FRAMEWORK FOR OBJECTIVE RISK ASSESSMENT IN BRIDGE MANAGEMENT

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ABSTRACT
Many agencies have encountered difficulties in funding robust bridge risk management programs. Part of the problem may be the difficulty of communicating priorities between agencies and legislators; in particular, the lack of usable information for informing tradeoffs among alternative investments. To fill the funding gap, there may be a need to fill the communication gap.

Risk incorporates the uncertainty of exogenous events which may adversely impact an agency's ability to accomplish its program objectives. While uncertainty of events is a given, inclusion of risk in asset management is based on the concept that there are asset characteristics that can be measured and managed. In order to combine bridge risk assessment with other investment needs unrelated to bridges or risk, a common measurement scale for project benefits, tied to program objectives, would be very helpful. This can be defined by identifying objectives that all parts of the program share (such as safety), or by reducing all project benefits to dollars or some other common measure.

The application of risk management methodology is closely tied to the needs of asset management business processes. These include needs identification, project benefit and cost estimation, priority setting, and resource allocation. This paper argues that appropriate measures can closely link risk management into existing asset management processes, and that the information produced in this form may be helpful to decision makers responsible for allocating resources broadly across infrastructure categories in a statewide context.

Keywords: Bridges, Structures, Risk, Management

INTRODUCTION

Bridge owners face a variety of risks, understood as probability or threat of unexpected outcomes that is caused by external or internal vulnerabilities, and that may be avoided through preemptive action. Risks can have desirable or undesirable consequences, and may be systemic (affecting the agency or inventory as a whole), or site-specific (affecting specific bridges). Uncertainty of planning metrics can be a contributor to systemic or site-specific risk.

In bridge management, risk assessment focuses more specifically on the threat of damage, injury, or loss related to conditions or events occurring on specific structures. Risk is managed by increasing the resilience (or decreasing vulnerability) of individual structures, or of a portion of the network.

Developing and funding a risk management program for bridges is especially challenging because of the uncertain and long-term nature of project benefits, the large number of potential failure points in a transportation network, and the complexity of developing satisfactory programmatic cost estimates for risk mitigation. It is difficult to know when or where an extreme event might strike, but such events can and do happen with regularity across an asset inventory, causing significant amounts of potentially avoidable damage and injury.

When a major disaster strikes, the public naturally asks why a hazard was not recognized earlier and remediated. The inevitability of such questions may establish a form of accountability for managing the resilience of a transportation network. Moreover, legislative and regulatory action, such as 23 CFR 515.9 on Transportation Asset Management Plans, creates a legal requirement for risk management analysis.

Filling the funding gap

Many agencies have encountered difficulties in funding robust bridge risk management programs. To cite just one example, the Washington State Department of Transportation (WSDOT) in 2012 identified 629 bridges needing seismic retrofit, at a cost of $1.4 billion (*1*). This amount is five times the agency's typical annual budget for pavement and bridge preservation activities. Even with those substantial needs, only $22.4 million was budgeted for the 2011-2013 biennium. Even after passage of a significant gas tax increase, funding for seismic retrofits in the 2015-2017 biennium is only $6.7 million (*2*).

Many reasons could exist for this funding gap, but certainly public awareness of the severity of needs is not one of them. As local media have reported periodically, the risk to the state from major earthquakes has been repeatedly studied, and massive needs have been identified across all types of infrastructure including highways and transit, water and sewer systems, airports and seaports, schools and other public buildings (*3*). It is apparent that the needs estimates are far beyond the state's ability to fund them, but the legislature thus far has not been able to find a more realistic multi-year funding level.

Part of the problem may be the difficulty of communicating priorities between agencies and legislators. While WSDOT is certainly able to prioritize its bridge seismic needs according to relevant technical criteria (such as structure configuration, lifeline routes, traffic volume, and peak ground acceleration), it does not yet have the tools necessary to integrate this priority list with non-seismic programs (such as scour remediation or bridge preservation) (*4*). The legislature lacks appropriate information to balance the risk mitigation needs of highways against those of school buildings and other critical assets (*3*). To fill the funding gap, there may be a need to fill the communication gap.

Toward a framework for risk assessment

Modern bridge management systems, including AASHTOWare Bridge Management (BrM), have multi-objective performance frameworks for project evaluation, priority setting, and resource allocation. The objectives to be maximized, such as those presented in legislation and agency strategic plans, include safety, mobility, condition, and environmental sustainability. At the same time, agencies are continually called upon to minimize life cycle costs and manage risk.

