Toward System Performance Standards for Infrastructure Systems Impacted by Natural Hazards

Craig Taylor[1], Aff.M. ASCE, Stuart D. Werner[2], M. ASCE, and Bill Graf[3], M. ASCE

[1] President, Natural Hazards Management Inc., and Research Associate Professor, University of Southern California, cetaylor@earthlink.net
[2] Principal, Seismic Systems and Engineering Consultants, sdwerner@ix.netcom.com
[3] Earthquake Risk Group Manager, URS Corporation, William_Graf@urscorp.com

ABSTRACT

Even though many disciplines familiar to the audience may have adopted a systems approach to the development of standards, the same is not currently widespread for natural hazards standards for infrastructure systems and components. Beginning with the formation of American Lifelines Alliance (ALA), this paper emphasizes the evolution of attempts to promote a systemic approach to performance standards for components in infrastructure systems. Covered are selected projects performed through ALA. In addition, projects for the Multidisciplinary Center for Earthquake Engineering/Federal Highway Administration (MCEER/FHWA), the California Department of Transportation (CALTRANS), the Port of Los Angeles, the Port of Oakland, San Francisco International Airport, and the United States Geological Survey (USGS) indicate the importance of a systemic approach to the development of standards for components in infrastructure systems. At the same time, reasons are provided as to why the notion of "system performance" standards have not yet been more widely extended to natural hazards generally.

INTRODUCTION

Systemic failures have occurred over time as a result of natural disasters. In more recent times, the Port of Kobe lost all its berths during the 1995 earthquake and subsequently a significant long-term share of its trans-shipment throughputs as the Port took a year to rebuild its berths. (See Werner et al., 1997). The 2005 Hurricane Katrina revealed many systemic weaknesses now under study, and not the least of which was the failure of the levee system surrounding New Orleans to cope with storm surge associated with a category 4 hurricane.

Decision-making procedures in the aerospace industry have long preoccupied themselves with potential systemic failures. (see for instance NASA, 1995; oral comm., J. Collins, 7/05.) The same is less true for natural hazards, excluding those decision-making procedures for a very special class of facilities such as dams and nuclear power plants.

Indications of lagging progress in incorporating systemic metrics into natural hazards decision-making procedures include the use of uniform design criteria, the application of subjective importance factors, the use of design metrics originally applied to life-safety issues when no such issues are present, and the application of benefit-cost methods that, while quantifying "mean" risk, may ignore risk aversion toward extreme consequences.

This paper covers some of the activities that the authors have been associated with and include system metrics and consider risk aversion in overall natural hazards decision-making procedures. Afterwards, this paper includes a very brief discussion of why these methods are still not prevalent in natural hazards decision-making procedures.

NATURAL HAZARDS DECISION-MAKING ACTIVITIES INCORPORATING SYSTEM METRICS AND CONSIDERING RISK AVERSION

Significant advances in incorporating system metrics and the consideration of risk aversion have occurred between 1998 and 2005 when the American Lifelines Alliance (ALA) was supported by the Federal Emergency Management Agency. Figure 1 shows a recent version of the ALA acceptable risk procedures, and these explicitly include quantitative consideration of system performance and implicit consideration of risk-aversion by decision-makers. Focusing on the development of guidelines and standards to be implemented by Standards Developing Organizations, ALA has produced useful documents ranging from guidelines for wastewater systems to a report on extreme ice thicknesses from freezing rain. The authors have variously contributed to specific ALA documents and initiatives, including Eguchi et al. (2004a, 2004b) and Taylor et al. (2003).

Even before efforts through ALA, the first two authors have engaged in a long-term project supported by MCEER/FHWA and more recently by CALTRANS that has developed a methodology and computer program (named REDARS) for performing seismic risk analysis of highway-roadway systems. This software provides deterministic or probabilistic estimates of how system-wide travel times can be affected by earthquake damage to this system, in terms of various performance metrics including economic losses, delays in access to or egress from any user-designated key location in the region, delays in travel times along user-designated lifeline routes that are essential to emergency response, and trip production or attraction at any designated location. (Werner et al., 2004, 2006)

