A New Approach to Risk: The Implications of E3

Abstract

The fundamental thesis of this paper is that no matter how much physical science and technology are involved in complex systems, no system is ever purely or solely physical or technical. Certainly no system of which we are aware is purely scientific or technical in its operation or management. Furthermore, while research on and the modeling of complex systems usually rely heavily on the consideration of technological variables and processes, they typically fail to consider the contributions of individual psychological, organizational, and contextual factors. This paper argues that we need models that avoid committing errors of the third kind, solving the wrong problem precisely. The paper sets out a mechanism for developing models that include contextual as well as technological variables.

Introduction

What do the Exxon Valdez spill, the Katrina levee failure and flood, and the Piper Alpha Platform failure disasters have in common? They occurred because of the failure to recognize oil infrastructure, ship-safety and flood control as complex infrastructure systems. Such systems require risk assessments that include psychological, social, organizational, and political processes--in addition to those typical of traditional engineering practices. As a result, we suggest reformulating the problem of risk. To give appropriate weight to social processes in risk assessment, we suggest applying findings from other disciplines including Agent-based modeling (ABM), the use of Geographic Information Systems (GISs) to integrate multi-scale and multi-discipline input, Technology Delivery System (TDS) design, and High Reliability Organization (HRO) management principles.

The Assessment and Calculation of Risk

In engineering infrastructures that must cope with natural hazards, designers traditionally calculate risk for two reasons: to prioritize design so that the most likely and potentially most damaging hazards get the most attention, and to evaluate the adequacy of design. For example, when a design lowers the threat of a hazard to a value comparable to other acceptable hazards, that design is good enough. Risk assessment shapes design, construction and management of infrastructure systems solutions so great attention needs to be paid to how it is done.

Risk assessment in complex systems is strongly dependent on five crucial factors:

1. the inherent complexity of the system and the environment in which it exists and operates;
2. the models used to represent the system; i.e., how the system and its environment, and hence its complexity, are represented in the first place;
3. whether the models give equal weight to technical, individual human, organizational, and socio-political (e.g., legal) variables in determining the operation and the failure modes of the system; for instance, whether certain variables (e.g., engineering or technical) are emphasized or privileged over others, and whether the representation of the system is fundamentally biased or flawed to begin with;
4. as a direct result of factor 3., the number and kinds of terms included in determining the probability, or the probabilities, of failure of the system, and;
5. how the consequences of the failure of the system are also represented and determined.

The fundamental thesis of this paper is that no matter how much physical science and technology are involved in a complex system, no system is ever purely or solely physical or technical. Certainly no system of which we are aware is purely scientific or technical in its operation or management.

Every "system" consists of a complex set of (a) technical processes and variables that interact strongly with a complex set of (b) individual human (i.e., psychological) , (c) organizational, and (d) socio-political processes and variables. Technical, individual, etc. variables that compose the system can only be distinguished from one another with great difficulty. In other words, the variables are so strongly coupled that it is almost impossible to determine where one kind typically begins and others end or leave off.

By its very nature, modeling complex systems is inherently interdisciplinary. This means that determinations of the probabilities of system failure are also inherently interdisciplinary. In turn, the assessment of risks associated with complex systems is inherently interdisciplinary as well.

In spite of this, the modeling, and risk assessment of complex systems have not been as interdisciplinary as they need to be. As a result, a basic and fundamental error underlies the vast majority of risk assessments. This error is known as the Error of the Third Kind, or the Type Three Error (E3) (Mitroff and Linstone, 1992).

E3 is defined as the "probability of solving the 'wrong' problem precisely." Whereas Type One (E1) and Type Two (E2) errors are well known and utilized in statistics, E3 is not. E1 and E2 (accepting or rejecting a "null hypothesis") relate to problems that are already known or well defined. In sharp contrast, E3 pertains to how problems are defined or formulated in the first place. In this sense, E3 is both prior to and more basic than E1 and E2.

This paper shows that by taking (a) technical, (b) individual human, (c) organizational, and (d) socio-political variables **equally into account**, E3 can be expressed on a quantitative basis like E1 and E2. Anything less leads to dangerously misleading risk assessments.