Over the past three decades, therefore, agencies' bridge management system development and implementation efforts have been focused on life cycle cost estimating and assessment of bridge level risk. In the United States, research in state Departments of Transportation such as New York, Minnesota, and Florida have improved on the federal Bridge Sufficiency Rating, a 1970s legacy measure that emphasizes risk. They have developed improved field assessments, incorporated geographically-referenced hazard data, and modern economic models. NCHRP Project 20-07 Task 378 has developed a set of guidelines on quantifying risk for bridge management systems.

Risk incorporates the uncertainty of exogenous events which may adversely impact an agency's ability to accomplish its program objectives. While uncertainty of events is a given, inclusion of risk in asset management is based on the concept that there are asset characteristics that can be measured and managed. In order to combine bridge risk assessment with other investment needs in a larger program for priority-setting or resource allocation, a means must be found to place the bridge risk on a scale that is comparable across all investment categories. This can be by identifying objectives that all parts of the program share (such as safety), or by reducing all project benefits to dollars or some other common measure.

The application of risk management methodology is closely tied to the needs of asset management business processes. These include needs identification, project benefit and cost estimation, priority setting, and resource allocation. Although the overall level of risk is difficult to estimate at the asset and network levels, risk analysis still provides useful tools that serve the more specific needs of these business processes. They can compare the impacts of any two specific projects and direct resources to programs having the most significant likely impact.

RISK ASSESSMENTS USED IN CURRENT PRACTICE

A variety of practices are currently in place to assess risks on highway bridges.

Federal Sufficiency Rating

One of the oldest risk measures used in bridge management is the National Bridge Inventory (NBI) Sufficiency Rating (SR), which was developed in the 1970s and has been a cornerstone of federal management of the national bridge program ever since (*5*). The SR formula can be understood as a proxy for the likelihood of service disruption. The SR is calculated on a scale of 0 (worst) to 100 (best), with the following components:

55% of the rating:
- Condition (deck, superstructure, and substructure ratings)
- Load-carrying capacity (inventory rating and its impact on mobility)

35% of the rating:
- Geometrics (lane width, clearances, alignment)
- Condition and load-carrying capacity (additional weight for overweight truck hazard)
- Waterway adequacy (resistance to scour and overtopping hazards)

15% of the rating:
- Essentiality for public use (changes the relative weights given to the above factors based on traffic volume and network importance)

Up to 13% reduction for:
- Special safety and mobility deficiencies (increases bridge priority to account for especially long detour routes or substandard safety features, affecting a relatively small fraction of bridges)

The SR does not consider likelihood of natural extreme events, and contains very minimal consideration of traffic volume. It was used for priority-setting in the early days of the bridge program, but was not well-suited for benefit/cost analysis since it disadvantaged the large structures which cost more to repair and replace. It is still used in some states as a performance measure, however.

New York State DOT Bridge Safety Assurance Program

Mandated by the New York Highway Law amended in 1989 (also known as the Graber Law), the New York State Department of Transportation (NYSDOT) embarked on developing comprehensive bridge management and safety assurance programs and its own uniform code of bridge inspection (*6*). It conducted a national survey of bridge failures since 1950 and identified hydraulic, overload and collision as significant modes of failure for New York state bridges. Steel and concrete details were considered significant as they presented potential failure vulnerability due to built-in design obsolescence in its existing bridge population. Seismic failure mode was included in this program due to potentially severe consequences if even a single one occurred in the north-eastern US. The six failure modes were then prioritized based on their significance and consequence to New York's transportation network.

In order to assess the vulnerability of its large bridge population, NYSDOT utilizes a multi-level process (Figure 1) with each level successively refining the list of bridges. This enables more detailed evaluation of structures with greater vulnerability. Screening, classifying and rating steps in this process provide increasing understanding of the specific vulnerability of a bridge. Bridges with greater vulnerabilities are progressed first through steps that focus on corrective actions on the most critical bridges in the shortest time. This results in an efficient and staggered progression through the assessment process.

It is important to note that NYSDOT's vulnerability rating step is common across all failure modes. It is intended to provide a uniform measure of a structure's vulnerability to failure based on its likelihood of failure and its consequences should one occur. NYSDOT accomplishes this by separately assigning vulnerability scores that evaluate the likelihood and consequence of failure. It then adds them together to determine the vulnerability rating. These vulnerability ratings range between 0 (best) and 20 (worst). NYSDOT uses the vulnerability rating for short, mid- and longer term priority-setting for needed remedial actions within its operational and capital program planning.

