The Origins, Impacts and Future of High Reliability Organizations Research: A Reflective Essay

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Abstract

This is a reflective description of the development of High Reliability Organizations research starting from its early origins. It covers the original intentions of this research, the original organizations visited to conduct it and the research strategies employed. It also describes the findings of this research and the impact, both intended and significantly beyond intended, of its published accounts. It assesses the spread of the concept of high reliability organizations (HROs) as a prescriptive model for a wide variety of organizations, many of which lie significantly outside the objectives, technology and environment of the original organizations researched. Lessons learned are described from this experience.

The essay then presents an argument about the uncertain future for high reliability organizations and offers a new understanding of the concept of "reliability" itself as an organizational performance standard. This perspective stems from the dramatic rise in inter-organizational networks as well as the changing problem environment that will increasingly surround future organizations – one of uncertainty, turbulence, complexity and the rapid and large-scale propagation of public problems themselves. We also note as well the magnified consequences of policy, organizational and managerial error under these conditions.

The essay concludes with a new proposed meaning for reliability different from the "high" reliability of HROs one as an organizational and inter-organizational process of resilience through contingent design and re-design in the face of problem environments of increasing scale, complexity, turbulence and uncertainty. It also offers a set of propositions for the management of design error in the face of this new approach to reliability.

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1. Introduction

Forty years ago a group of researchers undertook to investigate a small group of organizations managing quite hazardous technical systems. Among these were: the U.S. Navy's nuclear aircraft carriers "USS Carl Vinson" and "Enterprise" and their flight-deck operations. Also the Diablo Canyon nuclear power plant in San Luis Obispo, California owned and operated by the Pacific Gas and Electric company (PG&E). Finally, the Oakland Center air traffic control facility whose control sectors included the busy air space over the San Francisco and Oakland area as well as a long overwater sector extending out into the Pacific Ocean.

Each organization was known for continually achieved reliable outputs and their very high performance levels in the management of accident-free and low-error operations. Each was tasked with managing technical systems which if they failed could inflict major, if not catastrophic consequences, in lives lost and property destroyed. How this organizational reliability was achieved was a looming question to the original researchers, given their contrast with many organizational case studies and the thinness of prior theoretical explanations or descriptions of such performance readily available in organization theory.

1.1 Early Support for the research

Support for the research project came in several forms. First, there was approval for access and visits to each of the organizations and observation of their activities by key leaders in the authority structure surrounding each of the organizations, as well as approval of those in charge of their operations themselves. A Navy Admiral and the Captains in change of and responsible for operations on both the carrier Carl Vinson and the carrier Enterprise supported the project after talks with the principal investigators of the project, one of whom had himself been a Marine pilot who had flown planes off of and onto aircraft carriers.

The PG&E Vice-President for Nuclear Operations and the Diablo Canyon Plant Manager also met and talked with the PIs and expressed interested in the project's possible research findings. Finally, Federal Aviation Authority (FAA) contacts and the Supervisor of the Oakland Center Air Traffic Control facility met with the PI's and were likewise interested in the research.

In each case, the key individuals themselves seemed keen about possible utility of the research. They knew their organizations were good but they were interested in finding out from the perspective of organization researchers just why they were good and whether they could be better. In each case they gave permission for the researchers to

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visit and observe their operations as well as to interview personnel occupying a variety of positions with diverse functions.

Further, the organizations and their leaders provided a wide range of additional types of access and some unexpected perquisites. Among these were: access to all places on the carriers except the reactors; accommodations on the carriers during periods at sea; and even plane shuttles to and from the carriers when they were at sea.

Prior to the start of the Diablo Canyon research PG&E allowed several of the researchers to spend time observing and interviewing at a multi-generator oil-fired plant in Pittsburg, CA in order to practice and see contrasts to Diablo Canyon.

At the Diablo Canyon nuclear plant researchers were allowed unescorted access throughout the plant and escorted access to the reactor building and other containment areas. They were allowed to observe Diablo Canyon control operators in operation and to conduct extensive interviews with staff and their managers. Also, they were allowed to observe daily meetings of the Outage Control Center during a major reactor outage taking place at the plant. Further, they were offered transport from the Oakland airport to and from the San Luis Obispo airport in the PG&E corporate airplane and from there by shuttle to the Diablo plant.

