Networked reliability: from monitoring to incident management

Mark de Bruijne
Delft University of Technology, The Netherlands
M.L.C.deBruijne@tudelft.nl

ABSTRACT

The environment of many HROs in modern, western countries have undergone dramatic changes in the last decades. They have changed from High Reliability Organizations (HROs) into High Reliability Networks (HRNs). In nearly all industries, the formerly vertically integrated, state-owned monopolies were 'unbundled' and in many segments, competition was introduced. Consequently, the services of modern-day large-scale technical systems are provided by networks of organizations.

In-depth research in a number of infrastructure industries explored the consequences of these changes for the reliable provision of services in networks of organizations. In networks of organizations, reliability is increasingly achieved through 'real-time' management. This paper highlights three important consequences of these findings and provides some tentative conclusions about their effect on the design and use of Information Systems in complex, large-scale technical systems.

Keywords

High Reliability Organizations (HROs), reliability of service provision, networks of organizations, real-time management, Information Systems

INTRODUCTION

High Reliability Organizations (HROs) have been regarded within organizational theory as a special breed of organizations. The organizations were identified as a subset of a larger set of organizations that dealt with increasingly complex, tightly coupled and therefore increasingly hazardous and risky technologies (Perrow, 1999:139). What defined HROs from the average run-of-the mill organizations and their high-risk brethren was their capacity "to successfully manage potentially high-hazard operations on a regular basis" (Rochlin, 1989:161); their continuous reliable and safe performance while nevertheless operating close to the "edge of the envelope" (Roberts and Rousseau, 1989:133). The researchers of HROs were struck by the apparent success these organizations seemed to achieve (e.g. LaPorte and Consolini, 1991;Roberts, 1990a;1990b;Roberts and Rousseau, 1989). Their body of knowledge came to be known under the heading 'High Reliability Theory' (HRT) even though the level of thinking about these systems remained descriptive, and falls short of a causal theory. HRT argued that HROs have nurtured a number of conditions that are associated with their remarkable levels of reliability (Rochlin, 1999). However, HRT-theorists consistently point out that there are no recipes here.

RELIABILITY-ENHANCING CONDITIONS

High-Reliability Theory (HRT) focuses on how organizations that manage technologies maintain extraordinary levels of safety and reliability and avoid cascading failures and catastrophic errors to achieve their missions (LaPorte and Consolini, 1991;Roberts, 1990a;1990b;Rochlin et al., 1987). The continuous, safe and reliable operation of large-scale technologies by organizations that manage air traffic control operations, aircraft carrier flight operations and nuclear power plants, seem to defy what is generally known about systems and organizations (e.g. Perrow, 1999).

HRT researchers compiled various lists of so-called reliability-enhancing conditions, which captured more subtle, yet still unexplained dynamics that enable HROs to manage complex systems with remarkably reliable end-results. However, even among HRT researchers, there is disagreement on the actual number of reliability-enhancing conditions (van Eeten and Roe, 2002:106, note 8;Roe et al., 1998:41). The conditions mentioned in the literature are not completely independent. So far, the research has failed to converge on a single, definitive set. Based on an extensive review of the available lists of reliability-enhancing conditions Table 1 presents a list that – although it fails to represent every reliability-enhancing property ever mentioned – may be considered to capture the core of the existing HRT literature (de Bruijne, 2006:78, note 33).

1. Commitment to reliable operations in mission and goals
2. Sustained high technical performance
3. Structural flexibility and redundancy
4. High degrees of responsibility and accountability
5. Flexible decision-making processes
6. Continual search for improvement and training for worst cases
7. Reliability not marginalizable, not fungible
8. Organizational culture of reliability
9. Strong presence of external groups with access to credible and timely operational information

Table 1. HRO-characteristics and reliability-enhancing conditions (de Bruijne, 2006:63)

However, in the last decades, the environment of HROs changed considerably. Three interrelated trends produced a paradigm-shift. This paper highlights these changes and assesses the effects for the reliability-enhancing conditions based on recent research on reliability in infrastructure industries. A question that arises from these developments is: what are the consequences for the design and use of Information Systems in HROs?

