Handbook of Research on Industrial Advancement in Scientific Knowledge

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Chapter 9
Assessing HRO Principles for Reliable Performance in Asset-Intensive Organizations:
Expecting the Unexpected

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ABSTRACT

Asset-intensive organizations rely on physical assets that are expensive, complex, and have a significant impact on organizational performance. The management of such assets is essential when seeking for reliable performance in a world of increasing uncertainties. The observation that asset-intensive organizations deal with increasingly complex and tightly coupled systems and often operate in highly demanding environments may indicate that they should adopt practices from high reliability organizations (HRO) to ensure and maintain reliable performance in the fourth industrial revolution. This chapter operationalizes the HRO concept in the field of physical asset management, measures to what extent the underlying principles are recognized, and explores the relationship between the HRO principles and asset performance using a descriptive survey. Results indicated that the HRO principles are recognized and may, therefore, serve as an instrument for reliable performance when adopting new technologies. A positive relation between asset performance and the five HRO principles was identified.

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INTRODUCTION

Asset-intensive organizations such as utilities, heavy engineering, pharmaceuticals and transportation, rely on physical assets that are expensive, complex and have a significant impact on organisational performance. The management of such assets is essential when seeking reliable performance. The new paradigm of the fourth industrial revolution (Bloem et al., 2014), in which operational technology and information technology will increasingly merge, has a significant impact on asset-intensive organizations. Digital technologies will be more and more integrated into physical assets, not only enabling further communication between machines and people but also between machines themselves.

Despite the promises of advanced digital technologies in managing physical assets, adding more technologies also increases the technical complexity of physical assets (Martinetti, Braaksma, & van Dongen, 2017). This increased complexity may result in chains of reactions that decrease predictability and cause unexpected failures, which are often stated by asset-intensive organizations as the primary operational risk to business (LaRiviere, McAfee, Rao, Narayanan, & Sun, 2016).

The observation that many asset-intensive organizations deal with increasingly complex tightly-coupled systems, intensified by the pace of technology and digitization summarised by the industry 4.0 paradigm, and often operate in highly demanding environments, has led the authors to the idea that they should adopt practices from High Reliability Organizations (HRO) (La Porte, 1996; Roberts, 1990; Roberts & Rousseau, 1989). These practices may support them in ensuring and maintaining reliable performance of their assets in the fourth industrial revolution. In current published literature, there is limited empirical evidence of the usefulness of the HRO concept outside the more mature safety domain from which it originated. This chapter aims to extend current insights on the application of HRO by assessing the HRO concept in the context of asset-intensive organizations. It provides practical examples for practitioners in managing uncertainties to prevent mindlessness when adopting new digital technologies. This chapter operationalises the HRO concept to determine to what extend HRO practices are recognised in asset-intensive organizations, and it explores the relationship between the HRO practices and perceived asset performance.

This chapter is structured as follows. The first section introduces the main concepts from literature in asset management and organizational reliability relevant to this research. The research design in the next section includes a detailed description of the methodology that has been followed. The next two sections present the results and the implications for practitioners. The chapter concludes with the conclusion and recommendations for further research.

LITERATURE BACKGROUND

This section defines asset management and the need for reliable performance. It introduces the concept which has been used as the foundation for the survey among asset-intensive organizations which will be described in the results section.

Asset-Intensive Organizations as Reliability-Seeking Organizations

The management of physical assets, like buildings, infrastructures, utilities, plants, and transportation, is addressed by the discipline of asset management. Asset management is defined as a “coordinated

activity of an organization to realize value from assets" (ISO, 2014, p. 14). Asset management involves the balancing of costs, opportunities and risks against the desired performance of assets to achieve organizational objectives. Many different methods and tools are available to manage physical assets effectively. Many of these methods and tools are discussed under the topic of maintenance management, which can be considered as a predecessor of asset management (Amadi-Echendu, 2004). Based on an extensive review of 37 maintenance concepts, Fraser et al. (2015) concluded that Reliability Centered Maintenance (RCM), Total Productive Maintenance (TPM) and Condition Based Maintenance (CBM) are the three most important and popular maintenance concepts as summarized by Ruitenburg (2017).