An interdisciplinary approach to modeling complex systems allows us to formulate and determine the E3s associated with them. Combating E3s in practice also requires an interdisciplinary approach. Organizations that relegate risk assessment to individuals with narrow technocratic expertise will inevitably commit E3s. Only by incorporating multiple perspectives and being alert to discrepancies between models and reality can organizations deal with risk in a realistic way.

Background.

Work on this paper started almost two decades ago with an investigation by one of the authors (Bea) of the dramatic failure of the Piper Alpha offshore oil and gas drilling and production platform in the North Sea. This platform served as a "hub" in a major part of the oil and gas infrastructure in the North Sea. The investigative report stated that the majority of the causes of this failure (80 % or more) were firmly rooted in human, organizational, and institutional malfunctions. The remaining causes could reasonably be attributed to malfunctions in the engineered parts of this complex system. This was a rude awakening because the platform was intensely studied prior to its failure using traditional engineering approaches and "engineering fixes" were put in place. However, these fixes proved to be totally ineffective.

Defining the problem as primarily an "engineering problem," commits a major E3. Hence, problem definition is critical in designing, operating, maintaining, and managing critical complex infrastructure systems (CISs). In the Piper Alpha situation a new problem was exposed that involved other parts of this production infrastructure. When the first fires and explosions erupted on the platform, personnel on interconnected production platforms realized that the pressures in the pipelines had dropped. In response to the drop in pipeline pressure and organizational pressures to "catch up" on back production, these platforms increased production to the Piper Alpha platform, further escalating and accelerating the "final melt down" of the system.

It was subsequently recognized that a broader, more holistic problem definition is of critical importance in designing, operating, maintaining, and managing CISs. Findings such as this are now common in investigations of other disasters (e.g. Challenger and Columbia, Texas City and Bhopal, Katrina and Betsy, etc.) Most recently, this background was incorporated into an NSF funded research project to investigate the causes of the failure of the flood defense system for the Greater New Orleans Area (Seed, et. al., 2007, 2007a, 2007b; Kardon, et. al., 2006).

The human, organizational, and institutional causes are termed "extrinsic." The categories of uncertainties traditionally addressed by engineers – natural or inherent (aleatory) and those associated with parametric, state, and analytical model uncertainties (epistemic) are termed "intrinsic." Because the neglected extrinsic factors are actually fundamental to system performance, expected risks were under-predicted by factors of 100 or more. These findings are consistent with a large body of research that highlights the role of "extrinsic" factors in large-scale system failures (e.g. Clarke and Short, 1993; Perrow, 1984; Roberts, 1990; Vaughan, 1996, 1999).

Traditional engineering analyses and processes also result in inappropriate strategies for managing risk. Another example of an E3 that is the result of thinking that overemphasizes improving "things" such as system components, rather than addressing "process" and "people" factors that produce risk and the consequences of risk. Compelling evidence for this is available in reports of major catastrophes such as Bhopal (Shrivastava, 1987), Columbia (Columbia Accident Investigation Board, 2003), and Katrina (Farber, et. al., 2007).

A Proposal for Studying Complex Systems

This paper proposes a new approach to developing a holistic approach to understanding and managing risks and their consequences associated with CIS failures. As shown in Figure 1, this new approach incorporates analytic methods that model relationships among factors and processes taking place at four levels of analysis: physical systems, organizational processes and practices, and the broader societal context.

Level 1, physical systems and their components, is the domain of traditional engineering risk analysis and management. Level 2 includes human elements of organizations traditionally studied by psychologists. These include individual differences, personality, training, etc. Scholars specializing in the sociology of organizations, management science, organizational communication, and related fields traditionally study level 3, which encompasses organizational attributes and processes. Included in this level is a range of factors, including organizational structure,