HROS AND THEIR ENVIRONMENTS

Although HRT has become more or less renowned for its examples of nuclear aircraft carrier flight operations (e.g. Roberts, 1989;1990b;Roberts and Rousseau, 1989;Roberts et al., 1994;Rochlin et al., 1987;Rochlin), the 'theory' was also considered applicable to other organizations that enjoyed high records of safety or reliability performance over long periods of time. Organizations that were considered HROs, existed largely in the public domain as large-scale monopolies that maintained a tight level of control over large-scale integrated systems (Rochlin, 2001:72). HRT-researchers studied a number of public infrastructure industries: air traffic control centers (LaPorte and Consolini, 1991) nuclear power plants (Bourrier, 1996;Pool, 1997;Schulman, 1993a;1993b), electricity grids (Roberts, 1990a;Schulman, 1993a), and even regular power plants (Schulman, 1993a) as HROs. The majority of these 'classical' HROs were able to develop themselves over time with sufficient resources to reliably operate large-scale technologies in relatively safe and shielded public domain.

Infrastructures as HROs

Although the history of infrastructure industries varies considerably across countries and sectors, the dominant pattern shows infrastructure industries developing "[f]rom local to regional and finally large-scale integrated, hierarchical systems" in the course of the 19th and 20th centuries (Coutard, 1999:3). From World War Two until the 1980s, infrastructure industries in western countries were dominated by large-scale, state-owned monopolies. During these decades, infrastructure industries became increasingly centralized as technical and organizational innovations enabled infrastructures to be increasingly centrally and hierarchically controlled (e.g. Graham and Marvin, 2001). The large-scale, vertically integrated hierarchical organizational structures and the development of sophisticated 'control equipment' provided by advances in information technology (IT) allowed managers and engineers to centralize control with increasing levels of reliability and efficiency (e.g. Beniger, 1986;Davies, 1996;Nightingale and Poll, 2000). Until the 1980s, many large-scale technological systems – among them infrastructure industries – in modern western societies were provided through single organizations that employed integrated, automated systems of command and control. Decades of state-ownership and the national expansion of utility industries allowed the infrastructure industries to evolve into HROs and accommodate increased societal demands for reliability and continuity of service provision (e.g. LaPorte, 1988).

A CHANGING ENVIRONMENT FOR HROS

However, three interrelated trends in the last decades dramatically altered the environment of many HROs.

First, the mission of HROs – to ensure the extremely safe and reliable operation of the technological systems they operate – relatively gained in importance. The increased use of services provided by infrastructure industries in particular gave rise to additional quality and reliability demands. Large-scale infrastructure industries nowadays "[g]uarantee the ongoing production, distribution, use and disposal of almost all goods in almost all organizations of a society" (Joerges, 1988:25).

Second, since the late 1970s, developments in IT reversed the trend of central command and control, which until then accommodated the growth of large-scale technical systems. IT radically changed the ability to control large-scale systems. With new technologies the operations of HROs could be apparently smoothly decentralized, while keeping the appearance of an integrated system.

Low cost, high efficiency and the increased flexibility of IT paved the way for the third trend: the unbundling of large-scale systems and the introduction of competition in many areas (Kessides, 2004). IT "knit separate actors, transactions, and locations together into a continuous process" (Weick, 1990:12). In short, IT enabled a more efficient use of infrastructures and other large-scale technologies, with the additional benefits of efficient, flexible and responsive controls (Davies, 1996;Nightingale et al., 2003). Under the label of 'economic restructuring' or 'market reform', developments such as privatization, liberalization and deregulation figured prominently in many large-scale systems. This set off a process of institutional fragmentation of HROs – especially those that formerly operated in the public domain. Instead of providing services through large scale integrated monopolies, with central control, large-scale systems were unbundled and competitive markets, with private and mixed forms of ownership were introduced."[T]he number of actors and technologies in networked industries" increased rapidly (Coutard, 1999:8) and caused an increased splintering – i.e., institutional fragmentation – in the delivery, management and development of infrastructures (Graham and Marvin, 2001).