RCM was developed in the aviation industry, to assess the reliability of the designs of new aeroplanes (Smith & Hinchcliffe, 2003). RCM can be defined as "a process used to determine what must be done to ensure that any physical asset continues to do what its users want it to do in its present operating context" (Moubray, 1997, p. 7). In response to the maintenance and support problems encountered in manufacturing environments, the Japanese developed and introduced the concept of TPM. TPM is a maintenance system defined by Nakajima (1988), which covers the entire life of equipment in every division including planning, manufacturing, and maintenance. Its purpose is to limit the disruptive consequences

of equipment failures in production systems to ensure reliable performance. Where RCM and TPM are clearly defined maintenance concepts, CBM is instead a large collection of different but similar approaches to maintenance (Veldman, Wortmann, & Klingenberg, 2011). In general, the primary goal of CBM is to perform a real-time assessment of equipment conditions to make proper maintenance decisions, consequently reducing unnecessary maintenance and related costs (Gupta & Lawsirirat, 2006). For example, the condition of physical assets can be measured by equipping them with (additional) sensors. Knowing which activities have been executed or knowing that some physical assets have been deployed for heavy work for a long time, enables the organization, for example, to adjust the maintenance schedules in response.

Based on the three important concepts in maintenance, all sharing a strong focus on technical reliability, asset-intensive organizations can be characterized as reliability-seeking organizations. The main emphasis in academics is on the application of tools and techniques to improve the quality, safety and reliability of the physical asset itself, regarding the physical asset as a technical system (Gits, 1992). However, many physical asset systems can also be characterised as socio-technical systems. Socio-technical systems are work systems that involve complex interactions between humans (e.g. operators, mechanics), machines (e.g. installations, infrastructure, rolling stock) and various environmental aspects (Trist, 1981). This concept is also acknowledged by Van Dongen (2011), who states that the management of physical assets, like rolling stock, can not only be guaranteed by technically perfect designs and maintenance concepts. The managers, operators, and mechanics determine, to a great extent, the final result. Therefore, it can be argued that besides the technical reliability, the reliability of the organization should also be taken into consideration when seeking reliable performance.

Reliable Performance in the Fourth Industrial Revolution

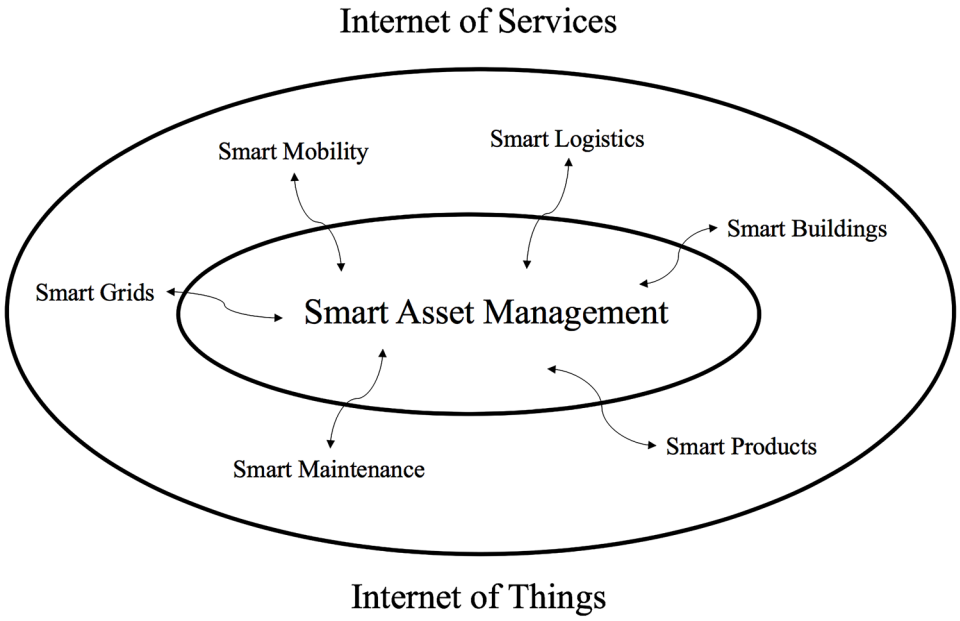
Industry 4.0, also referred to as the 'Fourth Industrial Revolution', is currently a much-discussed topic that has the potential to affect entire industries by transforming the way goods are designed, manufactured, delivered and paid. The rapid adoption and application of pervasive digital technologies in several industries, as advocated by the industry 4.0 paradigm, not only radically change products and services, but also fundamentally reshape organizations (Yoo, Richard J. Boland, Lyytinen, & Majchrzak, 2012),

