Decision Analytic Techniques for Assessing Critical Infrastructure Resilience and Risk

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Abstract - Operating performance measures for critical infrastructure are common metrics used by practitioners to gauge the health of their critical infrastructure. Since the events of 9/11, the nation has become increasingly aware of the importance of capturing protection and resilience information for critical infrastructure for different types of potential hazards. As the national risk landscape continues to evolve (e.g., weather patterns grow more erratic) the need to understand and capture this information grows even more important. A complete assessment of performance should integrate the notions of vulnerability, resilience and consequences related to system operations. Managers need metrics to assess the performance of their systems and tools that provide a systematic approach for informing decisions under uncertainty. Such tools could also allow managers to better understand the risks their organization face and evaluate the options available to reduce those risks.

In order to consider a holistic assessment of operational risk, it is first necessary to agree on the definition of risk. In the National Infrastructure Protection Plan (NIPP), risk for critical infrastructures is defined as a function of the threats (T), vulnerabilities (V), and consequences (C) possibly generated. Resilience measures factor into the risk equation as a modifier of the level of consequences. These components of risk and the different steps of emergency management (preparation, mitigation, response and recovery) can be visualized under a bowtie representation (Figure 1).

The vulnerability and resilience postures of critical infrastructure to a specific threat or hazard (manmade or natural) will influence the size of consequences. In general, low vulnerability will result in fewer consequences, whereas, high vulnerability will result in larger consequences. Along a similar train of thought, high resilience features will result in fewer consequences as opposed to lower resilience features, which will result in higher consequences.

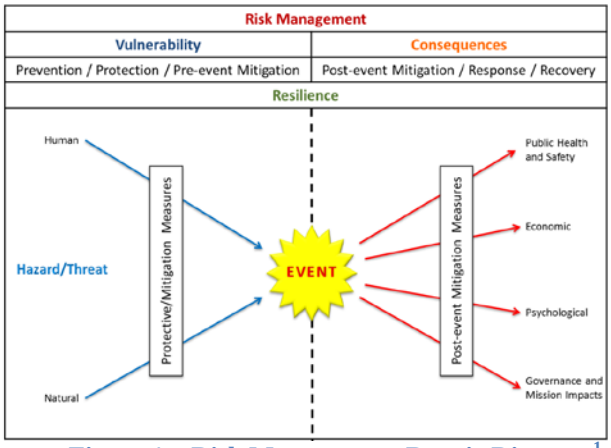

Figure 1 – Risk Management Bowtie Diagram[1]

Decision analysis techniques can be applied to develop specific indicators and metrics that assist in the analysis of risk performance of a critical infrastructure. Utilizing the principles of multi-attribute utility theory (MAUT), the components of risk (e.g., threat, vulnerability, resilience, and consequences) can be disaggregated into individual subcomponents, each focusing on capturing the multiple dimensions that comprise the components of risk. This process requires a close working relationship between decision analysts and subject matter experts to ensure adequate information is captured (appropriate and comprehensive representation) for each of those components of risk. As the different components are disaggregated into subcomponents, it often becomes apparent that there many levels of information are necessary for adequate representations of such complex notions.

An example of the process described above can be illustrated using the concept of resilience. There exist a plethora of definitions surrounding resilience in many different contexts. In general, resilience of critical infrastructure can be defined as *"the ability of an entity — e.g., asset, organization, community, region — to anticipate, resist, absorb, respond to, adapt to, and recover from a disturbance."*[2] In order to capture resilience, the subcomponents that comprise resilience are, anticipation, resisting, absorbing, response, adaptation and recovery. Each of these subcomponents can be decomposed further. For example, recovery can be characterized by the

[1] Adapted from Petit, F.D., G.W. Bassett, R. Black, W.A. Buehring, M.J. Collins, D.C. Dickinson, R.E. Fisher, R.A. Haffenden, A.A. Huttenga, M.S. Klett, J.A. Phillips, M. Thomas, S.N. Veselka, K.E. Wallace, R.G. Whitfield, and J.P. Peerenboom, Resilience Measurement Index: An Indicator of Critical Infrastructure Resilience, Argonne National Laboratory, Decision and Information Sciences Division, ANL/DIS-13-01, Argonne, Ill, USA, 2013.
[2] Ibid.

existence of restoration agreements, the existence of backup to critical services and the time it will take for the infrastructure to regain full operations.

After each risk component is decomposed, subject matter experts are interviewed to estimate weights for each component and subcomponent. The weight represents the relative importance of a component or subcomponent in the overall representation of an infrastructure's vulnerability, threat, resilience and/or consequence. The methodology relies on a decision analytic approach that helps manage risk under conditions of uncertainty[3,4] and quantitatively captures the subject matter expert "value structure" for each of the components and subcomponents. This value structure, similar to the creation of a utility function in economics, captures the relative importance of the different components on a consistent and meaningful scale.

Each key performance indicator that characterizes a specific component of risk is thus defined by the aggregation of its levels of information. The associated indices are defined to vary between 0 and 100, which facilitates comparison among the risk components and subcomponents of a critical infrastructure. The meaning of a score of 62, for example, on a risk component is difficult to interpret in isolation. An individual score becomes more meaningful when it is compared with a set of similar critical infrastructure facilities or assets. The comparison can be made at the different levels of the organizational trees from the overall indicator values (e.g., vulnerability) to the base (data) levels (e.g., relative effectiveness of keypads in access control). The lower-level comparisons provide good starting points to identify measures that may be worthy options for consideration to be added or upgraded at the facility. The higher-level comparisons provide a good indication of how a facility's posture (e.g., vulnerability), compares with that of other similar facilities.

Assessing the risk related to the operations of complex organizations is not easy. It becomes more difficult when it is necessary to define specific indicators that characterize the performance of an organization in terms of protection, vulnerability, resilience, consequences and even capabilities in general. This paper proposes a methodology, based on traditional principles in use in industrial risk management (MAUT, tree organization) to define key risk performance indicators. Combining and comparing these indices provides the potential for improved risk management. These indices provide decision support for comparing within a critical infrastructure promoting a proactive approach and improvement in facilities' preparation in the context of business continuity and emergency management. Ultimately, the user has to decide what is acceptable or not in terms of protective and resilience measures and consequences. The methodology is not developed to replace decision makers, but to support their decisions and to propose possible actions that can assist in the management of complex interconnected systems.

Keywords—critical infrastructure resilience; decision analysis; multi-attribute utility theory

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[3] Keeney, R.L., 1992, Value-Focused Thinking: A Path to Creative Decisionmaking, Harvard University Press, Cambridge, Mass.

[4] Keeney, R.L., and Raiffa, H., 1976, Decisions with Multiple Objectives: Preferences and Value Tradeoffs, John Wiley and Sons, New York.