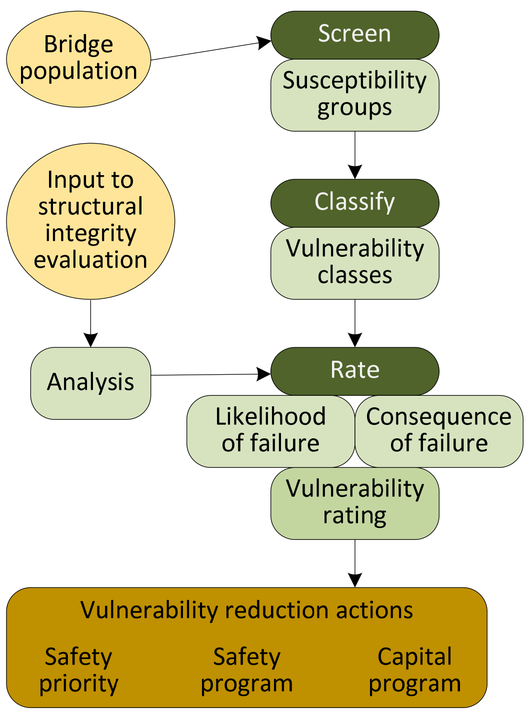

FIGURE 1 New York's multi-level vulnerability assessment

Minnesota DOT Bridge Replacement and Improvement Management (BRIM)
Minnesota DOT uses a risk-based prioritization tool, developed as an Excel spreadsheet called BRIM, to identify and rank most of the bridge projects that are submitted for its Statewide Transportation Improvement Program (STIP) (*7*). BRIM does not develop separate estimates of likelihood and consequence of an event, but instead uses a set of rating tables to convert directly from bridge characteristics in its Pontis database to a measure of utility which it calls the Bridge Performance Index (BPI). These tables were developed entirely from judgment.

Figure 2 shows the table for scour. Minnesota, like many other states, uses a scour classification system that is more detailed than Federal standards. The BPI is reduced if certain defects (formerly smart flags) are present. Similar tables were also developed for fracture criticality, fatigue, overweight trucks, over-height trucks, driver loss of control, and overtopping of the bridge or approach.

The BPI scores represent bridge qualities that the agency controls, that it spends money to improve over time, that reduce the likelihood of transportation service disruption. The BPI score does not consider the site-specific likelihood of adverse natural events such as earthquakes or floods.

In order to use the BPI score for priority-setting, BRIM further adjusts the BPI by moving scores within the 0-100 range based on traffic volume, bridge length, detour length, and network class. The BPI score is used directly for prioritization, without considering project cost or long-term cost, making it a true worst-first framework.

		SCOUR			
		Smart flag reduction			
Code	Description	None	1	2	3
A	Not a waterway	100	100	100	100
E	Culvert	100	100	100	100
M	Stable; scour above footing	90	90	70	40
H	Foundation above water	90	90	70	40
N	Stable; scour in footing/pile	80	80	60	30
I	Screened; low risk	70	70	50	30
L	Evaluated; stable	70	70	50	30
P	Stable due to protection	60	60	40	20
K	Screened; limited risk	60	60	30	20
F	No eval; foundation known	50	50	40	20
C	Closed; no scour	50	50	25	20
J	Screened; susceptible	40	40	30	10
O	Stable; action required	40	40	20	10
G	No eval; foundation unknown	20	20	15	10
R	Critical; monitor	10	10	5	0
B	Closed; scour	0	0	0	0
D	Imminent protection reqd	0	0	0	0
U	Critical; protection required	0	0	0	0

FIGURE 2 Minnesota Bridge Performance Index table for scour

Florida DOT Project Level Analysis Tool (PLAT)

Florida DOT implements the products of its bridge management research in the Project Level Analysis Tool (PLAT), an Excel spreadsheet model built on the AASHTOWare Pontis database to analyze the performance of any one selected bridge (*8*). The PLAT, in turn, contributes estimates of cost and effects to the Network Analysis Tool (NAT), a separate spreadsheet model which is used for priority setting and programming of bridge work on a district and statewide basis.

Philosophically, the performance management approach taken in the PLAT and NAT is to attempt to quantify all costs and benefits in dollar terms at the project and network levels. Each project may affect transportation system performance in a variety of ways: initial cost, life cycle cost, safety, and mobility. These project benefits are considered together in a multi-objective optimization framework. In the FDOT models, the utility function for this multi-objective framework is social cost, consisting of agency, user, and non-user costs.

Florida bridges experience a variety of hazards: hurricanes, tornadoes, wildfires, floods, collisions, advanced deterioration, and fatigue. The causes are, at least in part, outside agency control and subject to random external factors. They are quantified in terms of the likelihood of a hazard event. All of these hazards can cause a bridge to be damaged or destroyed, delivering a consequence to the agency (the cost to repair or replace the structure) and an impact on the public (disruption of transportation service and of the larger economy). Figure 3 shows the basic ingredients.