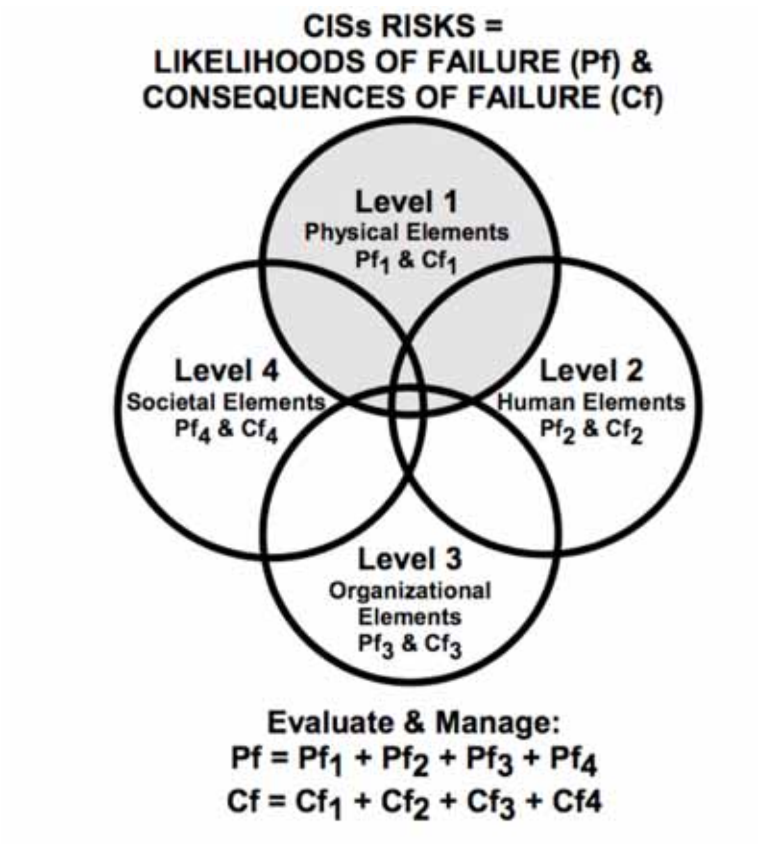

Figure 1: Evaluating and Managing CISs Risks

culture, management, and problem-identification and problem-solving strategies. Level 4 incorporates broader societal factors that affect both organizational processes and the physical elements of CISs. This level consists of more macro-level factors such as governance, laws and regulatory regimes, and social, demographic, and economic forces that must also be taken into account in CISs risk and vulnerability analyses.

Often level 1 analyses fail to address the critically important issues associated with the consequences of failure – particularly those associated with rescue and recovery resilience. Levels 2, 3 and 4 are the important additional elements contributed by individual differences psychology, organizational and social sciences to enable a more holistic assessment of risks and the management alternatives that are available to reduce the likelihoods of failures and consequences contributing to the CISs risks (Roberts and Sloane, 1988; Roberts, et. al., 2004; Roberts, et. al., 2005).

The guiding logic of our approach is that a full understanding of CIS vulnerability can only be achieved through the analysis of interactions within and across these four levels, in context and over time. As discussed above, prior engineering research has focused on the first level—the physical elements that make up engineered systems—while treating the other two levels as "extrinsic" to formal analytic frameworks. In contrast, this paper recognizes that managing risks associated with CISs is a multi-dimensional problem that must be addressed through collaborative research and educational activities that cross and transcend disciplinary boundaries.

An Approach to Assessing Risks Associated with CISs

The probability of failure, P(F), of a CIS is:

1. $P(F) = P(F_I \text{ U } F_E)$, where I stands for Intrinsic Factors, E stands for Extrinsic Factors, and U stands for the Union operator. I typically stands for technical factors such as the failure of levees and pumping systems, while E stands for organizational/social factors such as the breakdown of communications between different entities charged with managing a CIS.

2. In turn, $P(F) = P(F_I / E)\ P(E) + P(F_I / \text{Not } E)\ P(\text{Not } E) +$

   $P(F_E / E)\ P(E)$.

The first term in equation 2 addresses the likelihood of system failure due to Intrinsic Factors (technical) given (i.e., conditional upon) the uncertainties associated with Extrinsic Factors (psychological, organizational, social, legal, etc.). The second term addresses the same likelihood given no Extrinsic Factors. By our initial assumption that every complex system is composed of the interactions between technical and social variables, the second term is impossible. We include it, nonetheless, for an important reason that will become apparent shortly. The third term addresses the likelihood of system failures due directly to Extrinsic Factors.

Equation 2 leads to an interesting and important way to measure E3. Recall that E3 is the probability of solving the wrong problem precisely. This can be expressed as follows in equation 3:

3. $P[P(F)] = P[P(F_I / E)\ P(E) + P(F_I / \text{Not } E)\ P(\text{Not } E)]$.

P[P(F)] is a probability distribution/function like any other probability distribution/function. It is the probability that the probability of failure function only includes the first two terms. That is, P(P(F)) is a way to measure whether assessing the probability of failure of a complex system, is solving the wrong problem through the use of the wrong, (i.e., incomplete) formula.