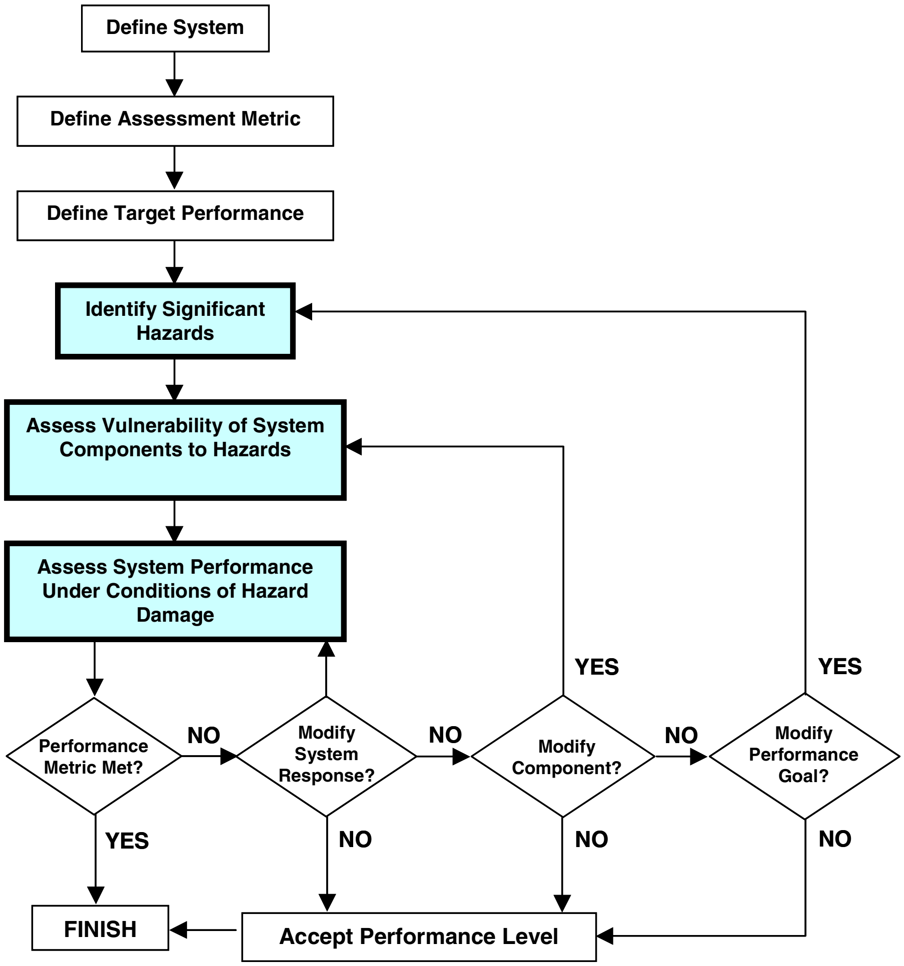


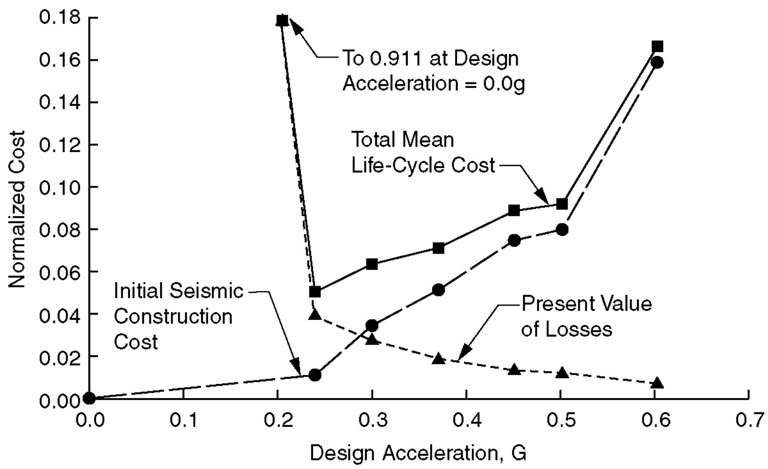
Figure 1. Acceptable Risk Evaluation Procedure for Infrastructure Systems

Again starting before ALA, the first two authors have also carried out several major projects to support decision processes related to seismic risk reduction planning at major ports and airports. These decision processes focused on assessing: (a) seismic design criteria for the Pier 300 wharf at the Port of Los Angeles (POLA) as part of the POLA 2020 expansion program; (b) review of seismic design options for potential runway expansions for the San Francisco International Airport; and (c) various options for seismic upgrade of berths throughout the Port of Oakland. These authors also recently completed a United States Geological Survey research project to examine uncertainties in evaluating a hypothetical berth system in the San Francisco Bay region. (Taylor et al., 1995, 2000, 2005)