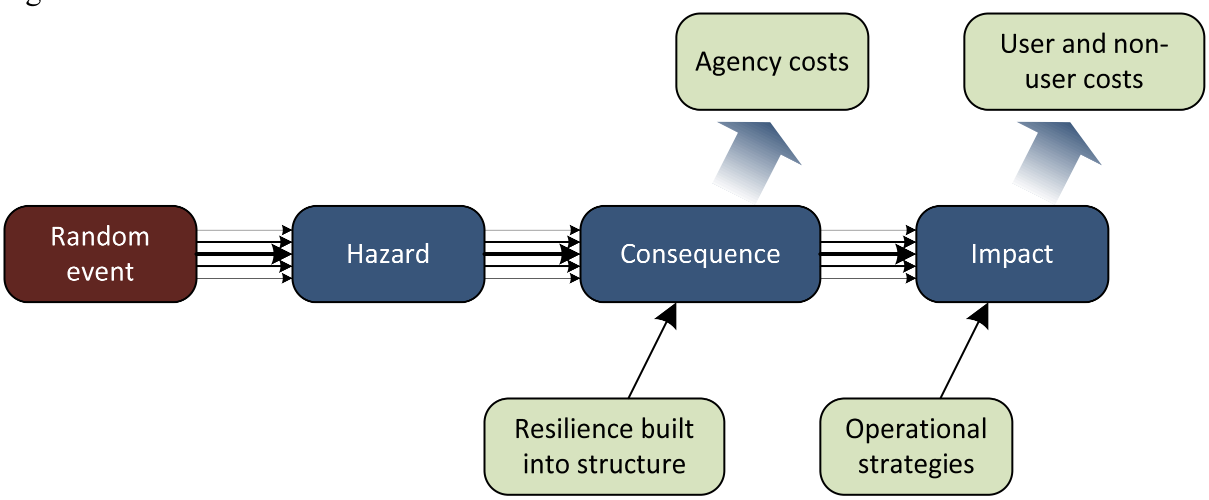

FIGURE 3 Basic ingredients of risk analysis in PLAT

Hazards are modeled probabilistically. At a given bridge site, the hazard can strike with various levels of severity that can be forecast only with a broad concept of probability distribution. Once a hazard strikes, the damage to the structure and impact on the public are also probabilistic, subject to a limited degree of agency control.

For bridge management purposes, the main decision variable in the Florida risk analysis is the selection and timing of programmed actions to increase the resilience of the Department's structures, thus indirectly influencing the social costs caused by hazards. The controllable costs of structure resilience and operational strategies are combined with the more random future outputs of agency, user, and non-user costs due to hazard events, to produce forecasts of life cycle costs. In effect, the programmed and consequential costs of risk are included within the life cycle cost analysis.

In order to place a dollar value on hazard consequences, regional or statewide historical records of hazards and their dollar-valued recovery costs were summarized and used as a gross indication of future risk. This risk is allocated to specific bridges in a way that is reflective of structure resilience and significance. A bridge is assigned more risk if it has a higher probability of an adverse event, if it has less resilience, if it is expensive to replace, or if it is used by a large number of people.

For natural hazards, the probability of an adverse event in most cases is developed from geographically-referenced hazard maps maintained by the state and federal governments. Specialized statistical models were developed for the likelihood of fuel truck collisions, overloads, over-height collisions, advanced deterioration, and fatigue. Resilience in most cases was based on data already available in the FDOT Pontis database, such as structure type, scour assessment, and condition.

Using this perspective, risk is spread in a consistent manner among bridges, and from year to year over time. Risk may gradually increase over time because of traffic growth and deterioration. If a risk mitigation or replacement action takes place, resilience improves and risk is reduced for the time subsequent to the action. The life cycle cost (LCC) of this scenario is the sum of discounted social costs incurred throughout the life of the crossing served by the bridge. Risk-related costs are high without the mitigation action, and lower once the action is applied. The action itself also has a cost. If the life cycle that includes the action has lower total LCC than a life cycle without the action, then it is attractive to perform the work.

For project selection purposes in any given year, LCC can be computed for a variety of feasible actions, including doing nothing, to select the action which minimizes LCC. The total benefit of a project is the savings in LCC relative to doing nothing.

If a project is delayed, this lengthens the period of higher risk costs, and thus increases LCC. The benefit of accelerating a project by one year is the one-year savings in life cycle cost. In a priority programming context where a limited budget must be allocated among projects each year, the best projects are those which would save the most in risk costs, relative to each dollar spent, if they are done this year rather than waiting another year.

