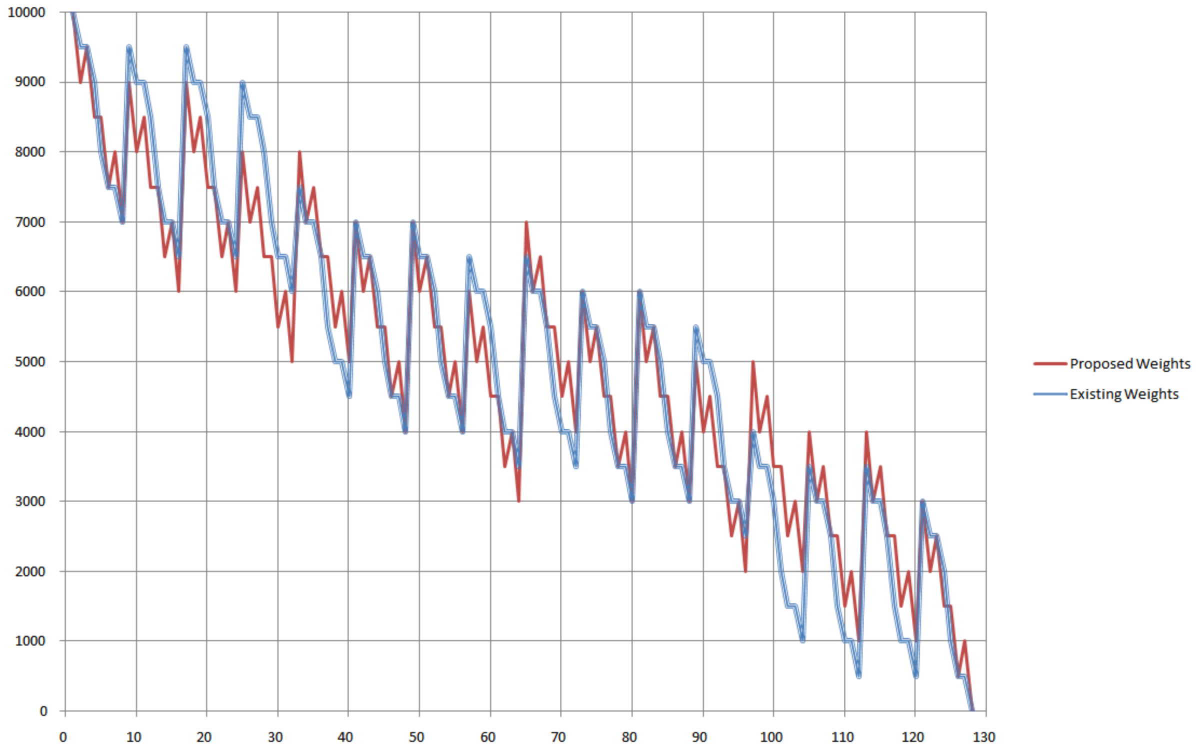


The only variables in the study are the magnitude of the weights associated with each risk condition. By changing the weights, the user receives instant visual feedback on changes to the scoring. This feedback allows for the identification of favorable or non-favorable trends in the scoring when weights are adjusted.

5.0 *Analysis*

In order to better visualize any changes to the weighting, the spreadsheet was setup to provide a side by side comparison of the existing and proposed weights. This allows for quick comparisons of the risk scores to identify trends. Figure 5.1 provides an example of the comparison chart.

Figure 5.1 – Example Comparison Chart



5.1 *District Survey Results*

The next phase of the study consisted of establishing proposed weights for testing. The results of the District Survey from the Task 2 report were the basis of the comparison. Results were analyzed to identify trends in the District responses regarding adjustments to the weights for each risk condition. Due to a mixture of quantitative and qualitative responses from the survey, a tabulation of the data was created to aid in developing a set of proposed changes to the weights. The results of the survey are presented In Figure 5.2.