At the Oakland Center facility researchers were allowed access to the air traffic control operations center and the opportunity to observe individual controllers in their work and to interview them during breaks in their operations. A visit to the FAA headquarters allowed members of the research team to learn about and observe the training of air traffic controllers at the FAA Academy in Washington, D.C.

2. The Research Approach and Strategy

The HRO research as noted relied on extended time spent on-site in these organizations, access to and continuous observation of control centers, and extensive interviews with personnel at all levels of the organizations, from maintenance to operators, supervisors and, ultimately, top-level personnel in the hierarchy of the organizations. The field work extended across nearly ten years of observation and interviewing.

It was an important point for researchers to establish at the beginning a role in the organizations as researchers and learners *not* prescribers or consultants nor employees of higher management. This proved to be a novel role to many members of the organizations, many of whom had little experience with people trying to learn from them and far more experience with consultants, hired to offer solutions as experts.

Not only were the researchers not being paid by the organization, but they readily admitted to members of the organizations they spoke with and interviewed that they didn't know many details about their technical systems or operations and weren't there to tell them what they were doing wrong. Instead, they suggested that they were there

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to find out why and how they were so good and had such impressive records of reliability and safety in the face of high volume activities and a wide range of operational conditions.

Researchers described their role as that of unobtrusive observers of operations and as just “flies on the wall” in meetings. Follow-up questions were asked in later interview sessions and conversations with individuals about viewed operations and meetings.

Many of the interviews conducted with individuals started with basic questions about their job descriptions and responsibilities and how they came to end up in their job. As part of job description questions it was frequently asked: “What’s a good and bad day” for them and their organization? There was a strong effort made to have at least one of the researchers on scene when important meetings or actions were occurring. In regular mutual debriefs researchers sought to piece together the flow of behaviors and activities they were seeing, and how they might be providing the resulting performance levels of the organization.

Later, after the bulk of observations, interviews and mutual debriefs, the researchers met with groups of organizational personnel to describe to them what they thought they’d observed and understood. It was important to them to see if their findings made sense to organizational personnel, and they enlisted their help in checking for errors in their observations and/or conclusions. After the field visits were over, in some cases researchers showed participants draft manuscripts they were writing and asked them to check for accuracy.

One of the more interesting comments in reaction to the researchers’ descriptions was made by one work crew supervisor: “Each of us knew what we were doing but we didn’t know how it connected to the overall organization in a larger perspective. You gave us the perspective and the words to explain it.”

3. What Was Observed[1]:

In the organizations that were researched, safety management was organized around worst-case hazards and accidents they wanted to make “never events” and to preclude from happening, not just probabilistically but deterministically. These were events, such as an accident that released radiation into the environment at the nuclear plant or from a nuclear carrier; a collision between commercial aircraft under air traffic control; and for the carriers also a loss of carrier aircraft launch and retrieval readiness under wartime or threat conditions.

[1] For published descriptions see Anonymous [20]; Anonymous [21, 22 and 23]; Rochlin [36 and 37]; Roberts [34]; Roberts et.al [35]; and Anonymous [44].

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Importantly, this precluded event standard of reliability for the nuclear and aviation events were also shared in a public dread of their occurrence[2]. This public dread turned out to create important political and resource support for the work of the HROs. Many other organizations managing hazardous systems that are not subject to active public dread are often forced to make compromises in safety to pressures for cost savings, time saving or other expediencies and efficiencies. The safety approach taken by HROs

in addressing their precluded events turned out to be a very comprehensive form of error management.

3.1 The Reliability and Safety Approach of HROs:

The HROs examined by the early HRO researchers stressed the ability to anticipate and enumerate, often through careful failure modelling, simulation exercises and risk analysis, errors and failures that could precipitate precluded events. In this process they also identified prior conditions and chains of events that could lead as precursors to these failures and accidents.

Through this analysis HROs formalized and continually enlarged and enhanced an identified "precursor zone" of those conditions, states or practices, both *technical and organizational*, that increased the likelihood of errors and failures that could lead to precluded events [38]. These precursors could range from operating equipment outside of design-basis temperature and pressures to having too many people or too much noise in a control room.

One major precursor was operating under uncertainty, including conditions that hadn't been analyzed or experienced before. In fact, for U.S. nuclear power plants, it is actually a violation of federal law to operate these plants "outside of analysis" [50].

