MANAGING THE MAINTENANCE OF VIRGINIA’S ROADS AND HIGHWAYS

Presented to
Project Steering Committee
By

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Agenda

1. Welcome – Wayne Ferguson and Dan Roosevelt
2. Project Overview – Yacov Haimes and Michael Pennock
3. Discussion
4. Lunch
5. Continued discussion
6. Review of information and support needed from steering committee
7. Summary
8. Adjourn
Goal

Develop a risk-cost-benefit modeling and analysis framework to aid the management of maintenance of Virginia roads and highways by the Virginia Department of Transportation.
Presentation Topics

- Knowledge Management
- Principles of Risk Assessment and Management
- Risk of Extreme Events
- Hierarchical Holographic Modeling
- Risk Filtering and Ranking
- Review of Project Tasks
- Information Needs and Discussion Topics
Knowledge Management and Information Systems

The major assets of any organization in this era of dominance of information technology are the quality of the personnel that operate these organizations. According to the Governor’s Commission, VDOT will have 24 percent of its employees eligible for retirement within five years. Furthermore, “VDOT has many professional and competent individuals; however, there are inconsistencies with best management practices to be found in certain key functions which hamper organizational performance.”
One CEO is quoted as saying: “I wish we knew what we know.” Indeed, valuable knowledge, experience, wisdom, and precious institutional memory accumulated over the years with valuable resources are left untapped and their value remains largely wasted by organizational boundaries.
Knowledge Management

• Knowledge exchange can be viewed as a market in which there are buyers, sellers, and brokers of knowledge
• Organizations benefit from having an efficient knowledge market but are inhibited by boundaries
  – *Vertical Boundaries* – barriers between the managerial levels of an organization
  – *Horizontal Boundaries* - barriers between the subdivisions or specialties of an organization (i.e. stovepiping)
  – *External Boundaries* – barriers inhibiting interaction between different organizations (e.g. a producer and supplier)
  – *Geographic Boundaries* – barriers created by distance and physical separation
Knowledge Management

Knowledge-Management Principles:

• Knowledge originates and resides in people’s minds.
• Knowledge-sharing requires trust.
• Technology enables new knowledge behaviors.
• Knowledge-sharing must be encouraged and rewarded.
• Management support and resources are essential.
• Knowledge is creative and should be encouraged to develop in unexpected ways.

Knowledge Management

“Knowledge management: Strategies and processes to create, identify, capture, organize, and leverage vital skills, information, and knowledge to enable people to best accomplish the organization mission.”

Knowledge Management

“Knowledge management addresses the work processes that help people create and leverage knowledge... Knowledge management means making information available effortlessly, in a usable form, to the people who can apply it in their context, so that it is actionable and, thereby becomes knowledge. It means getting: the right information, to the right people, in the right format, at the right time, so they can derive knowledge, and do their jobs better.”

[Brooks 2000]
To be effective and meaningful, risk management must be an integral part of the overall management of a system. This is particularly important in the management of technological systems, such as the physical transportation infrastructure, where the failure of the system can be caused by failure of the hardware, the software, the organization, or the humans involved. Indeed, evaluating the total trade-offs among all important and relative system objectives in terms of costs, benefits, and risks cannot be done seriously and meaningfully in isolation from the broader resource allocation perspectives of the overall organizational structure of VDOT.
Multiobjective Trade-off Analysis is at the Heart of Risk Management

Risks, costs, and benefits are often measured in different units; nevertheless, to manage the system, an acceptable balance is sought.
Technological Age

Risk Management $\approx$ Optimal Balance

Uncertain Benefits

Uncertain Costs

Technology Management:

Man/Machine/Software
- Planning
- Design
- Operation
Risk

A Measure of the Probability and Severity of Adverse Effects

William W. Lowrance, 1976
Risk vs. Safety

Measuring risk is an empirical, quantitative, scientific activity (e.g., measuring the probability and severity of harm).

Judging safety is judging the acceptability of risks – a normative, qualitative, political activity.

(After William W. Lowrance, 1976)
System Failure

Hardware Failure

Human Failure

Software Failure   Organizational Failure
Risk Assessment

Risk Assessment
• What can go wrong?
• What is the likelihood that it would go wrong?
• What are the consequences?

[Kaplan and Garrick 1981].

Answers to these questions help risk analysts identify, measure, quantify, and evaluate risks and their consequences and impacts.
Risk Management

Risk Management

• What can be done and what options are available?
• What are the associated trade-offs in terms of all costs, benefits, and risks?
• What are the impacts of current management decisions on future options?