RISK IN THE CONTEXT OF ASSET MANAGEMENT

Asset management includes procedures to relate decisions to their effects on agency performance goals, such as safety, mobility, and environmental sustainability. For bridges, condition is a special kind of performance goal because it usually affects road users indirectly, if at all, by means of safety and mobility. However, condition directly affects treatment selection and therefore it affects cost. Risk works in a manner similar to condition: it is unknown to road users unless safety or mobility are affected, but it affects the choice of mitigation action.

Resilience and vulnerability

For certain asset management purposes, it would be useful to have a measure of risk that can be used in the same way that condition is used. Specifically:

- It can be assessed in the field using objective, repeatable procedures derived from observable properties of the asset.
- It has a bounded scale where one end is the best possible performance and the other end is the worst possible performance.
- It provides a fair comparison between two assets regardless of their relative size or utilization, on the best-to-worst scale.
- It can be tracked over time as performance changes due to agency actions and exogenous factors.

Transportation agencies are increasingly concerned with transportation network resilience, and asset management can help to maximize this characteristic by improving the resilience of individual assets. Resilience is defined as:

> "… the capability of a system to maintain its functions and structure in the face of internal and external change and to degrade gracefully when it must" (*9*).
>
> "'Vulnerability' seems largely to imply an inability to cope and 'resilience' seems to broadly imply an ability to cope. They may be viewed as two ends of a spectrum" (*10*).

"Internal and external change" can be interpreted as changes caused within the asset itself (i.e. normal deterioration) and change caused by external forces (natural extreme events, such as floods and earthquakes). "Maintain its functions and structure" can be interpreted as the avoidance of transportation service disruptions.

Reviewing the examples given in the preceding section, it can be seen that the Sufficiency Rating and the measures developed in New York and Minnesota fit this pattern. Resilience is a desirable quality so it could be expressed as a score on a 0-100 scale where 100 is best possible, which is the same range as the sufficiency rating and the bridge health index. Vulnerability is an undesirable quality, so it could be expressed on a reversed scale, where 0 would be best.

Good-fair-poor and network resilience targets

The analogy between condition and resilience can be taken further. Each potential hazard or hazard scenario can be recorded in a manner similar to structural elements, using resilience states. The resilience states might correspond to the good-fair-poor distinction used in federal performance regulations (23 CFR 490). Alaska's Geotechnical Asset Management Plan (*11*) offers the following guidance for standardizing resilience state definitions among dissimilar hazards and asset classes:

> Good: The asset is fully sufficient to resist anticipated hazards and normal deterioration according to current standards.

Fair: The asset is sub-standard, and as a result there is elevated likelihood of mild-to-moderate disruption to mobility, safety, economic efficiency, or other performance objectives on the corridor. Risk mitigation may reduce this likelihood.

Poor: The asset is ineffective in resisting anticipated hazards, and as a result there is high likelihood of severe disruption to corridor performance objectives. Significant investment such as reconstruction may be needed.

The Risk Assessments feature of AASHTOWare Bridge Management can be configured to support resilience or vulnerability assessments structured in this way.

Network resilience targets can be defined and tracked in the same way as federal condition targets. Since safety and mobility risks are proportional to traffic volume, it would be reasonable to weight the network measures by average daily traffic rather than deck area. To make risks comparable between transportation assets and other types of public facilities, such as schools, resilience could be weighted according to the amount of time spent by people when exposed to the risk. Then an agency's performance dashboard for seismic risk might look like the hypothetical example in Figure 4. The performance measure in this graph is computed from average daily traffic, planning metrics for average speed and average vehicle occupancy, and the field assessment of seismic vulnerability or resilience.