3.2 Precursor Management in HROs:

The HROs developed the ability to monitor by sensors or human reporting across all levels and departments a drift toward a precursor zone or a slippage into one. They could quickly detect and correct the condition. HRO researchers came to term this process "precursor resilience." But if an HRO couldn't correct the condition, they would very likely shut down operations rather than operate in a precursor zone.

It was both an organizational (and, ultimately, a socially accepted) priority to cease operations rather than to accept precursor risk with respect to precluded events. In fact, there were a variety of veto powers distributed (among supervisors, pilots, control operators and maintenance foremen) to stop activities (to refuse to fly, to refuse permission to fly or close off a sector, to shut down or "scram" reactors) if they were under precursor conditions.

[2] For radiation leaks see Weart, *The Nuclear Fear* [55] and for aviation see Clark and Rock, "Processes Contributing to the Maintenance of Flying Phobia" [8].

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There are also verbal signals that can be sent by a variety of personnel that highlight a drift into precursor conditions. If operators say things like “I find myself in unstudied conditions” or if maintenance personnel say “I’m not comfortable working under these arrangements” they will be taken seriously by supervisors and others in the organization.

Precursor management was a recognition that the key to high reliability and safety is not operational and organizational invariance but rather the *management of fluctuations* in both organizational and technical conditions to stay within acceptable bandwidths [44].

The researchers were told that important organizational factors such as active and shared communications, the attention of workers to larger system reliability issues at stake in addition to the job at hand, and also credibility and trust between specialized departments themselves can erode over time and must be continuously monitored and refreshed.

Reliability and safety, they believed, are not achieved once and for all but are ongoing processes of careful bandwidth management, achieved with the contribution of watchfulness that is widely distributed among employees across departments and levels. These were all part of what has come to be termed a “safety culture” [15, 10, 43; 48].

3.3 Elements of a “Safety Culture” in the HROs:

One widely accepted definition of general *organizational* culture is:

“the pattern of basic assumptions which a given group has invented, discovered, or developed in learning to cope with its problems of external adaptation and internal integration, which have worked well enough to be considered valid, and, therefore, to be taught to new members as the correct way to perceive, think, and feel in relation to those problems. Culture can include assumptions, values, practices and artifacts.” [Schein 43].

What makes a culture a “safety” culture? A practical description in relation to what was observed in HRO behavior was offered by one of the research participants:

“In HROs, reliability with respect to safety from precluded events is not a fungible value, it is not traded-off with respect to speed, efficiency, cost and output.”

Many of the safety culture elements and practices of HROs were directed toward avoiding cognitive and perceptual errors that individuals or groups could make that could lead to precluded events. In particular these were: errors of misestimation, misspecification, misperception, and misunderstanding [45].

In most accounts of major accidents, including the Three-Mile nuclear mini core melt that released radiation, the Chernobyl reactor explosion that put pieces of molten core outside the plant on the ground, the Deepwater Horizon oil rig explosion, and the

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Fukushima fuel melt due to loss of back-up power for cooling after a tsunami event flooded reserve generators located in a basement, someone associated with the organization was quoted to the effect that: “Gee, I didn’t know that could happen.”

It has been argued in later HRO literature interpretations that HROs are continually in the process of “managing the unexpected” (Weick and Sutcliffe [56]. But the HROs could not have achieved the reliable performance they had if they had been routinely managing the unexpected.

Instead, it was a common practice in the HROs to *enlarge expectancies*. In American nuclear power plants, for example, not only must “design-basis” accidents, which a plant is designed and built to avoid or withstand, be carefully modeled and probabilistically analyzed, but also the *possibilities* of “beyond-design basis” accidents must also be analyzed [51].

It was a safety culture practice in HROs to play games that support a process of enlarging expectancies. Control operators and maintenance personnel would often play what they term “the what-if game?”. One person may approach another and suddenly ask something like: “What would you do if there was a quake right now and you lost your display and connection to the system monitors?”

HRO’s also conducted simulations of unlikely emergency events. In work planning sessions at Diablo Canyon contests occurred to construct the most inventive worst-case scenario for an upcoming work activity and its outcome. Participants “scored points” with others for coming up with complex scenarios. Also, often in work planning sessions researchers observed that the question was frequently asked: “What are we leaving out?”

3.4 Other elements in support of safety the HRO safety culture:

In the HROs researched there is a major focus on system-level reliability and safety, beyond individual tasks and job descriptions, with a consequent sensitivity to the possibilities of system failure from individual actions and decisions [17; 32;38].