Answers to these questions help decisionmakers build on the risk assessment process and benefit from sound current and future policy options and their associated tradeoffs.
Risk Assessment

1. What can go wrong?

• Hierarchical holographic modeling (HHM), has served as an effective medium with which to answer this first question.

• HHM can identify the plethora of sources of accidents and hazards that might threaten the system’s survivability and dependability.

• A sample of the multiple visions and perspectives through which the HHM philosophy identifies the myriad sources of risk may include:

  • Hardware
  • Software
  • Institutional
  • Organizational
  • Managerial
  • Temporal
  • Geographical
  • Resource allocation
  • Systems integration and configuration
Risk Assessment

2. What is the likelihood that it would go wrong?

• This second question asks what is the probability of a loss in the system’s dependability and survivability?

• To answer this, the analyst can rely on:
  a) Statistics (documented history),
  b) Expert evidence, using such tools as the fractile method or triangular distribution, and
  c) Scenario analysis, when no prior experience or evidence is available on which to develop probabilities.

• Scenario analysis is common for new untested technology or for plausible terrorist attacks that have not happened yet.
3. What are the consequences?

• This third question may prove to be the most difficult to answer of the first three, because of the inherent interdependencies among our critical infrastructures.

• The consequences may be primary, secondary, or tertiary in their impact.

• Nevertheless, scenario analysis can again fill the gap in our knowledge and offer a mechanism with which to complete the risk-assessment process.
Risk Management

4. What can be done and what options are available?

- The fourth question taxes the imagination of all the professionals commissioned, appointed, or elected to deploy measures that would provide assurance for the system’s dependability and survivability.

- A viable starting point is the list of sources of risk identified through the HHM.

- The analyst, working with the decisionmaker(s), generates viable options to mitigate, control, or, if possible, avoid the risk(s).
Risk Management

5. What are the associated trade-offs in terms of all costs, benefits, and risks?

• This fifth question constitutes the essence of good management, where all costs, benefits, and risks are traded off in a multi-objective framework.

• These are measured in units that are non-commensurable, and any attempt to assign weights to these attributes is likely to lead to a major distortion of the analysis, and the risk management process itself.
Risk Management

5. What are the associated trade-offs in terms of all costs, benefits, and risks?

Note that safety is the level of acceptable risk, i.e., the level of assuring the system’s dependability and survivability. “Safety” is not an absolute goal; rather, it depends on a balance between realizing an acceptable level of risk and the resources needed for assuring that level.
6. What are the impacts of current management decisions on future options?

• This sixth question is a most critical one for any managerial decisionmaking, because, unless the negative and positive impacts of current decisions on future options are assessed and evaluated (to the extent possible), these policy decisions cannot be deemed to be "optimal" in any sense of the word.

• The dynamic nature of almost all systems necessitates evaluating the propagation of the consequences of current policy decisions over time and their impact.
6. What are the impacts of current management decisions on future options?

In sum, good management must incorporate and address risk management within an all-encompassing, holistic, multiobjective framework that incorporates and addresses all critical risks, the relevant resource allocations, and other related management issues.
Quantitative Risk Management

HHM Models

Risk Filtering & Ranking

Influence Diagram

Evidence-based probabilities

Partitioned Multiobjective Risk Method

Multi-objective Decision Trees

Fault Trees

Multiple Objective Resolution

- Minimize Vulnerability
- Minimize Cost
- Minimize Damage
- Maximize Performance
The Fallacy of Expected Value

Note:

Probability = Area of shaded region

Risk = Probability x Damage
Hierarchical Holographic Modeling (HHM)

Hydrological Decomposition
Hierarchical Holographic Modeling (HHM)

Political Decomposition

MAUMEE RIVER BASIN
INDIANA, MICHIGAN AND OHIO
GREAT LAKES BASIN COMMISSION

Center for Risk Management of Engineering Systems
University of Virginia, Charlottesville
Matrix Organization of a Production System

Manufacturing

Manager
Plant 1  Manager
Plant 2  Manager
Plant 3

Marketing

Manager
Product A

Manager
Product B
Product-Plant Decomposition

Higher Level Coordinator

Product Manager A
  - Plant 1
  - Plant 2
  - Plant 3

Product Manager B
  - Plant 1
  - Plant 2
  - Plant 3

First Level
Second Level
Third Level
Plant-Product Decomposition

First Level
- Product A
- Product B

Second Level
- Plant Manager 1
  - Product A
  - Product B
- Plant Manager 2
  - Product A
  - Product B
- Plant Manager 3
  - Product A
  - Product B

Third Level
- Higher Level Coordinator
Using HHM to Identify Risks

• Use Hierarchical Holographic Modeling (HHM) to identify all of the different components of a system
  – Concept: Must view a system from all possible perspectives to gain the most information possible

• Failure scenarios for each system element can be elicited by asking “What can go wrong?” or, alternatively, “How can we make the system fail?”