The Practical Significance of E3

E3 is critically important in understanding system failures. As noted earlier, work relevant to this article started almost two decades ago with a study of an oil platform failure. This experience led to researcher involvement in investigations of other failures of engineered systems including the Exxon Valdez, the Columbia space shuttle, the Texas City BP refinery, and the flood protection system for the Greater New Orleans area (Farber, Bea, Roberts, Wenk, and Inkabi 2007; Bea 2007a, 2007b; Seed, et. al., 2007, 2007a, 2007b; Kardon, et. al., 2006). The theme developed from these experiences was that the majority (80 percent or more) of the causes of failures were human – organizational – institutional in nature. These causes are termed "Extrinsic." The balance of the causes of failure can be traced to two categories of uncertainties traditionally addressed by engineers – natural or inherent (aleatory) and those associated with parametric, state, and analytical model uncertainties (epistemic). These causes are termed "Intrinsic."

This was an important finding because it helped to explain why traditional engineering analyses of the likelihoods of failures do not match the actual or actuarial likelihoods of failure – they under-predict the real likelihoods by factors of 10 or more. Engineering models do not include the critical human and organizational parts of the system – resulting in a critical E3. A similar situation also was found with the consequences of failure – these too were under predicted by factors of 10 or more. Thus, “expected” risks taken as the product of the likelihood of failure and the consequences given failure were under-predicted by factors of 100 or more.

Traditional engineering analyses and processes result in “distorted” approaches to better manage risks (combination of likelihoods and consequences of failures). Again, another major E3. Frequently, attempts are made to fix “things” rather than “processes and people.” Traditional approaches focus on proactive assessments and management strategies. But, experience with these failures clearly indicates there are important limitations to proactive assessments and the associated management strategies. The future changes things; systems are more organic than mechanical; and predictability is extremely limited. Even reactive (after the accident or failure) analyses and associated approaches are limited because they focus on “things” not on “processes and people.” This leads to trying to fix the wrong things in the wrong ways.

Ways to Deal with E3

A major cause of E3s is that key portions of interactive systems – particularly the “soft” human and organizational portions – are omitted from analysis in part because of the absence of rigorous modeling methodologies. Agent-based modeling (ABM) is a promising method for addressing these issues (Axelrod and Tesfatsion, 2007; Gilbert and Terna, 2000; Homeland Security Institute, 2006). ABM is a specific simulation technique that models complex adaptive systems via computer-generated agents that interact in a virtual environment. These “agents” can represent individual people, but they can also represent social groupings such as operating teams, organizations, firms, communities, and agencies. The interactions occur according to representative programmed behavioral rules that create the unpredictable self-organizing behavior seen in complex adaptive systems. The behavioral rules are informed by case studies, observations of CISs operations, and expert judgment.

Geographic Information Systems (GISs) provide another important modeling tool. GISs have long been used to store, manipulate and display spatial data. In addition to their obvious utility in managing environmental data, they allows designers to encode solutions so they can be evaluated and compared with each other quantitatively in terms of whatever measures are determined to be useful. In addition, because a GIS allows the display of concepts and relationships in map form to large audiences, it is the ideal tool for integrating traditional engineering and social science analyses. GISs can serve as a monitoring tool to integrate sensor data, field reports, remote sensing data, etc., so system management can be integrated with design solutions. Finally, for managing complex systems, generalization algorithms (Radke and Mulan, 2000, Radke, et. al. 2000) aggregate observational data so that broad trends can be recognized and responded to.

A key objective in this research is to create and validate methods and procedures to enable meaningful characterizations and quantifications of P(E). However, quantifications are not the primary goal. The primary goal is to develop insights into how P(E) can be reduced by improving the process and people aspects of CISs. The quantifications provide ‘metrics’ to assist evaluations of alternatives and progress toward improving the quality and reliability of CISs.

Ultimately, we need better delivery of Risk Assessment and Management Infrastructure Systems technology. Some preliminary work was done to design an advanced Technology Delivery System (TDS) (Bea 2007b). This work resulted in identification of three inter-related components: 1) the public/s (people affected by the CISs), 2) the governments (of, by, and for the people with responsibilities for the CISs), and 3) industry (responsible for providing CISs).