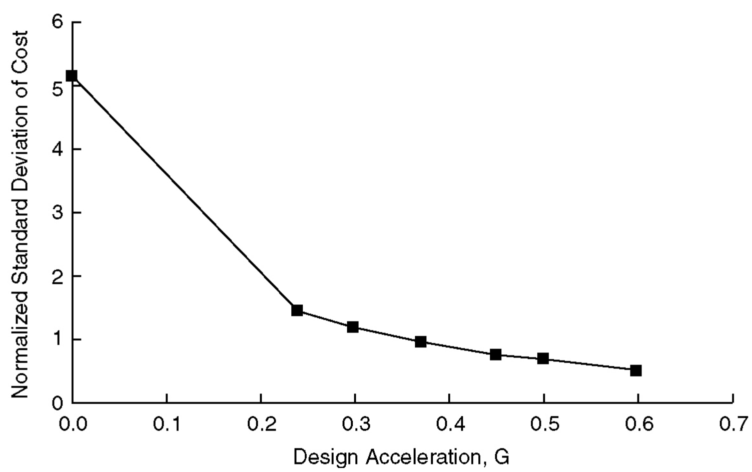
Notable in these projects has been the consideration of business interruption losses, a systemic measure, and the consideration of risk aversion. The first of these projects yielded Figure 2, which shows first (in 2a) the results of using merely risk-neutral benefit-cost approach (the bottom of the “U”-shaped curve is the risk-neutral optimal design level, much lower than the

Earth & Space 2006

uniform criteria currently used) and second (in 2b) how risk-aversion can yield a higher design level (more in accordance with current uniform risk criteria). These four projects have incorporated advances in financial engineering (see Alesch et al., 2002, for an extended discussion).



a) Mean Value of Total Life-Cycle Cost



b) Volatility (Standard Deviation) of Total Life Cycle Cost

Figure 2. Sample Evaluation of Seismic Upgrade Levels (CLE) In Terms of Mean Total Cost and Its Volatility (Measured by Standard Deviation of the Total Cost) (See Alesch et al., 2002)

In the rebuilding of the Kobe ports, non-uniform design criteria were used, with some berths designed to extremely high earthquake strong ground motions and permanent ground displacements. A systemic approach to seismic design levels for ports suggests that there can be variable design levels, some lower than those suggested by uniform design levels and some much higher—the latter to protect business continuity at a port.

CHALLENGES TO THE CONSIDERATION OF SYSTEM METRICS

The authors have developed a brief list of five major reasons why progress in incorporating systems metrics and criteria has been lagging.

The first reason is that *for a large number of infrastructure facilities and equipments, uniform design requirements are desirable.* For these facilities and equipments, which may in some cases even be part of such critical facilities as very high voltage electric power substations, the application of uniform design requirements can create significant efficiencies in manufacturing and design processes.

The second reason is that *engineers and supporting scientists have formed a strong consensus around minimum "acceptable risk" levels to be used in assessing wind and earthquake design levels for life-safety* (often a 475-year return interval is used). For the sake of efficiency, these practitioners desire to adapt, with minimal modifications, their tools to the consideration of other acceptable risk situations, including those in which system performance considerations may be important. Too often, systems performance becomes unduly narrowed to mean the performance of key components treated as systems. Even within this unduly restrictive notion of systems performance, too few credible analyses are made of critical downtimes for these key components as the performance metrics become reduced to physical terms and ignore the social, operational, and economic features of repair times after natural disasters.

The third reason is that *acceptable risk metrics and criteria for system performance have not received a full consensus.* This is a major theme, for instance, in Taylor and VanMarcke (2005). One can for instance cite several metrics and many system-specific criteria that can be used to assess the system performance of natural gas and electric power systems, respectively (See Eguchi et al. 2004a, b). In spite of the several systems performance metrics that are available, the use of these metrics can provide critical information more understandable by administrators and the general public.

A fourth reason is that *system evaluation methods are still evolving in their application to natural hazards and some such methods are costly to implement.* Those that are costly to implement can be used at a planning level, and provide guidance for general system improvements including preferred design and redesign criteria and additional system redundancy desirable. However, such complex programs are typically not available for design practitioners. Moreover, as Figure 1 indicates, these system evaluation methods typically need to be used iteratively until specific solutions are found that are acceptable in terms of system performance.

The fifth reason is that research and development continue to be needed to make sure that systems evaluation methods are reliable and pertinent. The challenges of validating complex systems evaluation methods is significant given the relatively few events in which data are gathered in enough detail for an evaluation of the overall system model (e.g., only the 1994 Northridge and the 1989 Loma Prieta earthquakes are currently being used to validate REDARS). Reliability also becomes a very large issue in terms of financial and/or economic projections that may enter into natural hazards decision-making. Whereas facilities designed and redesigned may have long life-spans, credible planning horizons for infrastructure owners tend to be much shorter and the current uses of macro-economic analyses, when suitable, tend to be limited to existing and not future conditions. Pertinence becomes an issue because systems evaluation methods tend to limit the nodes and links evaluated, and so tend to ignore the vast number of links and nodes that are typically found in infrastructure systems.

SUMMARY

In spite of large-scale system failures from natural disasters and many near system failures (e.g., the electric power grid after the 1994 Northridge earthquake), system performance metrics and criteria have only occasionally been used in decision-making for natural hazards risk-reduction.