with an increasing pace. As briefly summarised by Hofmann and Rüsch (2017), Hermann et al. (2016) identified four industry 4.0 components based on their review of academic and business publications:

1. **Cyber-Physical Systems:** Industry 4.0 is characterised by an unprecedented connection via the internet or other distributed ledgers and so-called cyber-physical systems, which can be considered systems that bring the physical and the virtual world together (Akanmu & Anumba, 2015).
2. **Internet of Things:** "Smart, connected products offer exponentially expanding opportunities for new functionality, far greater reliability, much higher product utilization, and capabilities that cut across and transcend traditional product boundaries" (Porter & Heppelmann, 2014, p. 4).
3. **Internet of Services:** There are strong indications that, similar to the internet of things, an internet of services is emerging, based on the idea that services are made readily available through web technologies, allowing companies and private users to combine, create and offer new kind of value-added services (Andersson & Mattsson, 2015)
4. **Smart Factory:** The concepts of cyber-physical systems, internet of things and internet of services are closely linked to each other and enable the so-called 'smart factory', which is built on the idea of a decentralized production system, in which "human beings, machines and resources communicate with each other as naturally as in a social network" (Kagermann, Helbig, & Wahlster, 2013, p. 19). Something similar can be stated for 'smart asset management' (Figure 1) which relies more and more on cyber-physical communications.

However, as more heterogeneous modules, originally produced by diverse actors, are combined to create innovations, which is indeed the case based on the key components of industry 4.0, organizations

Figure 1. Industry 4.0 and smart asset management based on the smart factory
(Kagermann et al., 2013, p. 19)



increasingly run the risk of complex systemic failure or other forms of unintended consequences (Perrow, 1984). When complex systems fail, there is an initial tendency to attribute the failure to human error. Yet, as described by Madni and Jackson (2009), research has repeatedly shown that in many cases it is not human error but organizational factors that set up adverse conditions that increase the likelihood of system failures.

Reliability, as pursued by many asset-intensive organizations, is a complex and challenging organizational trait to achieve, in which managers face the challenge of coping with new (digital) uncertainties in the face of diminishing reservoirs of organizational slack (Schulman, 1993). Two main theories of reliability can be distinguished in relation to the performance of complex, hazardous operations (Wildavsky, 1989), which may serve as guidance for asset-intensive organizations in pursuit of reliable performance.

Reliable performance can be achieved by routine-based reliability and mindfulness-based reliability as described by Butler and Gray (2006). Routine-based reliability posits that reliable performance can be achieved efficiently by creating repeatable packages of decision rules and associated actions. Organizationally, routine-based reliability involves the design and execution of standard operating procedures and decision-making processes, which may be unique to the organization or widely accepted across an industry (Spender, 1989). Routines are based on interpretations of the past more than anticipations of the future. Organizations adapt to experience in response to feedback about outcomes (Levitt & March, 1988). While routines are essential tools for creating reliable performance, they are not without limitations (Weick, Sutcliffe, & Obstfeld, 2008) and predispose us to see situations in particular ways (Langer, 1989).