The three trends caused a paradoxical change in infrastructure industries and HRO environments: although they became technically more complex and interconnected, their management became institutionally fragmented.

Changing conditions

As a consequence of the abovementioned trends, large scale systems such as infrastructure industries have changed. HROs and infrastructure industries in particular became institutionally fragmented. However, the implications of these changes remain largely unknown as HRT failed to address if and how *networks of organizations* can reliably manage large-scale complex technologies. HRT-theorists listed a number of factors that make it harder to achieve high levels of safety and reliability in a network of organizations than in single organizations (e.g. Grabowski and Roberts, 1996;1997;1999). Next to the demanding problems that have to be resolved to attain high reliability, high inter-organizational reliability of large-scale technical systems through networks of organizations is more difficult as a result of a number of network-related characteristics that may diminish the ability of those who operate the systems to maintain reliable service provision.

Competing interests.

Networks of organizations may provide incentives that stimulate members to pursue organizational goals that may be mutually conflicting and completely at odds with system reliability. To ensure the (reliable) operation of systems, networks of organizations need to maintain and sustain collective goals and efforts that promote the objectives of the entire network (Grabowski and Roberts, 1996:3). Establishing reliability between organizations is far more difficult among organizations in a networked setting than within a single organization (Ramanujam and Goodman, 2003:831;Roberts, 1994:4). Reliability design features that deal with human and organizational errors, such as checks and balances, redundancies and authority structures, may no longer be possible or provide the same reliability results.

Information asymmetry

The second reason why the reliable management is more difficult through networks of organizations is because *information asymmetry demands continuous coordination and communication*. Networks of organizations create conditions of information asymmetry among organizations. Invariably, the ability to 'manage' networks of organizations is significantly reduced compared to HROs. Consequently, maintaining reliability demands continuous (re)negotiation, communication and coordination of reliability-related issues. When dealing with tasks "[t]hat cross departmental lines or that require interdepartmental coordination and participation" (Schulman, 1993b:362), shared information and uniform cultures are essential to maintain reliability. This requires a shifting attention from the importance of communication within organizations to the importance of communication *across* organizations (Gossling et al., 1998). The use of divergent perspectives, which is advocated to increase reliability at the organizational level, may actually increase the likelihood of incidences when divergent perspectives cross organizations and connect more than one organization (Weick et al., 1999:112). This becomes increasingly important when considering the long-term nature of reliability. Reliability lapses in large-scale technical systems and HROs are mainly the result of so-called latent or *'creeping errors'* (e.g. Beamish, 2002;Reason, 1997;Snook, 2000;Vaughan, 1996).

Centralization

A third reason for difficulty is the *avoidance of a natural tendency towards centralization*. The reliable management of large-scale, complex technologies naturally tends towards centralized decision making and control (Rochlin, 1989). This often eases the management burden and increases efficiency, even though multiple organizations may be involved in the provision of services in networks of organization. This centralization tendency affects the ability to organize reliability through decentralization and autonomy and conflicts with reliability measures that seek to reduce complexity and coupling (e.g. Perrow, 1999). On the other hand, as responsibility for reliability is distributed under competitive conditions in networks of organizations, social shirking may occur (Sagan, 2004).

Dynamics

Fourth, there is *continuous adjustment to dynamic issues*. Reliability is a dynamic issue, an ongoing accomplishment (e.g. Weick, 1987). Consequently, problems regarding the management of reliability can migrate within a network of organizations (Grabowski and Roberts, 1997).

DOES INSTITUTIONAL FRAGMENTATION AFFECT THE RELIABILITY OF HROS?

The previous paragraphs demonstrated how the responsibility for the reliable provision of vital services in large scale systems changed from a primarily intra-organizational task to an inter-organizational challenge. Instead of one or comparatively few public organizations cooperating under hierarchical command and control, large networks of organizations with competing interests became involved in the management of critical infrastructures and the reliable provision of services. The question left to be answered is how changes in the institutional environment of HROs influences their ability to provide reliable services?