There is also a widely shared and internalized sense of personal responsibility and identity in promoting and sustaining high levels of system reliability and safety, including attention to precursors.

A commitment related to this, seen in the HROs, is a continuous search for improvement. This reflects a shared belief stated by one nuclear power plant manager: “If we’re not getting better then we’re really getting worse”.

There is also a widespread commitment, as noted, that safety stands above all other organizational values including cost, speed, efficiency as well as the production of outputs.

A major artifact in HRO safety culture is also formal procedures. There are procedures in many organizations, but frequently in many organizations, at the actual work and shop levels, at least some of them are ignored because: they are obsolete, ambiguous, or wrong in their instructions and haven’t been corrected or simply that they are inconvenient and are replaced by “work arounds”.

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But researchers never found people ignoring formal procedures at any level of the HROs. One reason is that procedures were a living document of the current operational knowledge base of the organization. Many had been revised several times in a formal revision process.

Implortantly, the main sources of these revisions were suggestions from the people who actually used them. In a very real sense, given this participation, the people who most used them “owned” the procedures.

4. Special Conditions Surrounding HROs

As noted earlier, the hazards posed by the precluded events at the core of HRO attention (nuclear accidents at a power plant that could spread radioactivity over a large area, or the collision of large commercial airliners) are regarded by the public with fear and dread [Weart [55]. This dread provided a stable foundation economically and politically for their support and also a significant degree of operational autonomy.

Dread is stable because it is a forward-looking prospective property. It contrasts with the retrospective public condemnation that is often associated with accidents in other organizational domains. Condemnation it has been noted runs in an “issue attention cycle” and fades relatively quickly over time amidst competing concerns of costs, speed or convenience that come to outweigh the preeminence of safety [13].

Also at the core of HRO operations is a *mature, well-understood technical system*. HROs are not and cannot be experimental R&D-type organizations, with surprises and uncertainty surrounding their activities and outputs. They are not seeking one-off solutions to separate and distinctive problems. Instead, their reliability rests on and produces highly repetitive outputs. HROs are running the same machinery and technical systems for the same purpose over many repetitions, over many hours, days, months and years. This allows operators and managers to gain deep experience centered around organizational processes and their objectives.

Finally, the nuclear, air traffic and carrier operations were overseen by *competent and aggressive external regulators* focused on safety: the Nuclear Regulatory Commission (NRC), Federal Aviation Administration (FAA). The Nuclear Operations aboard carriers reports to both the ship’s commander and is also under the close oversight of the Naval Nuclear Propulsion Program (NNPP) in the Department of Energy.

5. Important Properties and Limitations of our HRO research:

HRO researchers did not begin with a theory or hypothesis about what contributed to the safety and reliability of the organizations under study. Rather, the HRO researchers simply undertook to describe, and did so quite carefully, what was observed from a close and extended on-site study of their organizations.

Each organization was extraordinarily reliable in providing intended services in the face of continual hazard. But researchers used the term "high reliability" more as a nominal category than a scaled property. As such, this categorical concept did not allow their

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identification or differentiation along any numerical comparative scale of "higher" or "lower“ reliability organizations.

Nor did it allow the differentiation, among the discrete and quite unusual characteristics observed, of what their separate relative importance was to the overall safety of the organization. Researchers took the organizations as they found them and placed them in the nominal category of “high reliability organizations”.

This also meant that they did not know how they became HROs. Did they start out this way? This certainly wasn’t the case with the Diablo Canyon plant because its beginnings were a trial of errors, starting with major ones in the original construction documents.

Researchers did know that for each organization, there was in deep memory and/or vivid experience among many personnel of a past major operational failure in similar technical systems: a midair collision of two fully loaded commercial airlines over the Grand Canyon, a crippling crash on the USS Forrestal, and the melt down of Three Mile Island nuclear power plant.

But the lack of detailed individual organizational history unfortunately did not allow the formulation of even an ordinal maturity model because the researchers had no formal idea of a set of intermediate “reliability” states that led to the "mature" point of becoming a "high reliability“ organization. This was to have big consequences on the impact of the published research.