While routine-based approaches focus on reducing or eliminating situated human cognition as the cause of errors, mindfulness-based approaches concentrate on promoting highly situated human cognition as the solution to individual and organizational reliability problems (Weick & Sutcliffe, 2011). Reliability would be equated not with invariance but with resilience (Schulman, 1993). From a mindful perspective, "one's response to a particular situation is not an attempt to make the best choice from among available options but to create options" (Langer, 1997, pp. 113-114). Mindfulness-based approaches hold that the ability of individuals and organizations to achieve reliable performance in changing environments depends on how they think: how they gather information, how they perceive the world around them, and whether they can change their perspective to reflect the situation at hand (Langer, 1989). The problem, as also pointed out by Akkermans and Van Wassenhove (2013) in response to grey swans (Taleb, 2007, p. 37), is that people have to know where to look, and that people need to be willing to expect the unexpected, and act swiftly and decisively when the unexpected happens. As Schulman (1993, p. 371) concluded in his analysis of the Diablo Canyon case: "…a core capability of adaptation and resilience is the key to maintaining organizational reliability at the highest levels".

The introduction of new pervasive digital technologies in organizations creates unseen and unexpected fault lines, and organizations must now learn to carefully deal with those fault lines to take full advantage of new digital technologies. (Yoo et al., 2012). A different approach to ensure and maintain reliable performance of physical assets is therefore required. Companies should be accompanied and supported on their road to Industry 4.0 in a practical manner. This could be achieved through concepts and frameworks, which features different building blocks and dimensions of Industry 4.0 and therefore may serve as an orientation guideline (Hofmann & Rüsch, 2017). This is where the concept of High Reliable Organizations (HRO) might be helpful in guiding asset managers and asset owners for safeguarding reliable performance in an increasingly digitally connected world.

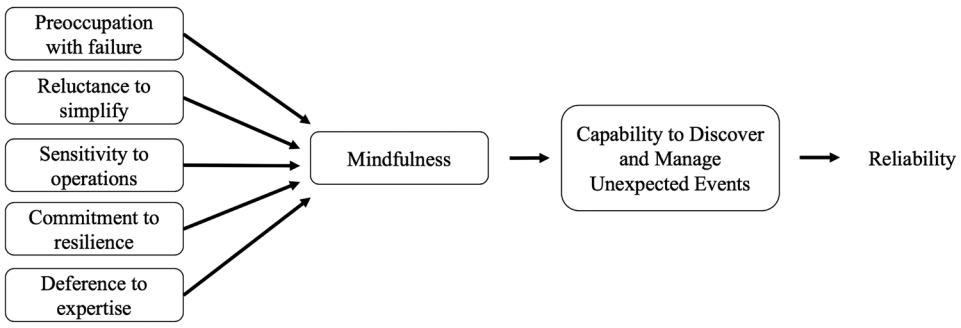
A Mindful Approach for Reliable Performance

Reliability-seeking organisations are not distinguished by their absolute errors or accident rate, but rather by their "effective management of innately risky technologies through organisational control of both hazard and probability" (Rochlin, 1993). HROs are a subset of high-risk organizations, designed and managed to avoid accidents in complex, tightly-coupled systems (Roberts & Rousseau, 1989). An HRO is, for instance, a nuclear power plant, an aircraft carrier, an air-traffic-control team, a firefighting unit, or a hospital's emergency department. HRO researchers argue that accidents in complex systems are not inevitable because there are processes in place that enable high-hazard organizations to effectively prevent and contain catastrophic errors helping them to achieve a consistent record of safety over long time periods (Roberts, 1990).

The key difference between HROs and other organizations is the sensitivity or mindfulness with which people in most HROs react to even very weak signs that some kind of change or danger is approaching (Weick & Sutcliffe, 2011). From the perspective of performance as a continuing process or set of activities, high reliability is a dynamic process of organising rather than one of being an HRO. Pursuing and achieving reliability is a continuous, ongoing accomplishment (Sutcliffe, 2011). Effective HROs tend to develop both anticipation and resilience to achieve reliable performance (Schulman, 2004). Anticipation refers to the prediction and prevention of potential dangers before damage is done, whereas resilience refers to the capacity to cope with unanticipated dangers after they have become manifest and learning to bounce back (containment). Unlike effective HROs, traditional non-HRO organizations tend to lean heavily toward one or the other of the two. Most organizations focus on anticipation of expected surprises, risk aversion, and planned defences against foreseeable risks (Weick et al., 2008). Weick and Sutcliffe identified five principles that they define as 'reliability-enhancing' (Figure 2):