Empirical research

A number of extensive field studies were conducted that focused on reliability-related issues in various, institutionally fragmented HROs (de Bruijne, 2006;van Eeten and Roe, 2002;2006;Roe et al., 2002;2005;Schulman et al., 2004). The studies covered various large-scale infrastructure industries (e.g. water, electricity and mobile telephony) and comprised over 130 interviews, extensive control room observations and literature reviews. A number of intriguing conclusions could be drawn based, especially on research in large-scale electricity and telecommunication systems (de Bruijne, 2006). The studies found that managing a technological system that is owned and operated by a network of organizations and striving to maintain a joint production of reliable – that is, continuous – services indeed proved a different challenge than managing the same task in vertically integrated systems.

Networks of organizations seemed to foster conditions that were detrimental to the previously identified reliability-enhancing conditions of HROs (see Table 1). The research found all of these conditions and their underlying assumptions to be negatively affected in a networked environment (de Bruijne, 2006;Schulman et al., 2004). Those responsible for the reliable provision of services within the network lost control of resources vital to the maintenance of control and reliability performance (e.g. less adequate information, loss of command and control over vital network elements and so on). The resulting increased complexity, unpredictability in networks of organizations further increased the difficulty of their reliable management. However, the research findings did not confirm the theoretically assumed negative relationship between (the effects of) institutional fragmentation and ability to reliably manage these networks of organizations even though operations *did* become more complex to manage and the large-scale technical systems behaved more volatile (e.g. de Bruijne et al., 2006;Schulman et al., 2004). What could explain the more or less continued high reliability of the provided services in the researched cases?

The research indicated that the conditions for reliability were actually quite different in HROs when compared to HRNs. Contrary to HROs, High Reliability Networks (HRNs) emphasize different reliability conditions in a networked environment (cf. de Bruijne et al., 2006;Grabowski and Roberts, 1996;Schulman et al., 2004). Implicit in the reliability-enhancing conditions of HROs are considerations reflecting organizational command and control over resources and information. When the newly identified conditions facilitating networked reliability are translated into the concepts provided by earlier high-reliability theorists, it appears that those responsible for the reliability of services in networks of organizations successfully manage reliability when they adjust to *different* conditions from those in traditional HROs. Reliability in networks of organizations is achieved differently than under conditions of organizational integration (See Table 2). The assumed preconditions for high reliability in HROs are no longer valid and need to be adjusted into preconditions for networked reliability in networks of organizations.

HRT reliability conditions	***Networked reliability conditions***
1. Commitment to reliable operations in mission and goals	1. Commitment to reliable operations by professionals responsible for the reliable provision of services
2. Sustained high technical performance	2. Sustained high technical performance when system reliability is threatened in real-time
3. Structural flexibility and redundancy	3. Structural flexibility and redundancy in the reliable management of the system (adaptive equifinality)
4. High degrees of responsibility and accountability	4. High degrees of responsibility and accountability through formal *and* informal (professional, peers) mechanisms
5. Flexible decision-making processes (in the HRO)	5. Flexible authority patterns within and *across* organizational boundaries
6. Continual search for improvement and training for worst cases	6. Continual short-term search for improvement and training for worst cases
7. Reliability is not marginalizable, not fungible	7. Reliability is partially marginalizable, fungible except when system reliability is threatened in real-time.
8. Organizational culture of reliability	8. Professional culture of reliability
9. Strong presence of external groups with access to credible and timely operational information	9. Strong presence of external groups with access to credible and timely operational information

Table 2. Conditions facilitating the management of reliability in networked, institutionally fragmented systems (de Bruijne, 2006:389)

HOW ARE HRNS DIFFERENT FROM HROS?