6. Reactions to the HRO Research: Or “Be Careful What You Wish For”

The published HRO research has attracted an audience of other organization researchers, and safety researchers such as: Bourrier [5]; MacRae [27]; Weick and Sutcliffe [56]; LeCoze, [26]; Pariès, et.al. [32]; and Schwiderowski, et. al., [47]). Analysts of patient safety in healthcare became particularly interested (Vogus and Sutcliffe [53] and Vogus and Iacobucci [54]).

Additionally, the Evidence Synthesis Program (ESP) of the U.S. Veterans Administration eventually produced a report titled “Evidence Brief: Implementation of High Reliability Principles” [52]. The Institute of Nuclear Power Operations (INPO) wrote a report called “Traits of a Healthy Nuclear Safety Culture” [18] that reflected some of the traits reported in the HRO literature and added to its influence by promoting interest in the concept of safety culture. That document also came to influence the strategy of nuclear regulators such as the U.S. Nuclear Regulatory Commission as well.

At the same time, the proponents of a contrasting theory of “Normal Accidents” (Perrow [33]) and others (Sagan [41]), were asserting that major accidents are technologically determined to happen in complex, tightly-coupled technical systems, irrespective of management. These theorists came to question the “optimistic” arguments of HRO findings, with Perrow [33] contending (in a non-falsifiable argument) that the apparent reliability of complex, tightly-coupled systems in HROs was because the HROs simply “haven’t had enough time to fully express themselves”.

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In one literature review of the impact of HRO research it was noted that: “Since 2001, HRO ‘theory’ spread to non-high-risk industries and the amount of published literature has more than doubled, including several literature reviews” [Cantu et.al [7]. But at the same time, this review also noted that “The results show HRO theory within the published literature has not significantly evolved past the original characteristics and hallmarks” (Cantu et.al. [7]).

It has also been the case that in the years since the first HRO publications no significant replication case studies have been undertaken.

In reality, the rapid increase noted after 2001 came from the prescriptive capture of the original HRO research and its extended application well beyond the special features and circumstances surrounding the original organizations. Many new readers were those who wanted their own organizations to be thought of as HROs. The idea became one of the latest fads in a series of fads that periodically sweep through the world of management. Increasingly writers about “high reliability organizations” were eager to sell HRO as a product to potential clients.

All of this was greeted with responses ranging from amusement to horror by the original HRO researchers. Ironically, it led to HRO researchers assuming a public cautionary role of stressing the limits of the very model they had publicly described [21; 46].

7. What was learned from reactions to the published HRO research?

First, HRO researchers underestimated the legal, regulatory and shareholder pressure on CEOs in a variety of organizations to increase “reliability” and avoid costly accidents, leading to a wider market interest in potential management improvements to do so.

Also, the lack of specificity in the definition of “high” reliability itself as a concept allowed it to be interpreted to apply generally to any type of improvement in organizational management.

Importantly, the fact that the published research did not offer or address any developmental process for the HROs observed, and the consequent lack of a maturity model of HRO stages and their potential measurement, meant in effect that consultants could offer any prescription for HRO development in any time frame without fear of any contradiction in the original literature.

Finally, as can be learned, if organizational researchers leave ambiguities in key concepts and fail to offer implications of their findings *and their limits*, these ambiguities will be clarified and gaps filled by lawyers and consultants. As has been said: “law [will] claim its legal meaning to govern its legal use”(Bergstrom [4]). And, consultants will discover an appropriate disease to match their available remedy.

8. The Growth of Uncertainty and the Future of High Reliability

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Many changes in society and technology raise distinct challenges to organizational reliability, in particular the reliability approach taken by the original HROs. As was noted earlier, the maturity of the technology and the long experience with its operation was a foundational basis for the high reliability of the researched organizations. But now organizations must face the rise of complex, uncertain and rapidly changing technologies.

8.1 Reliability Impacts of dramatic increases in the pace of technological change.

Many organizations must deal with rapidly upgrading and entirely new technical systems. Many technologies such as AI, adopted into organizations are new -- marketed and adopted very quickly. Little time is allowed for Beta and life-cycle testing of

these systems before running them in full application -- they are in effect being Beta tested by adopting organizations. For example, the Boeing 737 Max Maneuvering Characteristics Augmentation System (MCAS), resulted in several plane crashes. It was added to the 737 MAX without full testing or even instructions to pilots in the rush to market the new version of the 737 plane [N.Y. Times 3/23/19].