The linkages among these components are facilitated and enhanced with modern communication and information technology – including the media and (GISs). The fundamental objective is to provide improved information and knowledge that will help impact values, beliefs, and behaviors in ways beneficial to the publics and to the environments in which they exist. At present the concepts associated with the TDS are used in efforts to integrate flood protection strategies and procedures into improving the flood protection systems for the Greater New Orleans and Sacramento Delta areas.

Developing effective TDSs is one of the most critical parts of building resilient and sustainable CISs. Without the required societal and political 'wills', the technology 'ways' to improve resilience, sustainability, and reliability of CISs will not be effectively implemented.

For the last twenty years research on high reliability organizations (HROs) examined a number of adaptive management strategies that work to render organizations highly reliable and sustainable. One finding suggests that adaptable organizations change their structures in response to changing conditions. When their environments are very uncertain HROs flatten their structures considerably, returning to more hierarchical structures as their environments gain more certainty. Another characteristic of HROs is that they push decision making to the lowest level of the organization commensurate with the knowledge needed to make that decision. In other words, if a decision about refueling an aircraft in the fast paced and potentially dangerous environment of an aircraft carrier is best made by a chief petty officer on the deck, it is certainly not given over to the ship's captain on the bridge of the ship (Weick and Roberts, 2003). These kinds of structural and decision making strategies render the organization more resilient than are organizations who do not follow them. This resilience opens the organization up to the possibilities of looking for potential E3s and doing something to correct the situation.

It is hypothesized the adaptable CISs do much the same thing. A good deal of networking research has been done in organizational behavior. An initial step in understanding how CISs adapt and make decisions is to uncover their networks of relationships. It is hypothesized that more resilient CISs have more tentacles into other complex systems than less resilient CISs. Other aspects of the influence of both political decisions and organizational processes need to be included in dealing with CISs..

Engineers are trained to focus on technical errors. Narrow and exclusive focus on technical factors is a source of E3s, simply because engineers tend to place too much reliance on technical models without realizing the likelihood that those models fail to capture key elements of risk. If engineers and other system designers can learn to take a broader perspective, E3s can be reduced. Nevertheless, even “enlightened” technical designers inevitably have limited perspectives, based on their own training and limited sources of information. Minimizing E3s requires opening the planning process to those with other perspectives, including natural and social scientists. The planning process also needs to include individuals with “on the ground” experience with the system in question. Thus, what is frequently a closed technocratic planning process must become much more open and public.

A More Open and Public Perspective

Ideally, the environmental assessment procedure can provide one path toward this expanded planning process. Major infrastructure projects typically involve participation by government decision makers in either funding or licensing. The planning process used by these decision makers makes some effort to consider issues of resilience and sustainability, as well as potential interactions among infrastructures. A primary tool for considering these issues is environmental assessment. These assessments take the form of environmental impact statements

(EISs) or environmental impact reviews (EIRs) (Gerschwer, 1993). One part of creating better decision tools for infrastructure is understanding the role of environmental assessment in current planning efforts. Understanding what works and does not work (attempting to avoid E3s) creates the opportunity for improved methodologies. Criticisms of environmental assessments provide rich research issues (Klick, 1994; Lefcoe, 2006). Two relevant criticisms are that the process places undue confidence in predictions and too little emphasis on monitoring and adaptive management. In addition consideration of interaction between projects is handicapped by a series of Supreme Court decisions (Karkkainen 2002).

Despite the inadequacies of current environmental assessment, its aspirations are consistent with the kind of system analysis needed to avoid E3s. The National Environmental Quality Act (NEPA) directs all federal agencies to engage in systematic, interdisciplinary approaches that include integrated use of the natural and social science and the environmental design arts. (West Publishing C., 2008). It also requires agencies to recognize that environmental issues are worldwide and long-range and where consistent with U.S. foreign policy to maximize international cooperation in dealing with the decline in the quality of mankind's world environment. (West Publishing Co, 2008). The environmental assessment process also includes provisions designed to open the process to multiple perspectives. Public notice and the opportunity to submit written comments are routine. Perhaps more importantly, agencies are required to engage in consulting other agencies, many of which have different goals and perspectives that can be critical in identifying E3s. Too often project designers view environmental review as an irksome constraint on their planning, rather than recognizing it as an opportunity to avoid critical E3s.