To a certain extent HRT acknowledged that interactively complex and tightly coupled systems required multiple modes of governance to deal with changing conditions. Following Wildavski's (1991) analysis, HRT theorists concluded that traditional organizations typically focused on a single governance mode; planning defenses against foreseeable risks. Highly reliable organizations, on the other hand, sought a balance between governance strategies of anticipation *and* resilience so as to manage the unexpected and cope with uncertainty and risks (Weick and Sutcliffe, 2001). However, institutional fragmentation removed many conditions that allowed for anticipation. Instead of 'controlling' operations, restructuring demoted the organizations responsible for the reliability of service provision – the former HROs – to mere 'managers', lacking information and control over vital resources. Rochlin (1991:103) describes the vital difference. "If one has perfect knowledge, correct information, and a verified knowledge-based model that encompasses all possible variations, then one can indeed exercise 'control' over outcomes.… Management, on the other hand, involves decision-making under the acceptance of irreducible uncertainty, using heuristic models that are corrected on the fly, as necessary, as part of on-line trial and error learning."

Consequently, traditional HRO conditions that were considered to contribute to reliability of service provision no longer exist in HRNs. HROs had complete command and control over resources, unquestioned obedience from its members and the environment it operated in, and a relatively shielded existence from public attention. The research found HRT flawed in its assumptions regarding conditions that facilitate reliability and the levels of reliability achieved. The networked environment emphasizes different reliability-enhancing characteristics than those identified by HRT. The implication is that HRT, which until now has been presented as generic organizational theory of (un)reliability, is not as unconditionally applicable as assumed. In networks of organizations, different conditions appear to positively influence the reliability of service provision. HRT consequently needs to be modified to accommodate conditions of networked reliability (cf. de Bruijne, 2006;Schulman et al., 2004).

Nevertheless, the question remains how HRNs cope with the networked characteristics that no longer resemble those of the traditional HROs? HRT, because of its basic assumption of more organizational command and control over resources in traditional HROs, focuses upon anticipatory mechanisms that could improve resilience and be put into place relatively easily.

The identified networked reliability conditions as well as the problems resulting from anticipatory operations suggest that in a networked environment high reliability is achieved with a relative emphasis on resilience. Reliability in networks of organizations therefore differs from that in HROs as a result of the *relative shift from anticipatory long-term planning towards real-time resilience* (de Bruijne, 2006;de Bruijne and van Eeten, 2007).

CONCLUSION

The question that needs to be answered is what the implications of these findings – if any at all – are for the design and operation of Information Systems design and their use in HRNs (cf. Carlo et al., 2004;van den Eede and van de Walle, 2005;van den Eede et al., 2006)? On the one hand, the increased use of IT is necessary for networks of organizations to function in a coordinated fashion. The consequences of these changes for those who actually control and operate these systems were in part caused an increased interactive complexity of these systems, and therefore an increased risk of large-scale failure (de Bruijne, 2006). On the other hand, IT did enable those responsible for the reliable provision of services to by and large deal with the increased volatility, unpredictability and surprises of the networked operations, albeit in real-time and 'closer to the edge' than in HROs. In this sense, the paradoxical role of IT that was mentioned in previous research was confirmed (Carlo et al., 2004).

However, the shift from anticipation to resilience in the reliable management of HRN signals that the relative importance of crisis management to ensure the reliable operation of HRNs increases. The research uncovered how system operations in HRNs are increasingly forced into 'real-time' management. Like traditional HROs frequently mention the importance of human interaction within HROs (e.g. Weick, 1987) the research into reliability in HRNs stresses the importance of informal, rich interaction between operators across organizational boundaries. Coupled with the increased importance of crisis management and tools that support infrastructure operators, the research findings might cause IS-designers to allow for increased 'space and scope' for informal inter-organizational human interaction.