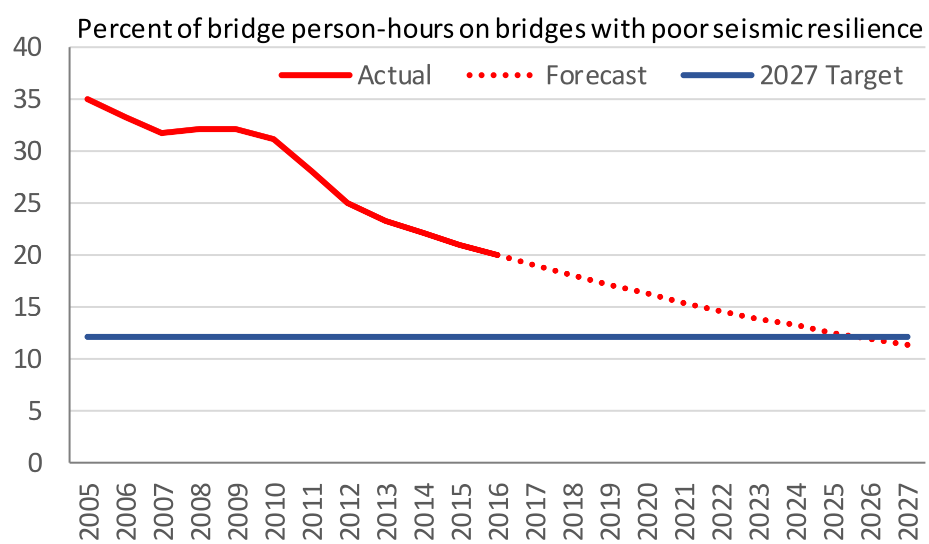

FIGURE 4 Performance dashboard presentation of resilience target tracking

Framework for risk assessment

Figure 5 depicts how NYSDOT utilizes its step by step, multilevel process to conduct hydraulic vulnerability assessment.