Risk Management Strategy Questionnaire: Summation of District Responses

Tabulation of Risk Factor Weight Feedback

		Current	Proposed	District 2	District 3	District 4	District 5	District 6	District 8	District 9	District 10	District 11	District 12
Question 4	Superstructure Condition	35%	30%	30%	-	-	30%	25%	-	-	Lower	-	Lower (12a)
	Substructure Condition	25%	20%	-	-	-	20%	- (6a)	-	-	-	-	Lower
	Deck Condition	5%	10%	10%	-	-	10%	25%	-	-	Higher	10% (11a)	-
	Load Capacity	5%	10%	10%	Higher	-	10%	-	-	-	Higher	10% (11b)	Higher
	Scour	20%	15%	15%	-	-	15%	-	Lower (8a)	-	Lower	10%	- (12b)
	Fatigue	5%	5%	-	-	-	-	-	- (8b)	-	-	-	-
	Impact Damage / Over Height Vehicle	5%	10%	-	-	-	10%	-	-	-	-	-	-
Question 5	Nearby Service sensitive facilities	5%	Lower	-	-	-	-	-	-	-	Higher	-	-
	Nearby heavy users	5%	Lower	-	-	-	-	10%	-	-	Higher	-	-
	Seismic Risk		Importance Factor										
Question 6	Superstructure Condition	40%	35%	-	-	-	-	- (6b)	-	-	Lower	-	-
	Substructure Condition	30%	25%	-	-	-	-	-	-	-	Lower	20%	-
	Deck Condition	20%	25%	-	-	-	-	- (6c)	-	-	Higher	30%	- (12c)
	Structural Condition Appraisal	5%	5%	-	-	-	- (5a)	- (6d)	-	-	-	-	-
	Waterway Adequacy	5%	10%	-	-	-	-	- (6e)	-	-	-	-	-

District Comments:
(6a) Super/Sub/Deck could equally put a bridge at risk.
(6b) Super/Sub/Deck should have equal weight.
(6c) Super/Sub/Deck should have equal weight.
(6d) Should consider only inventory rating.
(6e) Maybe switch this item with Scour in Aggregate Risk.

(8a) Existing Scour definition is inadequate.
(8b) Not a true assessment of bridge performance.
Should be Fracture Critical instead.

(9a) Using map would suffice.

(11a) Increased need to do deck replacements.
(11b) Load Capacity as important as scour.

(12a) Should be the highest but could be slightly lower than 30%.
(12b) Frequency should not affect weighting.
(12c) Intergral Decks of slabs in T-Beam bridges are not a double a dipping issue.
Superstuctures are bad too.

Based on the tabular results, the following proposed weights were developed for initial comparison. Figure 5.3 shows both the existing and initial proposed weights for both the Aggregate and Structurally Deficient scores.

Aggregate Score

	Super	Sub	Deck	Load	Scour	Imp/Over	Fatigue
Existing	35%	25%	5%	5%	20%	5%	5%
Proposed	30%	20%	10%	10%	15%	10%	5%