This might include for example:

- Scope and room for real-time management. More information than ever is collected within HRNs in real-time. Real-time management means that larger numbers of specialists with expertise in a variety of fields are drawn into control rooms to cope with an ever-increasing number of complex and volatile situations. New IT systems should be able to accommodate this expansion as a systemic response to reliability threats.
- IT systems should allow for the changed emphasis from anticipatory analysis to real-time improvisation and experience. This would mean, providing operators with scaled down versions of many of the intricate and often sophisticated IT systems in use in HROs. These would include, for example, planning tools that would allow operators in HRNs to develop trends in or at near real-time on a sufficiently sophisticated level.
- New control technologies should help operators keep up with these changes and gain a more adequate up-to-the-minute understanding of the condition of the technology operated in HRNs. Real-time information should be available to provide operators systemic oversight to assess threats to the reliability of service provision and

regain some semblance of control, albeit often at the last moment. Real-time management forces system operators to create an ongoing, cognitive, dynamic representation of system they are managing.

- The ability of operators to use their experience and professional expertise to customize the representation of the large-scale technical system provided by IT. IS should provide 'building blocks' in the design of control systems that allow operators to build the control system they are most comfortable with.
- IS design should allow for a relative increase in the ability to use real-time, rich informal communication and coordination during crisis operations in real-time. For example, this might include an increased ability to expand the representation of system conditions across organizational boundaries for communication and coordination purposes.
- Finally, the dynamic technical and organizational environment in HRNs demands that IS designs should be able to cope with the necessity for (near-)continuous upgrading. The volatile and dynamic environment in HRNs demands for continuous small- and large-scale adjustments in IT-systems throughout the HRN.

Future IS-research should do well to acknowledge these and many of the as-off-yet unknown consequences that are the result from a shift from HROs to HRNs.

ACKNOWLEDGMENTS

This research was partly funded by the Next Generation Infrastructures Foundation (www.nginfra.nl). The author would like to thank all those at the CAISO and KPN Mobile who contributed to this research as well as the members of the Delft University of Technology/Mills College, Networked Reliability Research Group. The standard disclaimer applies.

REFERENCES

1. Beamish, T. D. (2002) *Silent Spill, The Organization of an Industrial Crisis,* MIT Press, Cambridge.
2. Beniger, J. R. (1986) The Control Revolution , Technological and Economic Origins of the Information Society, Harvard University Press, Cambridge.
3. Bourrier, M. (1996) Organizing Maintenance Work At Two American Nuclear Power Plants, *Journal of Contingencies and Crisis Management,* **4,** 104-112.
4. de Bruijne, M. (2006) Networked reliability, institutional fragmentation and the reliability of service provision in critical infrastructures, Delft University of Technology, Delft.
5. de Bruijne, M. and van Eeten, M. (2007) Systems that Should Have Failed: Critical Infrastructure Protection in an Institutionally Fragmented Environment, *Journal of Contingencies and Crisis Management,* **15,** 18-29.
6. de Bruijne, M., van Eeten, M., Roe, E. and Schulman, P. (2006) Assuring high reliability of service provision in critical infructures, *International Journal of Critical Infrastructures,* **2,** 231-246.
7. Carlo, J. L., Lyytinen, K. and Boland, J., Richard J. (2004) Systemic Risk, IT Artifacts, and High Reliability Organizations: A Case of Constructing a Radical Architecture, *Sprouts: Working papers on Information Environments, Systems and Organizations,* **4,** 57-73.
8. Coutard, O. (1999) Introduction: the evolving forms of governance of large technical systems, In *The Governance of Large Technical Systems*(Ed, Coutard, O.) Routledge, London, pp. 1-16.
9. Davies, A. (1996) Innovation in Large Technical Systems: The Case of Telecommunications, *Ind Corp Change,* **5,** 1143-1180.
10. van den Eede, G. and van de Walle, B. (2005) Operational Risk in Incident Management: a Cross-fertilisation between ISCRAM and IT Governance, In *Proceedings of the Second International ISCRAM Conference*(Eds, Carle, B. and van de Walle, B.) Brussels, Belgium, pp. 53-60.
11. van den Eede, G., van de Walle, B. and Rutkowski, A.-F. (2006) Dealing with Risk in Incident Management: An Application of High Reliability Theory, In *Proceedings of the 39th Annual Hawaii International Conference on System Sciences*, Vol. 2 Kauai, pp. 37c- 37c.
12. van Eeten, M., Roe, E., Schulman, P. and de Bruijne, M. (2006) The enemy within: System complexity and organizational surprises, In *International CIIP Handbook 2006*, Vol. II (Eds, Dunn, M. and Mauer, V.) Center for Security Studies, ETH Zurich, Zurich, pp. 89-110.
13. van Eeten, M. J. G. and Roe, E. (2002) Ecology, Engineering and Management, Reconciling ecosystem rehabilitation and service reliability, Oxford University Press, Oxford.
14. Gossling, G. D., Roberts, K. H. and Jayaswal, A. (1998) *Improving The Representation Of Human Error In The Use Of The Flight Crew Human Factors Integration Tool*, Institute of Transportation Studies, Berkeley.