Given the speed of technological change, there has also been a decline in the motivation of some organizations to support existing core technologies with preventive maintenance because of expectations to upgrade or replace these systems with newer versions [Russell and Vinsel, NY Times (2/22/17)].

Overall fewer organizations are operating with mature technologies and fewer of their operators have the benefit of long-term experience with the systems they are operating.

8.2 The complexity of technical systems has also eroded regulatory competence and effectiveness to fully assess new components of ever more complex technical systems.

Like the MAX 737 MCAS, with its partial artificial intelligence (AI) system, many AI systems have now been adopted with little exploration of the likely effects of their implementation process on adopting organizations or of societal consequences of their use or abuse[3].

These new systems can also elude the technical competence of regulators to understand and regulate their use. The MCAS system employed in the 737 Max, for example confronted the FAA's inability to understand and assess the new system. "The FAA gave manufacturers more power in the certification process in 2003" including approvals of many parts of the system (*Business Insider*, 2017 [6].

In another earlier case, the U.S. Securities and Exchange Commission failed to understand and regulate new complex Mortgage-Backed Securities (MBS) and derivatives and their risks, not just to single investors but systemic risks to an

[3] For an insightful analysis of the complexities of this process see Macrae [28].

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interlocked world-wide credit system. These financial instruments and risks also exceeded the understanding of many bank executives and those executives of other financial institutions who bought and sold them. These risks contributed in 2008 to multiple worldwide financial collapses in the financial sector (Lewis [24]).

9. Rising Inter-Organizational Interconnectivity.

Another challenge to HRO-type reliability is that increasingly organizations and their operations are now more embedded in the operations of networks of other organizations. They are often increasingly dependent in supply chains for instance, upon upstream outputs and services of uncertain reliability.

Also multi-organizational networks encompass organizations that can be quite different from one another in technology, goals and safety concerns (deBruijne, [12] Anonymous [46]; Zuiderwijk [57]).

9.1 Reliability Challenges in Multi-Organizational Networks

The reliability of individual organizations in a supply chain may depend on inputs from other organizations with diverse management strategies and less commitment to safety. While it is not formally known how to “grow” a safety culture in a single organization, there is even less understanding of creating a safety culture extending across a multi-organizational network [46].

Multi-organizational networks can even introduce uncertainty when they are undertaking shared design processes. A recent study of inter-organizational “couplings” of shared personnel and plans among multi-organizational research and innovation projects revealed “a systematic degradation of the couplings that were planned to connect sub-groups of organizational actors. Over time, the projects became less collaborative than planned, and they have a tendency to fragment into isolated activities by subgroups of actors [in separate organizations]” (Klessova, [19]).

Ironically, there is another inter-organizational problem in the growing and shifting interconnectivity of critical infrastructures. Critical (“lifeline”) infrastructures such as electricity, water supply, telecommunications and transportation have become *more* interdependent under normal operation. But the character of these interconnections can also shift when latent interdependencies emerge under conditions of stress or in disruption or failure. It turns out that critical infrastructures are becoming increasingly vulnerable to the failure of other infrastructures [40].

A one-way serial dependency, for example, of a road on top of a levee under normal conditions can readily shift to a mutual dependency if the levee develops a leak. Then the levee itself becomes dependent on the road to bring trucks with stone (“rip rap”) and work crews to repair these leaks.

Individual consumers, who are normally at the end of the dependency chain in an electric grid or supply chain, can instead become key players in grid management or the

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prevention of shortages by refraining from heavy electricity usage during peak periods or from hoarding scarce supplies like hand sanitizers during the Covid-19 pandemic.

In these situations emergent inter-organizational dependency now may require improvisational interconnections and close coordination of actions among what were separate maintenance crews in order to restore service simultaneously to both [40]. There is often a lack of preparation among infrastructures for these contingent interconnections that emerge and require prior contacts and communication capacities shared across organizations to facilitate rapid restoration of service (Zuiderwijk, [57]).

10. The growth of unstable problem environments

Many organizations face increasingly uncertain legal, political, economic and natural environments. In these settings conditions may exceed expectancies and supersede error management frameworks [14; 45].

10.1 The Covid Example

In the Covid -19 global pandemic a wide variety of organizations faced a problem of widespread global interconnectivity and vulnerability, against a disease that featured high speed global propagation of cases that created a wide a variety of uncertainties in symptoms and treatment as well as disruptions across social and economic sectors.