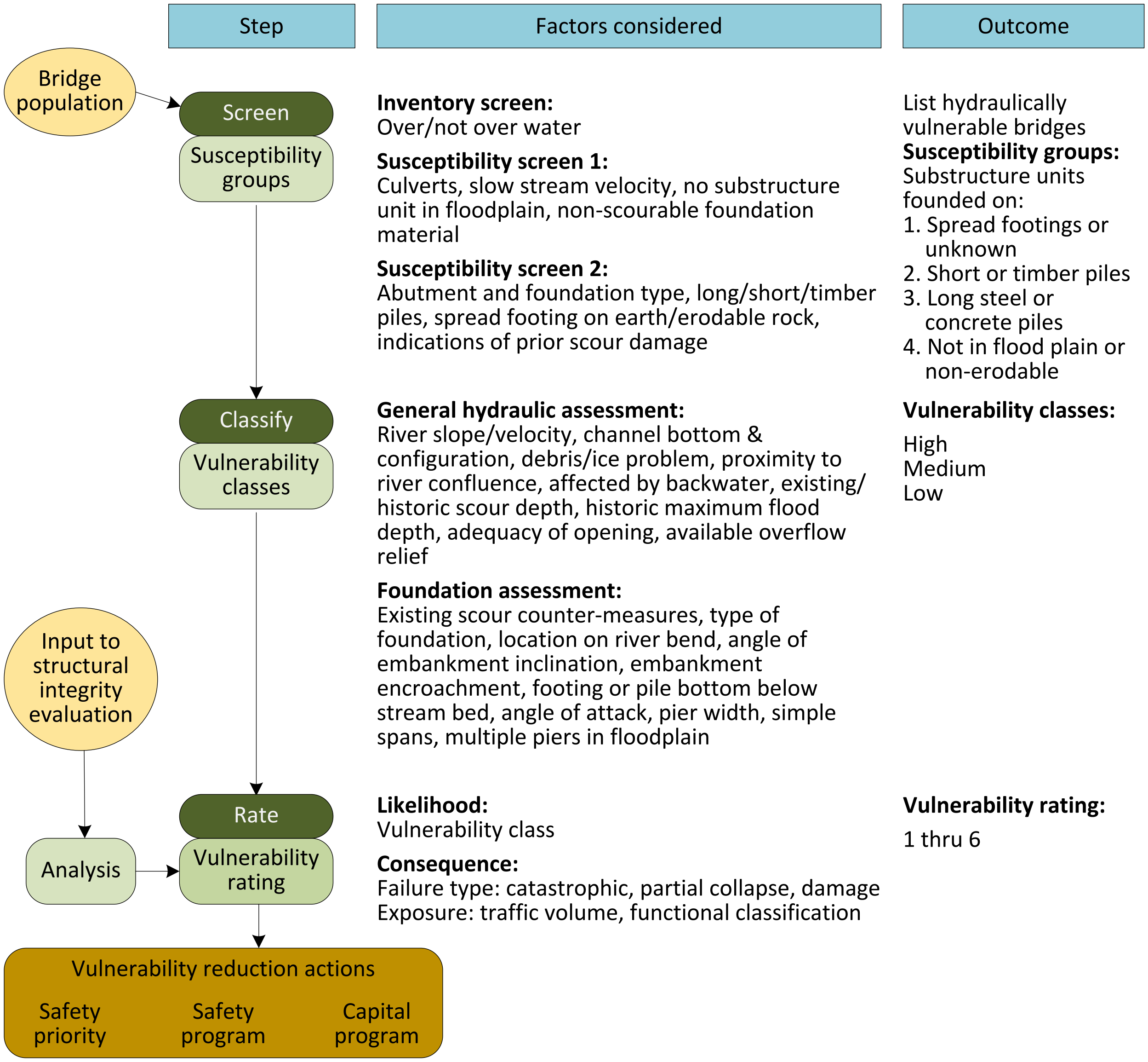

FIGURE 5 Assessment of likelihood and consequence factors – illustrative example

Step 1. Screening for hydraulic vulnerability

The bridge inventory is screened using information from NYSDOT's bridge inventory and inspection system (BIIS) database to identify bridges that do not span water. These are rated 6 i.e. "Not Applicable" and are eliminated from the assessment process. The remaining bridges are then subjected to a two-part susceptibility screening which consists of a review of bridge plans, construction documents, inspection reports and other available information to place bridges in four susceptibility groups 1 (high) through 4 (low), indicating each bridge's relative susceptibility to damage from hydraulic forces, to prioritize them for the next step.

Step 2. Classifying structure hydraulic vulnerability

This step involves evaluation of site hydrology and hydraulic characteristics using general hydraulic and foundation assessment procedures. It quantifies the potential vulnerability of a structure to hydraulic damage relative to other bridges in the classification process and places the structure in the HIGH, MEDIUM or LOW hydraulic vulnerability class. These classes indicate the likelihood of failure and are used in vulnerability rating of a structure. They are also considered in deciding whether a structure should be placed on a flood watch list or a post-flood inspection list.

Step 3. Rating structure vulnerability
The hydraulic vulnerability rating is determined using results of a classification process to assess the likelihood of failure and an evaluation of the consequences of failure in terms of failure type (catastrophic/partial collapse/structural damage) and its exposure (traffic volume and functional classification of route). Rating scores are assigned to the likelihood (1-10) and consequences of failure (0-10) and added together to arrive at final vulnerability rating, which will range between 0 (least vulnerable) and 20 (most vulnerable).

Step 4. Evaluation of vulnerability
This step conducts a detailed analysis of vulnerable bridges, on a prioritized basis, to provide quantitative assessment of the performance of an existing bridge in comparison to current hydraulic design requirements. Results of this analysis are then used in Structural Integrity Evaluation (SIE) to determine the stability of a bridge against hydraulic forces. This analysis is also valuable in designing hydraulic improvements and scour protection counter measures to eliminate or mitigate failure vulnerability of the bridge.

Estimating project benefits
A field assessment of vulnerability or resilience, such as what was described in the preceding section, can be the foundation for assessment of site-based risk for a wide range of hazards from seismic and scour to over-height trucks and advanced deterioration. They can meet many of the requirements for a risk management framework. Additional normalization may be necessary, however, for the following purposes:

- Setting priorities and allocating resources across dissimilar asset classes that are typically managed independently.
- Establishing a basis for prioritization that consistently and objectively considers the cost of risk mitigation and the magnitude of exposure to risks.
- Combining risk avoidance with life cycle cost savings in an overall assessment of project benefits.
- Quantifying the benefits of projects that combine multiple asset classes.
- Evaluating projects that postpone hazardous conditions for a period of time.
- Suggesting a reasonable starting point for balancing safety, mobility, environmental, and economic concerns.

Many of the business processes that require this kind of functionality are concerned with the allocation of agency funding. As a result, it is useful to adopt a relatively simple and standardized set of procedures to convert all types of risk mitigation benefits to dollar values consistent with the framework of life cycle cost analysis. Once in a dollar-denominated form, all the standard tools of economic analysis are available for prioritization, resource allocation, and optimization.

Where managerial or political judgment is required, such as when balancing safety vs environmental vs economic benefits, the economic model provides a starting point for consistent application of such judgment. For example, if an agency uses the Analytic Hierarchy Process, the data source may be a survey asking a panel of decision makers to express preferences between pairs of alternatives. The survey questions could be structured such that each pair consists of alternatives that have equal benefit/cost ratios according to purely economic criteria. The result would then be more valid in quantifying the extent to which safety or another performance concern should be over-weighted.

Converting from an assessment of vulnerability or resilience to an economic project benefit may consist of any or all of the following steps:

1. Estimating the probability of an extreme event of a given magnitude, or hazard scenario.
2. Estimating the probability that a structure will be damaged, if an extreme event occurs, based on the vulnerability or resilience assessment.
3. Estimating the probability that transportation service will be disrupted, if the structure is damaged.
4. Estimating the consequences of a service disruption on outcome performance measures such as accident rate, hours of travel delay, and miles of detours.
5. Converting performance consequences into a dollar amount.