15. Grabowski, M. R. and Roberts, K. H. (1996) Human and Organizational Error in Large Scale Systems, *IEEE Transactions on Systems, Man, and Cybernetics--Part A: Systems and Humans,* **26,** 2-16.
16. Grabowski, M. R. and Roberts, K. H. (1997) Risk Mitigation in Large Scale Systems: Lessons from High Reliability Organizations, *California Management Review,* **39,** 152-162.
17. Grabowski, M. R. and Roberts, K. H. (1999) Risk Mitigation in Virtual Organizations, *Organization Science,* **10,** 704-721.
18. Graham, S. and Marvin, S. (2001) Splintering urbanism, Networked infrastructures, technological mobilities and the urban condition, Routledge, London.
19. Joerges, B. (1988) Large technical systems: Concepts and issues, In *The Development of Large Technical Systems*(Eds, Mayntz, R. and Hughes, T. P.) Campus Verlag, Frankfurt am Main, pp. 9-37.
20. Kessides, I. N. (2004) *Reforming Infrastructure, Privatization, Regulation and Competition,* World Bank policy research report, The World Bank, Washington D.C.
21. LaPorte, T. R. (1988) The United States air traffic system: Increasing reliability in the midst of rapid growth, In *The development of large technical systems*(Eds, Mayntz, R. and Hughes, T. P.) Westview Press, Boulder, pp. 215-244.
22. LaPorte, T. R. and Consolini, P. M. (1991) Working in Practice but not in Theory: Theoretical challenges of "High-Reliability Organizations", *J Public Adm Res Theory,* **1,** 19-47.
23. Nightingale, P., Brady, T., Davies, A. and Hall, J. (2003) Capacity utilization revisited: software, control and the growth of large technical systems, *Ind Corp Change,* **12,** 477-517.
24. Nightingale, P. and Poll, R. (2000) Innovation in investment banking: the dynamics of control systems within the Chandlerian firm, *Ind Corp Change,* **9,** 113-141.
25. Perrow, C. (1999) *Normal Accidents, Living with High-Risk Technologies,* Princeton University Press, Princeton.
26. Pool, R. (1997) Beyond engineering, How society shapes technology, Oxford University Press, New York.
27. Ramanujam, R. and Goodman, P. S. (2003) Latent errors and adverse organizational consequences: a conceptualization, *Journal of Organizational Behavior,* **24,** 815-836.
28. Reason, J. (1997) Managing the Risks of Organizational Accidents, Ashgate, Aldershot.
29. Roberts, K. H. (1989) New challenges in organizational research: high reliability organizations, *Industrial Crisis Quarterly,* **3,** 111-125.
30. Roberts, K. H. (1990a) Managing High Reliability Organizations, *California Management Review,* **32,** 101-113.
31. Roberts, K. H. (1990b) Some characteristics of one Type of High Reliability Organization, *Organization Science,* **1,** 160-175.
32. Roberts, K. H. (1994) Functional and dysfunctional linkages, In *Trends in Organizational Behavior*, Vol. 1 (Eds, Cooper, C. L. and Rousseau, D. M.) John Wiley & Sons, New York, pp. 1-11.
33. Roberts, K. H. and Rousseau, D. M. (1989) Research in nearly failure-free, high-reliability organizations: having the bubble, *Engineering Management, IEEE Transactions on,* **36,** 132-139.
34. Roberts, K. H., Rousseau, D. M. and LaPorte, T. R. (1994) The culture of high reliability: Quantitative and qualitative assessment aboard nuclear-power aircraft carriers, *Journal of High Technology Management Research,* **5,** 141-161.
35. Rochlin, G. I. (1989) Informal organizational networking as a crisis- avoidance strategy: US naval flight operations as a case study, *Organization Environment,* **3,** 159-176.
36. Rochlin, G. I. (1991) Iran Air Flight 665 and the USS Vincennes: Complex Large Scale Military Systems and the Failure of Control In *Social Responses to Large Technical Systems, Control or Anticipation*(Ed, LaPorte, T. R.) Kluwer Academic Publishers, Dordrecht, pp. 99-125.
37. Rochlin, G. I. (1999) Safe operation as a social construct, *Ergonomics,* **42,** 1549-1560.
38. Rochlin, G. I. (2001) Networks and the Subversion of Choice: An Institutionalist Manifesto, *Journal of Urban Technology,* **8,** 65-96.
39. Rochlin, G. I., LaPorte, T. R. and Roberts, K. H. (1987) The Self-Designing High-Reliability Organization: Aircraft Carrier Flight Operations at Sea, *Naval War College Review,* **40,** 76-90.
40. Roe, E., Eeten, M. v., Schulman, P. R. and Bruijne, M. d. (2002) *California's Electricity Restructuring: The Challenge to Providing Service and Grid Reliability*, EP-P8949/C4505, EPRI, Palo Alto.
41. Roe, E., Huntsinger, L. and Labnow, K. (1998) High reliability pastoralism, *Journal of Arid Environments,* **39,** 39-55.
42. Roe, E., Schulman, P., van Eeten, M. and de Bruijne, M. (2005) High-Reliability Bandwidth Management in Large Technical Systems: Findings and Implications of Two Case Studies, *J Public Adm Res Theory,* **15,** 263-280.