GIS can provide a methodology for the kind of broad-gauged planning process needed to minimize E3s. For example, one use of GIS for environmental assessment broke the geographical area into cells of areas with similar vegetation, climate and soils. A model was used to predict, on a cell-by-cell basis, the growth and aging of a forest, including the size and distribution of each forest type. Those calculations in turn were used together with a habitat suitability model to predict impacts on wildlife (Eady, 1995). In another instance, the Bureau of Reclamation made good use of GIS in performing an assessment of the operations of the Glen Canyon Dam. Public interest was very high, with more than thirty thousand people commenting on the draft of the environmental EIS. Thus, GIS contributed significantly to the planning process, both in terms of procedure and in terms of allowing a broad synthetic analysis, as the White House Council on Environmental Quality (1997) explained:

> GIS provides the analyst with management of large data sets, data overlay and analysis of development and natural resource patterns, trends analysis, mathematical impact modeling with locational data, habitat analysis, aesthetic analysis, and improved public consultation. Using GIS has the potential to facilitate the efficient completion of projects while building confidence in the NEPA process.

We also need to consider the incentives that will lead system designers to broaden their horizons and augment the planning process. One such mechanism is the potential for civil liability. The potential for liability can push designers to consider broader ranges of risk. Similarly, insurance companies can play a proactive role in encouraging safe design, bringing to bear their broad range of experience with other system failures and safety methodologies.

In seeking to avoid E3s, we can also benefit from the rich literature about organizational learning. Organizations learn by embedding historical experience in their routines (Levitt and March, 1988). Organizational routines are based on implicit models that help the organization make sense of the world and respond to perceived problems. These models are as subject to E3 as are the more formal engineering models. However, without conditions motivating change, routines are often relatively stable and organizations generally tend to be inert, relying on existing models and adapting less than perfectly to and falling in and out of alignment with their environments (Nelson and Winter, 1982). Disaster preparation calls for a different form of learning in which organizations draw on not only their own experiences but also those of other organizations. Such network effects exist for a variety of learning processes (e.g., Argote, et. al., 1990; Baum and Ingram, 1998; Beckman and Haunschild, 2002).

High Reliability Organizations (HROs) are also concerned with learning. They are careful to accept input from individuals at all levels of the organization, thereby broadening their base of knowledge and perspectives, and they pay careful attention to unexpected outcomes and system failures. (Roberts, 1990; Weick and Roberts, 2003). Thus, they are able to detect the shortcomings of their implicit models and avoid E3s.

Over the past few decades, scholars from many disciplines have advocated relational or systems approaches, as opposed to reductionist approaches that study particular events and entities in isolation (Miller, 1972; Wolf, 1980). For instance, collaborative governance involving multiple organizations – both public and private – is a principal focus in recent environmental and administrative law scholarship. (Minow, 2003; Freeman, 1997). We are gaining solid information about how these interactions work in the context of regulation (Cunningham, et. al., 2003; Freeman, 2000), and in developing policy networks. (Agranoff, 2003). Researchers are beginning to understand how law can facilitate formal and informal relations that achieve the appropriate balance between accountability to public goals, and flexibility necessary for maximizing the utility of private-sector involvement (Bamberger, 2006; Karkkainen, et. al., 2000).

Conclusion

All too often, researchers and decision makers focus exclusively on E1s, the risk of accepting a false hypothesis about the true value of a variable. They fail to take into account E2s, the risk of rejecting a true hypothesis about the true value of a variable. Thus, statistical reliability trumps statistical power. But even more important are E3s – the risk that the entire model used in the analysis is wrong, often because it omits key variables. For researchers, this can be merely a methodological headache, which goes under the name of specification error or omitted variables bias. But for decision makers, the consequences can be literally deadly. Models can produce precise calculations of the value of a risk that are nonetheless meaningless because the model is radically incomplete.

In this paper, we attempted to propose methodologies for dealing with E3s in risk assessment. As we saw, E3s are to some extent subject to rigorous analysis, and promising methodologies exist with which to improve formal modeling. But the greater challenge may be to design human systems for risk analysis that allow E3s to be detected and corrected. Such systems require broad input and a willingness to reassess models in light of the unexpected. In designing such systems of risk assessment, we must both improve formal modeling and learn from the organization literature to design better processes for decision-making.