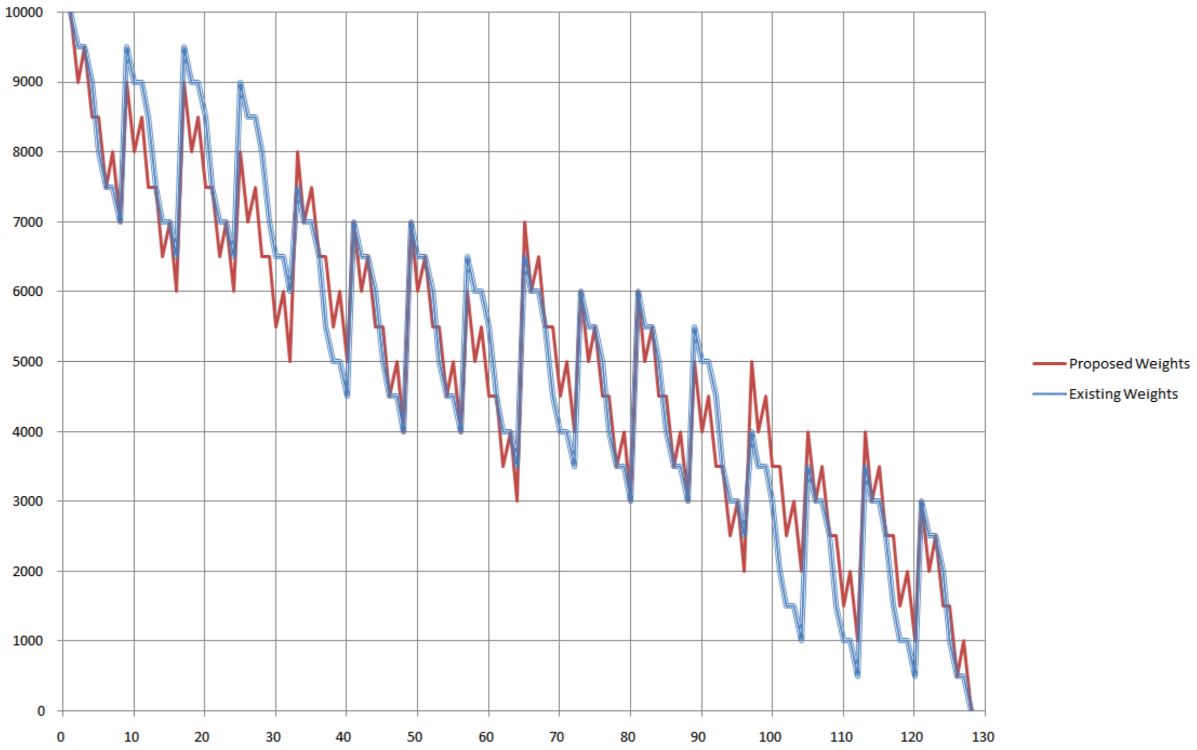
Structurally Deficient Score

	Super	Sub	Deck	Struc Cond Appr	Waterwy Adeq Appr
Existing	40%	30%	20%	5%	5%
Proposed	35%	25%	25%	5%	10%

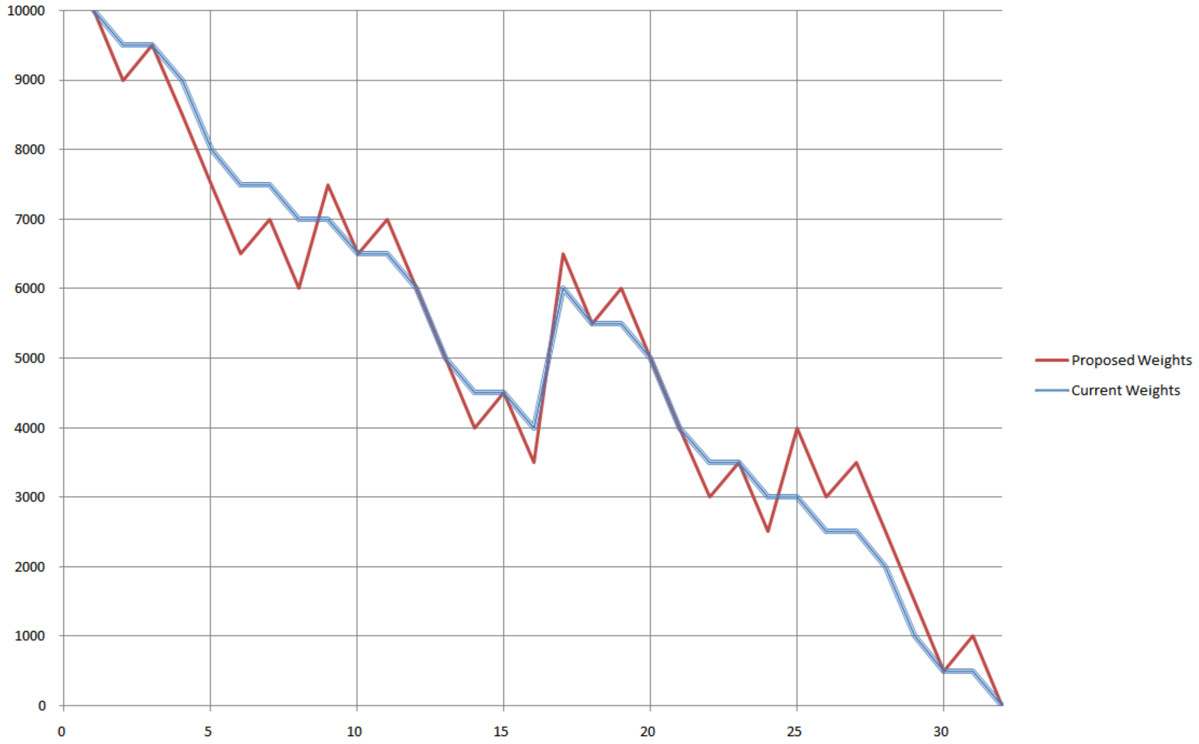
Figure 5.3 – Proposed and Existing Weights

Sections 5.1.1 and 5.1.2 provide a graphical representation of the comparison charts for both the Aggregate and Structurally Deficient Risk Scores respectively.

5.1.1 *Aggregate Risk Condition Weights*



5.1.2 *Structurally Deficient Risk Condition Weights*



6.0 *Recommendations*

Based on the comparison between the existing and proposed changes for both score types, it has been determined that the proposed changes to the weights for both the Aggregate and Structurally Deficient Risk Conditions do not produce drastic changes to the risk score (i.e. 15% maximum). While the changes in the risk score appear to be minimal, what cannot be ascertained within the scope of this study is the global impact any changes would have on the final prioritization. In order to determine the impact to the prioritization, the proposed adjustment to the weights should be implemented and tested against the current risk assessment prioritization list. By utilizing the state's entire bridge inventory, the impact of changes within the prioritization can be readily assessed through comparison. This would facilitate comparison of the existing and proposed weights.