43. Sagan, S. D. (2004) The Problem of Redundancy Problem: Why More Nuclear Security Forces May Produce Less Nuclear Security, *Risk Analysis,* **24,** 935-946.
44. Schulman, P., Roe, E., van Eeten, M. and de Bruijne, M. (2004) High reliability and the management of critical infrastructures, *Journal of Contingencies and Crisis Management,* **12,** 14-28.
45. Schulman, P. R. (1993a) The Analysis of High Reliability Organizations: A Comparative Framework, In *New Challenges to Understanding Organizations*(Ed, Roberts, K. H.) Macmillan, New York.
46. Schulman, P. R. (1993b) The Negotiated Order of Organizational Reliability, *Administration & Society,* **25,** 353-372.
47. Snook, S. A. (2000) *Friendly Fire, The accidental shootdown of U.S. Black Hawks over Northern Iraq*, Princeton University Press, Princeton.
48. Vaughan, D. (1996) *The Challenger Launch Decision: Risky Technology, Culture, and Deviance at NASA*, University of Chicago Press, Chicago.
49. Weick, K. (1987) Organizational culture as a source of high reliability, *California Management Review,* **29,** 112-127.
50. Weick, K. E. (1990) Technology as equivoque: sensemaking in new technologies, In *Technology and organizations*(Eds, Goodman, P. S. and Sproull, L. S.) Jossey-Bass Publishers, San Francisco, pp. 1-44.
51. Weick, K. E. and Sutcliffe, K. M. (2001) *Managing the unexpected: Assuring high performance in an age of complexity*, Jossey-Bass, San Francisco.
52. Weick, K. E., Sutcliffe, K. M. and Obstfeld, D. (1999) Organizing for High Reliability: Pocesses of collective mindfulness, In *Research in Organizational Behavior*, Vol. 21 (Eds, Staw, B. M. and Sutton, R.) JAI Press, Greenwich, pp. 81-123.
53. Wildavsky, A. B. (1991) *Searching for safety,* Transaction publishers, New Brunswick.