- Preoccupation with failure refers to HROs' constant preoccupation with potential errors and failures;
- Reluctance to simplify focuses on HROs' ability to collect, analyse and prioritise all warning signs that something may be wrong and avoid making any assumptions regarding the causes of failure;
- Sensitivity to operations refers to the ability to obtain and maintain the bigger picture of operations that enables HROs to anticipate effectively potential future failures;

Figure 2. A mindful infrastructure for high reliability
(Weick et al., 2008)

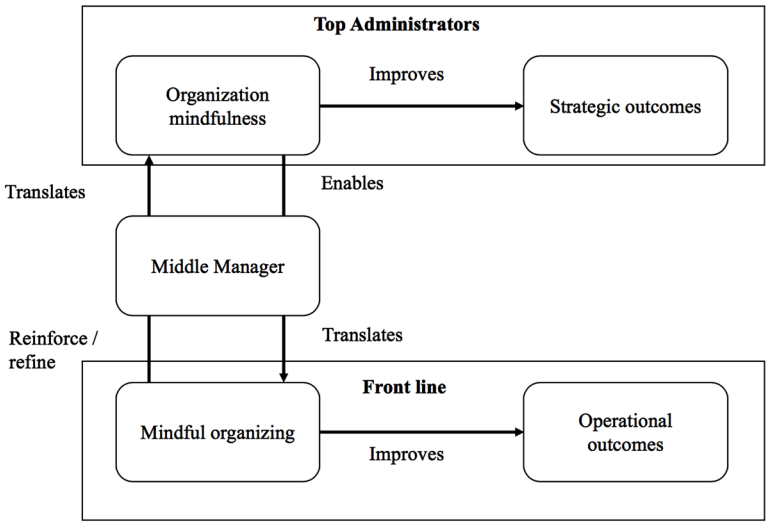


- Commitment to resilience is concerned with the ability of HROs to not only effectively anticipate errors but also to cope with and bounce back from errors and unexpected events;
- Deference to expertise refers to deferring decision-making in case of emergencies to individuals with the expert knowledge to deal with a specific problem, irrespective of their status within the organizational hierarchy.

These five principles do not operate in isolation. They must be supported by a systems-thinking approach enabling network interactions to build mindful relationships in and between organizations. Vogus and Sutcliffe (2012) suggested that two actions are required; that of 'organisational mindfulness' and 'mindful organising'. Both are required for organisations to achieve improved levels of organizational mindfulness (Figure 3). Senior management (Top administrators in Figure 3) is concerned with 'organisational mindfulness' focused on strategic outcomes. Operations (Front line in Figure 3) is concerned with 'mindful organising' focusing on operational outcomes. Middle managers play an important role in translating and enabling both organisational levels.

HROs can be valuable to other organizations because they are harbingers of adaptive organizational forms for an increasingly complex environment (Weick et al., 2008) and may be considered as a good practice in achieving reliable performance. The HRO concept provides insight into adaptive organisational forms for complex environments. For example, the qualities of well-functioning HROs can be generalised and applied to medical care (Sutcliffe, 2011). Furthermore, other studies on HRO showed the case of applying the principles of HRO to improve the quality and safety in hospitals (Cady, 2008; Chassin & Loeb, 2013) and to identify barriers and opportunities for adoption in the construction industry (Harvey, Waterson, & Dainty, 2016). This chapter investigates the application of the HRO principles at asset-intensive organizations.

Figure 3. Reconciling Organizational Mindfulness and Mindful Organizing
Adopted from Vogus and Sutcliffe (2012, p. 728)



RESEARCH DESIGN

The research approach consists of a descriptive survey of asset-intensive organizations in the Netherlands. Descriptive survey research is aimed at understanding the relevance of a phenomenon in a population, for instance, the level of adoption of best practices (Karlsson, 2016, p. 83).