Because of the scale, growth rate and formation of new variants by the virus, public health organizations such as the U.S. Centers for Disease Control, had to revise some of their lock-down directives and patient treatment recommendations to hospitals with newer understanding of COVID-19 properties and those of its subsequent variants [45]. In the United States, Public Health organizations faced surprising resistance to vaccinations and masks by citizens and also by some state and local officials.

Meanwhile, economy-wide impacts of public health regulatory measures and lockdowns left policy-makers as well as corporate and business executives, investors and thousands of small business owners unsure of recovery prospects and timetables. As one CEO asserted: “we have never seen so many factors in play at the same time on such a global scale” (Hannon and Chaudhuri [16]).

The Covid-19 pandemic had many features as a policy and managerial crisis that lie well beyond the foundations of high reliability organizations or of many current public health organizations [40]. This was a very different domain from the careful management of well-understood and bounded technical systems to produce repetitively safe and continuous outputs while avoiding well-defined unacceptable events – as well as defined precursors to them.

Given the uncertainties surrounding the Covid-19 virus, including its transmissibility, symptomology and treatment options, public health operations had to be conducted

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under unstudied conditions and with a variety of unforeseeable errors possible [45]. A description by a physician of treatment errors in ICU units describes "staff members working well out of their comfort zones, with unfamiliar systems and equipment, caring for a career's worth of critically ill patients in two months" (Ofri [31]).

Moreover, the COVID problem intersected with other social problems well beyond the range of public health organizations. In the United States, lower vaccine inoculations and higher death rates were correlated with income inequality, race and ethnicity. Transmission rates, for example, were higher in higher density low-income neighborhoods, as well as in institutions for the elderly.

What are the criteria for reliable performance in such conditions? Certainly thousands of deaths were an inevitable consequence of the disease itself, irrespective of any

managerial process. In the U.S. alone there were 1,134,000 COVID deaths 2020-2023 alone. How many deaths would constitute an HRO-style precluded event?

11. Part III: The Future of Reliability as a Performance Standard

What is being suggested here is a future of uncertainty, with wide and fast problem propagation as well as the propagation of error. In climate change, as one example, an uncertain trial and error project is currently being run on a global scale. There are now visible threshold effects from "steady global surface warming from 1973 to 1022 but increased warming rate after 1990" (Samset et.al. [42]).

These changes include more and higher wind speed hurricanes; wider ranging clusters of tornadoes, atmospheric rivers bringing higher rainfall and floods across the U.S and higher intensity, faster spreading, less predictable movement of wildfires, with different properties (e.g. "fire tornadoes" [1]) in many parts of the world.

Wildfire changes in California have meant that their directional uncertainties and speed of change can exceed the information processing, decision and action capacities of fire-fighting organizations. In a way similar to the COVID-19 pandemic, this mismatch is an invitation to error.

Will AI based control systems increase the reaction speed of human organizations to cope with these problems? Or will complex autonomous AI based technical systems lead to human social and behavioral changes that themselves exceed the anticipation and adjustment capacities for a variety of human regulatory and policy-making organizations to avoid errors or failures?

Right now there doesn't seem to be the imagination with respect to the full range of AI future capabilities and consequence possibilities, plus a clear vision of our own societal vulnerabilities, to regulate AI technology without error (Macrae [28]).

Given uncertainty and the growing problem challenges in problem environments can we expect to have any high reliability organizations in the future that avoid error and

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failure? In fact, what meaning would we attach to “reliability” to use it as a performance standard for any organization in the future?

At this point this retrospective confronts a major prospective question: did HRO researchers do all of their HRO research simply to chronicle a dying breed of organizations? Will their research be ignored or worse, sneered at, as a quaint remnant of an obsolete era? One engineering critique already has attacked even the concept of “reliability” used in relation to organizational research (Leveson, et.al. [245).

12. A New Role for Reliability in the Future?

What is proposed here is a new role for reliability in an emerging future. An added focus of reliability apart from the domain of management to the domain of *design*. This role

however will require a new approach to design: a process of sociotechnical design based on an integrated as well as *cumulative* discipline of engineering and social science analysis.

12.1 A new Role for Design

This integration will require new approaches to the training of engineers as well as social scientists that addresses the development of a sociotechnical design process founded on integrated sociotechnical analysis. (Aven and Ylonen, [3]; Moorkamp [30]).