References

Agranoff, R. (2003), A New Look at the Value-Adding Functions of Intergovernmental Networks, (paper presented for National Public Management Research Conference, Georgetown University, Washington, DC.).

Argote, L., Beckman, S. L., and Epple, D. (1990) The Persistence and Transfer of Learning in Industrial Settings. *Management Science*, Vol. 36(2): pp. 140-154.

Axelrod, R., and Tesfatsion, L. (2007) On-Line Guide for Newcomers to Agent Based Modeling in the Social Sciences. Retreived January 5, 2007 from www.econ.iastate,edu/testfatsi/abmread.htm.

Bamberger, K.A. (2006) Blurring Boundaries: Organizational Theory, Regulated Firms, and the Administrative State (working paper, University of California, Berkeley).

Beckman, C. M., and Haunschild, P. R. (2002) Network Learning: The Effects of Partners' Heterogeneity of Experience on Corporate Acquisitions. *Administrative Science Quarterly,* Vol. 47, 1, pp 92-124.

Baum, J. A. C., and Ingram, P. (1998) Survival-Enhancing Learning in the Manhattan Hotel Industry, 1898-1980. *Management Science*, Vol. 44, 7, pp. 996-1016.

Bea, R.G. (2007a). Reliability Assessment and Management Lessons from Hurricane Katrina, OMAE 2007-29650, *Proceedings 6th Int. Conf. On Offshore Mechanics and Arctic Engineering,* American Society of Mechanical Engineers, New York.

Bea, R.G. (2007b). Lessons From Failure of the Flood Protection System for the Greater New Orleans Area During Hurricane Katrina, OMAE 2007-29649, *Proceedings 6th Int. Conf. On Offshore Mechanics and Arctic Engineering,* American Society of Mechanical Engineers, New York.

Clarke, L., and Short, J. (1993) Social organization and risk: Some current controversies, *Annual Review of Sociology,* Vol. 19,pp. 375-399.

Columbia Accident Investigation Report (2003) Report, 6 vols. Government Printing Office, Washington, D.C.

Cunningham, N., Kagan, R.A., and Thornton, D. (2003) *Shades of Green: Business, Regulation, and Environment.* Stanford: Stanford University Press.

Eady, W. (1995). *The Use of GIS in Environmental Assessment*. Impact Assessment vol. 13. pp. 199- .

Farber, D.A., Bea, R.G., Roberts, K., Wenk, E., Inkabi, K. (2007). Reinventing Flood Control, *Tulane Law Review*, Vol. 81,No. 4, pp. 1085-1127.

Freeman, J. (1997) Collaborative Governance in the Administrative State. *UCLA Law Review* Vol.45, 1, pp. 1-99.

Gerschwer, L. (1993) Informational standing under NEPA: Justiciability ad environmental decisionmaking process *Columbia University Law Review,* Vol 93, pp 996-1001.

Gilbert, N. and Terna, P. (2000), How to build and use agent-based models in social science. *Mind and Society*, Vol. 1, pp. 57-72.

Homeland Security Institute (2006) *Homeland Security Risk Assessment: Methods, Techniques, and Tools,* 2, Arlington, Va.

Miller, J.G. (1972) *Living Systems.* New York: McGraw Hill.

Minow, M. (2003) *Partners, Not Rivals: Privatization and the Public Good***.** Boston: Beacon Press.

Kardon, J.B., Bea, R.G., and Williamson, R.B. (2006). Validity and Reliability of Forensic Engineering Methods and Processes, American Society of Civil Engineers, Herndon, VA.

Karkkainen, B.C., Fung, A., and Sabel, C. (2000) After Backyard Environmentalism: Toward a Performance-Based Regime of Environmental Regulation. *American Behavioral Scientist* Vol.44, 4, pp 690-709.

Karkainen, B. (2002) Toward a smarter NEPA: Monitoring and managing government's environmental performance. *Columbia Law Review*, Vol.102, pp.903-967

Klick, K.A. (1994) The Extraterritorial Reach of NEPAs EIS Requirement after Environmental Defense Fund v. Massey. *American University Law Review*,

Mitroff, Ian I., and Linstone, Hal (1992) *The Unbounded Mind*, Oxford University Press, New York

Perrow, C. (1984) *Normal Accidents: Living with High Risk Technologies.* New York: Basic Books.