A companion paper (*12*) discusses research-based methodologies that cover these logical steps. Likelihood probability models are provided for 16 hazards including earthquake, landslide, storm surge, high wind, flood, scour, wildfire, temperature extremes, permafrost instability, overload, over-height collision, truck collision, vessel collision, sabotage, advanced deterioration, and fatigue. Consequences of service disruption are estimated in dollars for recovery cost, safety, mobility, and environmental sustainability. These models are based on published research gathered from a wide variety of sources, and consistent with the AASHTO Guide for User and Non-User Benefit Analysis for Highways (the "Red Book") (*13*).

In cases where one or more steps cannot be performed due to lack of data, a generic process known as risk allocation may apply. It consists of estimating the total statewide annual losses from the hazard scenario under investigation, in a top-down fashion from agency statistics, news reports, external advocacy groups, polling of maintenance supervisors, or judgment. Then this total loss is divided among all bridges in the inventory according to vulnerability, traffic volume, and any other relevant available data. This creates a risk formula that can be developed quickly and later improved by means of additional research. Florida's risk models apply this approach (*8*).

IMPLEMENTATION OF A RISK FRAMEWORK

Implementation of any new program or process can be easy or difficult. New York State's Highway Law as amended in 1989 (the Graber Law) was in response to the catastrophic failure of the Schoharie Creek Bridge resulting in 13 fatalities. This law mandated creation of a comprehensive Bridge Safety Assurance (BSA) program. The successful implementation of a BSA program by NYSDOT depended upon objectivity, verifiability and transparency of the process that was to be used to assess the vulnerability of New York state bridges to all potential modes of failure. The BSA manuals NYSDOT developed met these criteria and enabled it to vigorously pursue the implementation of its BSA program. This program produces a list of bridges that need Safety Priority Action (short term), Safety Program (mid-term) and Capital Program (long-term) actions to address the vulnerability to failure. During the first year, 43 bridges were identified as high Safety Priority, due to vulnerability to hydraulic failure. In response, remedial actions to eliminate/mitigate the risk of failure were designed and completed. Most DOTs can undertake such short-term emergency projects to mitigate, if not eliminate, the hazard to public safety. For Safety Program and Capital Program actions NYSDOT uses its vulnerability rating in conjunction with a bridge condition rating. Funding issues do come into play in these instances as bridge needs compete with other DOT needs and priorities.

Bridge engineers understand their responsibility to assure bridge safety for the traveling public, and the necessity for their analyses to be very detail oriented. However, the general public and legislative leaders can understand likelihood and serious consequences of potential bridge failures, only if it is communicated in a simple and credible manner. NYSDOT experience indicates that there were three critical elements in its successful implementation of the BSA program. They were:

1. Commonly shared vision within DOT hierarchy: Collectively NYSDOT decision makers had a strong and clear vision about the BSA program. This vision was founded on objectivity, verifiability and transparency of the vulnerability assessment process that was developed and being implemented.
2. Authorizing environment: The general public, state legislative leaders and the Governor were supportive and understood that, while technical, NYSDOT's BSA program was objective, verifiable and transparent. NYSDOT's annual reports assured the legislature that BSA goals were set logically and were measurable. This was a convincing example of the Barcelona Principle, "Goal setting and measurement are fundamental to communications and public relations".
3. Organizational capacity: As it passed the Graber Law, state legislature also authorized additional staff positions specifically designated to carry out BSA activities. With this addition, NYSDOT had adequate in-house expertise available in its Structures Design and Construction Division to implement the BSA program.

It can be seen from the description of New York's methodology that it is highly summarized relative to an engineering vulnerability analysis. While the more detailed information is necessary for engineering decision making, the less detailed presentation was equally necessary for informing senior leadership and political decision makers who allocate resources.

CONCLUSIONS

Although risk assessment methodology is not as standardized as condition assessment, a combination of experiences from several states can provide a complete implementable framework. A simplified scale of vulnerability or resilience, with common well-understood definitions across hazards and asset classes, has been critical for most agencies that have successfully implemented risk management programs. Resilience can be used alongside condition as a means of prioritization, as has been done in New York State DOT.

The ability to convert a vulnerability or resilience assessment into a reasonable estimate of economic project benefits is essential for business processes that involve funding allocation, that must balance economic and non-economic objectives, and that must consider inter-temporal tradeoffs, such as advancing or delaying projects, in the face of fiscal constraints. Incorporating risk in the same framework as life cycle cost, safety, mobility, and environmental sustainability represents an application of multi-objective decision making that includes risk management. The case studies show that these elements are feasible using reasonable data requirements within bridge management systems or spreadsheets.

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