• Risk Identification phase results is a very large number of possible failure scenarios
Multiple Perspectives on the Hardening of the Water Supply System

- Physical A
  - Hardware
  - Pipes
  - Pumps
  - Wells
  - Aqueducts
  - WTPs
  - WWTPs

- Scope B
  - International
  - National
  - Regional
  - State
  - Local
  - Individual Plant
  - Individual

- Temporal C
  - Long-long (30+)
  - Long (10-30)
  - Intermediate (3-10)
  - Short (1-3)
  - Now

- Maintenance D
  - Affected by Budget
  - Standardization
  - Replacement Parts
  - Proper Operation
  - Technical Personnel
  - Planning for:
    - Life-Cycle
    - Phase Out

- Institutional E
  - Federal
  - Regional
  - State
  - Local
  - Individual

- Organizational F
  - Decision-Making Structure
  - Subordinate Structure
  - Communication
  - Daily Operations
  - Emergency

- Management G
  - Security
  - Short Term Emergency Response
  - Long Term Emergency Response
  - Desalination
  - Ships

- Resource Allocation H
  - Government
  - Loss of Funds
  - Proper Allocation
  - Management
  - O.M. & R.
  - Personnel
  - SCADA
Multiple Perspectives on the Hardening of the Water Supply System

- SCADA I
  - Software
  - Remote Control
  - Modeling Problem
  - Feedback System
  - Wrong Signals
    - False Positive
    - False Negative

- System's Configuration J
  - Centralization
  - Decentralization
  - Problem Isolation
  - Intraconnection
  - Interconnection/ Different Systems
  - Interconnection of H/W
  - Interconnection of H/W & SCADA

- Hydrology K
  - Surface Water
    - Lake
    - River
    - Reservoir
    - Glacier
  - Ground Water

- Geography L
  - Lay of Land
    - Mountains
    - Plains
    - Water Bodies
    - Climate
    - Seasonal Varieties

- External Factors M
  - Threats
    - Insider
    - Insider-Outsider
  - Outsider
  - Group
  - Natural Hazards

- Buffer N
  - Overdesign

- Contaminants O
  - Biological
  - Bio-organic
  - Pathogens
  - Chemical
  - Nuclear
  - Biological
  - Chlorination
  - Salinity
  - Chemical
  - Turbidity
  - pH
  - Toxicity
  - Sediment

- Quality of Surface & Groundwater P

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Using RFRM to Filter Risks

• Filter a large set of failure scenarios down to a small set of critical risks using Risk Filtering and Ranking Method (RFRM)
  – Concept: Uses a series of increasingly stringent criteria to remove non critical failure scenarios

• Takes a large, unwieldy set of failure scenarios (many of which are minor) and reduces it to the most important risks (i.e., top N risks).
The Eight Phases of RFRM

The eight phases of the process are as follows:

- **Phase I** Scenario Identification
- **Phase II** Scenario Filtering Based on Scope, Temporal Domain and Level of Decisionmaking
- **Phase III** Bi-Criteria Filtering and Ranking
- **Phase IV** Multi-Attribute Evaluation
- **Phase V** Quantitative Ranking
- **Phase VI** Risk Management
- **Phase VII** Safeguarding Against Missing Critical Items
- **Phase VIII** Operational Feedback
The overall goal of the effort is to develop risk-cost-benefit modeling and analysis framework (to be tested in either one residency or area headquarters) to aid the management of maintenance of Virginia roads and highways by the Virginia Department of Transportation. Specific objectives of the methodological framework are to enable VDOT and its management to:
• Assess and evaluate the tradeoffs associated with the cost, benefit, and risk to maintenance quality and reliability.

Possible policy options that could be considered:

(i) Continue with the current maintenance and operations program.

(ii) Consider expanding privatized maintenance contracts after appropriate procurements.

(iii) Consider expanding the delegation of maintenance to local governments.