Radke, J. and Mulan, (2000) Spatial Decompositions, Modeling And Mapping Service Regions To Predict Access To Social Programs, *Geographic Information Sciences*, Vol. 6, No.2, pp 105-112.

Radke, J. T. Cova, M.F. Sheridan, A.T, Mulan, and Johnson, R. 2000 Application Challenges for GIS science: Implications for Research Education, and Policy for Risk Assessment, *Emergency Preparedness and Response* (RAEPR)" *URISA Journal*, Vol 12, 2, pp

Roberts, K. H. (1990) Some Characteristics of One Type of High Reliability Organization. *Organization Science*, Vol. 1, 2, pp. 160-176.

Roberts, K.H. and Sloane, S.B. (1988) An Aggregation Problem and Organizational Effectiveness. In B. Schneider and D. Schoorman (Eds) *Facilitating Organizational Effectiveness*, Lexington, MA: Lexington Press, pp125-144.

Roberts, K.H., Madsen, P., and Desai, V. (2004) Bridging levels, variables, and methodologies. In F.J. Yammarino and A.E. Dansereau (Eds.) *Research in Multi Level Issues: An Annual Series*, Oxford, Elsevier pp. 69-78. Also in *Science Direct.*

Roberts, K.H., Madsen, P., and Desai, V. (2005) The Space Between in Space Transportation: A Relational Analysis of the Failure of STS 107. In M. Farjoum @ W. Starbuck (Eds.) *Organizations at the Limit: Lessons from the Columbia Disaster*, Maden, MA, pp 81-98.

Seed. R.B., Bea, R.G., Athanasopoulos, A.G., Boutwell, G.P., Bray, J.D., Cheung, C., Collins, B.D., Cobos-Roa, D., Harder, L.F., Kayen, R.E., Pestana, J.M., Porter, J., Reimer, M.F., Rogers, J.D., Storesund, R., Vera-Grunauer, X., and Wartman, J. (2007) Investigation of Levee Performance in Hurricane Katrina: The New Orleans Drainage Canals, *Proceedings Geo*-Denver 2007, ASCE,

Seed, R.B., Bea, R.G., Athanasopoulos, A.G., Boutwell, G.P., Bray, J.D., Cheung, C., Collins, B.D., Cobos-Roa, D., Harder, L.F., Kayen, R.E., Pestana, J.M., Porter, J., Reimer, M.F., Rogers, J.D., Storesund, R., Vera-Grunauer, X., and Wartman, J. (2007a) Investigation of Levee Performance in Hurricane Katrina: The Inner Harbor Navigation Canal**,** *Proceedings Geo*-Denver 2007, ASCE.

Seed, R.B., Bea, R. G., Athanasopoulos, A.G., Boutwell, G.P., Bray, J.D., Cheung, C., Collins, B.D., Cobos-Roa, D., Harder, L.F., Kayen, R.E., Pestana, J.M., Porter, J., Reimer, M.F., Rogers, J.D., Storesund, R., Vera-Grunauer, X., and Wartman, J., (2007) Investigation of the Performance of the New Orleans Regional Flood Protection Systems During Hurricane Katrina: Lessons Learned, *Proceedings Geo*-Denver 2007, ASCE. pp. 1-16.(b)

Shrivastava, P. *Bhopal: Anatomy of a Crisis*. Cambridge, Mass: Ballinger.

Vaughan,D. (1996) *The Challenger Launch Decision: Risky Technology, Culture, and Deviance,* Chicago: University of Chicago Press.

Vaughan, D. (1999) The Dark Side of Organizations: Mistake, Misconduct, and Disaster. *Annual Review of Sociology*, Vol. 25, pp 271-305.

Weick, K.E. and Roberts, K.H. (2003) Collective Mind in Organizations: Heedful Interrelating on Flight Decks. *Administrative Science Quarterly*, Vol. 38, pp 357-381.

West Publishing C. (2008) *Selected Environmental Statutes 2008 – 2009* Educational Edition, 2008.

White House Council on Environmental Quality (1997). *The National Environmental Policy Act: A Study of Its Effectiveness After 25 Years.* http://www.nepa.gov/nepa/nepa25fn.pdf.

Wolf, F. A. (1980) *Taking the Quantum Leap.* New York: Harper and Row.