Engineers will have to embrace the overlap in the concepts of reliability and safety. They will also have to address a wider range of design variables, including organizational variables (including safety culture) well beyond the physiological variables of human factors.

Social scientists, at the same time, will have to embrace and accept responsibility for their activity in a *design science*. They will have to work with engineers to formalize key social and organizational concepts (including “safety”) and develop frameworks for their measurement.

12.2 Design and Resilience

It is important to note that the problem uncertainty we have been describing can elude the foresight, planning and control strategy of much of design. Uncertainty challenges the practice of design-based causation in which action would be governed by prior goals and objectives, and the logic of achieving them, established formally in prior design.

Many design assumptions and constraints are in place, in other words, *“in order to”* achieve foreseen objectives. But that confident approach to the future may be undermined by uncertainty and surprise that is often the birthplace of error.

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This gives rise to a need for adaptive capacity and resilience, both of which lie in the domain of "efficient causes" -- actions that are taken *"because of"* the clarity and often urgency of immediate, real-time need (Aven [2]).

12.3 Design and Adaptation

Adaptation and resilience may well require localized real-time improvisational actions that serve as emergent forces pushing and shaping from behind, not prior controlling causal frameworks of design. In important ways this process resembles the description of complex adaptive systems (Cunha and Cunha [11]; Comfort and Rhodes [9]; Anonymous [23]).

This may sound as if design and adaptation are antithetical processes. But in actuality sociotechnical design is a process that could add to adaptive capacity. It could do so by designing in order to promote conditions that facilitate corrections and improvements in what might well be termed processes of *contingent re-design*, facilitating adaptive actions, even improvisational ones to what are currently unspecified events and

conditions. It is no *non-sequitor* to suggest that a sociotechnical design process could entail designing in part for conditions and response actions that might both actually be currently "outside of design" (See U.S. NRC [51]).

One example might be setting up a prior framework that encourages sociotechnical thinking in response to surprises by generating inter-organizational contacts and communication channels among diverse people with diverse skill-bases and perspectives from other parts of an organization or even outside the organization.

12.4 Benefits of Sociotechnical Design

An integration of technical and more sharply defined and specified organizational variables, could produce a more careful closeness of fit and reinforcing match between the technical characteristics of a system and the organizational and managerial capacity to manage and operate that system safely (Arven and Ylonen [3]).

Then a measurable maturity model might be developed to assess progress in key dimensions of *design process* reliability to support both safety and a contingent re-design process for resilience and adaptation in the face of uncertainty (Aven, [2]).

One design approach possibly helpful for a sociotechnical design process has been termed "design thinking". "Design thinking is an iterative, non-linear process which focuses on a collaboration between designers and users. It brings innovative solutions to life based on how real users think, feel and behave." (A-M. Teperi, et.al. [49]).

13. Conclusion: An HRO-Style Set of Error Management Principles for Design?

Perhaps an error-centered focus could be a strong foundation for the development of standards for reliability in the sociotechnical design process. For example, it could well be considered a design error to produce technical systems that require for safety

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response speeds or precision in control that exceed the speed and precision of human organizations, or of operator cognition and pattern recognition capacities.

New developments in AI also introduce the need for new design perspectives on error in the relation between AI systems and their human interface (Schwiderowski, et.al. [46]. For example, it would be a design error to introduce an AI design feature that would increase the volatility faced by operators, or reduce their ability to understand the optimization "solutions" of automated systems (such as automated electric power dispatching systems that rapidly change dispatching instructions to generators to optimize among very large numbers of shifting grid variables).

It is also likely to be an error to design technologies with automated control systems that do not allow control operators or pilots a "claw back" to manual control should those automated systems fail. This was a major problem as noted with the Boeing MCAS system. This implies that it will also be a challenge for regulators to understand the difference between regulating for reliability and reliable regulation (Macrae, [28]).

Finally, it would also be a design error to fail to provide design supports for interdependent networked infrastructures or supply chains to undertake contingent, even improvisational re-design processes for resilience and recovery in the event of external or internal "beyond design-basis" events (U.S. NRC, [51]; anonymous, [40]).

Through this approach reliability can be given new meaning and utility in shaping effective organizational performance in the emerging world of complex and rapidly evolving technical systems as well an increasing set of fast-moving, intersecting problems of enlarged scale and scope.

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