(iv) Optimal combination of (i – iii)

• Evaluate the extent to which VDOT is exploiting and benefiting from information technology.
Project Purpose and Scope

- Evaluate the effectiveness of the knowledge management process followed by VDOT.

- Evaluate the role of maintenance in the survivability and security of threatened transportation infrastructures.

- Transfer the findings to VDOT management and leadership.
Methods

The effort will consist of the following tasks:

Task 1. Assessment of Project’s Needs and Scope  
(in progress)

The main objective of this task is to seek a better understanding of the maintenance issues facing VDOT, and the processes within which current maintenance activities are identified, designed, scheduled, financed, performed (internally or by outsourcing), and inspected for quality assurance. This Task itself is a major undertaking, the results of which would guide the team, the project’s Steering Committee (see Task Two), and VDOT on assessing and determining the level that the other tasks can be realized within the appropriate resources and time table.
Task 2. Steering Committee

A steering committee has been formed to oversee the project progress and to recommend an effective direction for its success.
Methods

Task 3. Study of Available Literature, Resources, and Examples (in progress)

Reports documenting the experience at the national level in the maintenance of transportation systems (and other large-scale systems) published by the Transportation Research Board and other agencies will be consulted. By its nature, the proposed study will build on knowledge and experience from diverse disciplines.

A literature review will be performed on such areas as: Systems engineering, risk assessment and management, transportation systems, life-cycle project management, systems acquisition, organizational behavior, engineering economics, information technology, and information assurance.
Methods

Task 4. Identification and Classification of Opportunities and Sources of Risk
(in progress)

The project team has successfully deployed hierarchical holographic modeling in identification of sources of risk to hurricane preparedness and critical-infrastructure protection for VDOT.

The development and use of the HHM will help to ensure that 'no stone is unturned' in the understanding of maintenance activities of the agency.
Methods

Task 4. continued

Holographic sub-models will include identifying risk scenarios associated with (but not be limited to): organizational structure, time horizon, stakeholders (public and private), geographical, facility types, equipment and materials, finance and accounting, funding sources, allied or supporting infrastructures, failure or degradation modes.
Methods

Task 5. Risk Filtering, Ranking, and Management (RFRM)

The risk filtering, ranking, and management (RFRM) methodology recognizes that limited resources for the risk analysis must be focused early on those scenarios that contribute most to the overall risk in the system.

Qualitative screening of scenarios and classes of scenarios is appropriate initially, while quantitative assessments may be applied once the set of all scenarios (dozens) has been prioritized in several phases.
Methods

Task 5. continued

The multiple risk scenarios associated with the maintenance of Virginia’s transportation system identified in the previous task through the HHM will be filtered and ranked through the RFRM methodology.
Methods

Task 6. Models of Maintenance Efficacy and Impacts (in progress)

Models of the efficacy and impacts of major maintenance and inspection activities (e.g., bridge, drainage, pavement) will be adopted.

The focus will be on understanding the benefits and risks of particular maintenance/inspection programs.

For example, numerous models for maintenance of facilities have been developed and used in the past for better understanding of maintenance and inspection plans. Similar models have been developed for pavement management.
Methods

Task 7. Models of Extreme Events Related to Maintenance

Recent experience of VDOT showed the sensitivity of agency finances (for maintenance and operations) to the variability of weather.

Extreme scenarios such as natural disasters, tampering with information/records, and human errors will be identified and studied to provide an understanding of the vulnerability and sensitivity of VDOT maintenance activities to representative extreme events.

Models of the financial, safety, and other impacts of selected scenarios will be developed.
Methods

Task 8. Cost-Benefit-Risk Analyses of Maintenance Activities

A methodological framework (based on current tools, methods, and practices by the Center for Risk Management of Engineering Systems) and tailored for evaluating the costs, benefits, and risks of maintenance and inspection policies, including sub-contacting, privatization, or assigning maintenance to municipalities will be developed.

The framework will account for representative sources of risk associated with maintenance activities, and will be grounded in sound principles of financial management and public-infrastructure investment.