This paper points out how American Lifelines Alliance has taken a lead in developing reports and guidelines for use by Standards Developing Organizations in incorporating systems performance. In addition, this paper discusses several major projects in which the authors have been involved and that have benefited from the combination of systems evaluation procedures and financial engineering metrics and criteria. (For these metrics and criteria, see Alesch et al., 2002) The use of non-financial metrics and criteria can also provide information of value to infrastructure owners and the general public.

Yet, this paper also indicates five reasons why systems evaluation and performance metrics have only occasionally been used in natural hazards decision-making. Clearly, continued efforts are needed to render systems evaluation methods more accessible to policy-makers and design practitioners. Also needed are continuing efforts to render systems evaluation procedures more reliable and pertinent to key decision-making for reducing infrastructure risks from natural hazards.

Earth & Space 2006

REFERENCES

Alesch, Daniel J., Robert Nagy, and Craig Taylor, 2002, "Seeking Criteria for the Natural Hazard Investment Decision," pp. 155-179 in *Acceptable Risk Processes: Lifelines and Natural Hazards*, ed. by Craig Taylor and Erik VanMarcke, Reston, VA: American Society of Civil Engineers, Technical Council on Lifeline Earthquake Engineering Monograph No. 21.

Eguchi, Ronald T., Dennis K. Ostrom, Ronald A. Tognazzini, Craig E. Taylor, William Graf, C. B. Crouse, and Michael Shore, (2004), *Guideline for Assessing the Performance of Electric Power systems in Natural Hazard and Human threat Events*, in two volumes for American Lifelines Alliance, www.americanlifelinesalliance.org, April 30.

Eguchi, Ronald T., Douglas J. Nyman, Morris Gibson, John Zurcher, Craig E. Taylor, William Graf, C. B. Crouse, and Michael Shore, (2004), *Guidelines for Assessing the Performance of Oil and Natural Gas Pipeline systems in Natural Hazard and Human Threat Events*, in two volumes for American Lifelines Alliance, www.americanlifelinesalliance.org, April 30.

National Aeronautics and Space Administration (NASA), (1995), *NASA Systems Engineering Handbook*, SP-6105, June.

Taylor, C. E. and S. D. Werner (1995), "Proposed Acceptable Risk Procedures for the Port of Los Angeles 2020 Expansion Program," *Lifeline Earthquake Engineering: Proceedings of the Fourth U.S. Conference*, M. O'Rourke, ed., New York: American Society of Civil Engineers, August, pp. 64-71.

Taylor, Craig, Stuart Werner, and Richard Wittkop, (2000), "Seismic Risk Analysis," section 26 in *Airfield Development Program Preliminary Report 3D (Task D)*, Oakland, CA: ADEC for the San Francisco International Airport.

Taylor, C. E., W. P. Graf, J. H. Wiggins, L. Lund, and T. Volz, (2003), "Guidelines for Defining Natural Hazards Performance Objectives for Water Systems," *Advancing Mitigation Technologies and Disaster Response for Lifeline "Systems: Proceedings of the Sixth U. S. National Conference on Lifeline Earthquake Engineering,* ed. by James E. Beavers, Reston, VA: American Society of Civil Engineers, Technical Council on Lifeline Earthquake Engineering Monograph No. 25, pp. 455-464.

Taylor, Craig, Stuart Werner, Walter Silva, Marck Aschheim, and Larry Scheibel, (2005), *Exogenous Uncertainties in Earthquake Risk Modeling for Infrastructure Systems: A Demonstration Evaluation in Northern California* (with Stuart Werner, Walter Silva, Mark Aschheim, and Larry Scheibel), for the United States Geological Survey.

Taylor, Craig and Erik VanMarcke, editors, *Infrastructure Risk Management Processes: Natural Accidental, and Deliberate Hazards*, (2005), Reston, VA: American Society of Civil Engineers, Council on Disaster Risk Management, Monograph No.1.

Werner, Stuart D., Stephen E. Dickenson, and Craig E. Taylor (1997), "Seismic Performance at Ports: Lessons from Kobe," *ASCE Journal of Waterway, Port, Coastal, and Ocean Engineering,* November/December.

Werner, Stuart D., Craig E. Taylor, Sungbin Cho, Jean-Paul Lavoie, Charles K. Huyck, Charles Eitzel, Ronald T. Eguchi, and James E. Moore II, (2004), "New Developments in Seismic Risk Analysis of Highway Systems," *13th World Conference on Earthquake Engineering*, Vancouver, B. C., Canada, August 1-6, Paper No. 2189.

Werner, Stuart D., Craig E. Taylor, Sungbin Cho, Jean-Paul Lavoie, Charles K. Huyck, Charles Eitzel, Ronald T. Eguchi, and Howard Chung (2006) *Technical Manual: REDARS 2 Methodology and Software for Seismic Risk Analysis of Highway Systems*, Multidisciplinary Center for Earthquake Engineering Research, Buffalo NY, (in press).