The framework will be pilot tested on a selected site in consultation with the Steering Committee.
**Methods**

**Task 9. Policy Recommendations for Maintenance Activities**

Working closely with the project steering committee, recommendations for revision and/or continuation of selected maintenance policies of VDOT will be developed for presentation to the Executive Team (ET). Samples of policy recommendations for multiple organizational levels, processes, and organizational divisions will be developed.
Methods

Task 10. Training and Workshops

The results of the above tasks will be presented in training workshops to VDOT managers and engineers. The purpose of the training is to equip VDOT with the decision-aiding tools to support the improvement of its maintenance activities, as needs and opportunities emerge in the future.
Methods

Task 11. Archiving of Results in a Web Site

The results of the effort will be archived in a project web site for use by other DOTs and across VDOT. Case studies, spreadsheets, and reports will be provided at the web site for download by interested agencies. Contact information for VTRC and University of Virginia personnel will be provided.
Methods

Task 12. Interim and Final Reports

Interim progress reports and a final report will be provided according to the specified formats and schedules of the VTRC.
The benefits of the proposed effort include:

- Improved understanding of the efficacy of maintenance activities by VDOT
- Education of VDOT professionals in the practical use of policy analysis tools
- Effective use and justification of public funds for maintenance activities
- Improved quality of public transportation infrastructures
- Reduction of the vulnerability of transportation systems to potential extreme events
Deliverables

The deliverables of the project will be:

1. Review of literature and resources that support the improvement of maintenance activities by VDOT.

2. An enumeration and classification of sources of risk and opportunities for maintenance activities across VDOT.

3. A selection of existing and developed models that provide an understanding of the efficacy and impacts of major maintenance activities.

4. A selection of developed models that provide an understanding of the vulnerability of maintenance activities to extreme events (weather variability, natural disasters, funding, etc.).
Deliverables
(Continued)

5. A framework for cost-benefit-risk analysis of selected maintenance activities.

6. Representative samples of policy recommendations for maintenance activities, for discussion with the ET.

7. Training materials and workshops for dissemination of the results of the effort.

8. A web site for archival of electronic resources (reports, spreadsheets, databases).

9. Interim and final reports
Conceptual Model of Maintenance Process

**Constraints**
- Laws
- Budget
- Procedures
- Resources

**Random Inputs**
- Weather
- Usage
- Customer Requests
- Government Requests

**Input**
- Asset conditions

**Output**
- Asset conditions
- Costs incurred

**Decision Variables**
- Maintenance action for each asset

**Asset States**
Asset Performance with Frequent Maintenance

Condition

Time
Asset Performance with Infrequent Maintenance

Condition

Time
Needed Information and Support

• Existing maintenance or asset performance models
  – E.g., PONTIS

• Data
  – Past asset condition assessments
  – Past maintenance actions including their costs and effects on asset condition
  – Other relevant parameters that impact maintenance decision making

• Understanding of interactions and relationships of factors that affect maintenance and asset conditions
  – E.g., how does weather impact pavement?, how does traffic load impact pavement?

• Understanding of the constraints on the maintenance process
  – Rules and restrictions
  – Constraints on maintenance actions
    ▪ E.g., not possible to patch a collapsed bridge, etc.
Discussion Issues

1. Is the current maintenance schedule based on an optimally well-designed program? Are explicit tradeoffs being made on sound scientific and managerial grounds?

2. To what extent the currently available databases and information systems are being used effectively for inventory and maintenance planning and management decisions? In sum, how should VDOT design and implement a maintenance information system, given the ever evolving user’s requirements and the dynamic nature of the state of practice
Discussion Issues

3. To what extent is the current system working well with outsourcing maintenance projects? How are the contractors being selected and monitored? To what extent is their performance inspected for quality control and for ensuring timely delivery of services and at the contracted cost?

4. Are road conditions improving or deteriorating, and why?

5. Is the rising cost of maintenance due only to inflation and aging, or it is due to other factors related to the two above questions?
Discussion Issues

6. Can systemic risk assessment and management, which has proven its effectiveness in numerous other large-scale systems, provide principled-based answers to the transportation maintenance management challenge?

7. To what extent can knowledge management, enhanced communications, and the creation of an institutional culture within VDOT that is more conducive to building trust among the many parties lead to more effective and efficient maintenance management?
Discussion Issues

8. The development of a risk-cost-benefit modeling and analysis framework provides a decisionmaking methodology that could complement and supplement the ongoing VDOT efforts to produce an integrated information management system.

9. The framework to be developed by the Center for Risk Management of Engineering Systems would provide a set of tools and methods that decisionmakers could use in selecting the most efficient strategies to best maintain Virginia’s roads and highways.

10. There is a potential coupling of the information resources provided by the BMS, PMP, ICAS and other databases and the risk and decision analysis methodologies to be provided by this effort.
Discussion Issues

11. How can we apply the experience of VDOT to developing extreme event scenarios?

12. What additional risk scenarios can be developed from VDOT experience?

13. What data and information can VDOT provide in support of this project?