The research consists of a replication study (Weick & Sutcliffe, 2011) using a descriptive survey method (Forza, 2002, p. 155). It is aimed to identify to what extent the HRO principles, as identified by Weick et al. (2008), are recognised at asset-intensive organizations and to identify possible relations between these HRO principles and asset performance. Furthermore, the survey provides insights to what extent current practices of asset-intensive organizations incorporate the five principles of mindfulness as seen by HROs.

The survey research process, as described by Forza in research methods for operations management (Karlsson, 2016), consists of different processes that need to be followed to ensure the quality of the research. These processes include a strong link to the theoretical level, designing the survey, pilot testing, collecting and analysing data and interpreting and reporting the results, which will be briefly summarised below.

The authors collaborated with the Dutch Cooperation of Effective Maintenance (NVDO) in designing and executing the survey via an online survey tool. The NVDO represents a large number of asset-intensive organizations in the Netherlands. The unit of analysis is similar to the original assessment of Weick and Sutcliffe (2011) and is aimed at individual respondents. The target audience of this survey in asset-intensive organizations includes asset owners, asset users, asset managers and service providers. By measuring the attitude of the respondents of the survey towards a mindful infrastructure for high reliability, the authors assessed the current capability of asset-intensive organizations in the Netherlands to discover and manage unexpected events.

The theoretical foundations, constructs and operational definitions of a mindful infrastructure for high reliability (refer to Appendix) have been adopted from Weick and Sutcliffe (2011). Although the survey has been designed to be applicable in multiple domains the following steps were executed to validate the applicability of the survey to fit the field of asset management.

- The first step was to translate the original questionnaire into Dutch to align with the needs of the target audience for a better understanding (and response) of the questions.
- The next step was the validation of the Dutch questions by an expert team consisting of both practitioners of the NVDO and academics from the University of Twente. This step was critical in the operationalisation of the survey to ensure that the survey was consistent with the respondents' level of understanding but still complied with academic standards. The major changes were made in the reformulation and contextualization of the Dutch questions to ensure the right interpretations of respondents. Due to the nature of this study (replication study), the content of the constructs was not changed.
- A pilot test has been performed to assess the quality of the online survey (e.g. questions, survey length, direct and reverse wording) and to gain a better understanding of the respondents involved. Based on this pilot test and previous replication studies (Golzio, Lalla, & Manni, 2014) the measurement scales were changed, using four thresholds instead of two thresholds as suggested in the original assessment (Weick & Sutcliffe, 2011). This decision increased the range of options, permitting a more detailed interpretation of the opinions of the respondents.

As a final result, the survey consisted of eight sections (see also Appendix), using standard Likert scales. Each scale is directed to measure a specific area of mindfulness which contributes to the capability of the organization to discover and manage unexpected events (P), whereas the first three sections determine the need for mindfulness (M). The following sections had been included in the survey: The organization's mindfulness (M1), the organization's vulnerability to mindlessness (M2), where mindfulness is most required (M3), preoccupation with failures (P1), reluctance to simplify (P2), sensitivity to operations (P3), commitment to resilience (P4) and deference to expertise (P5). Each scale consisted of a different number of items ranging from seven to twelve items. Sections M3 and P6 contained a standard Likert scale from 'totally disagree' to 'totally agree'. The other sections contained a self-anchoring Likert scale from 'not at all' to 'a great deal'.

The global score of a section, as adopted from Golzio et al. (2014) is given by the sum of the values of the single items, $X_s = \sum_{i=1}^{I_s} X_{si}$, where I_s is the number of items in the section s. For each section, four thresholds were defined, demarcating five outcomes: very low, low, medium, high and very high. For example, section M1 has nine items and generates X_1, which ranges from 9 (number of items in the scale multiplied by score 1) to 45 (number of items in the scale multiplied by score 5). If X_1 is higher than 36, the organization has a very strong mindful infrastructure for high reliability. If X_1 is between 28 and 36, the organization has a strong mindful infrastructure for high reliability. If X_1 is between 19 and 27, the organization is on its way building a mindful infrastructure for high reliability. If X_1 is between 10 and 18, the organization has a weak mindful infrastructure for high reliability, and if X_1 is lower than 10, the organization should consider how it can immediately improve its mindful infrastructure for high reliability. The internal consistency of the scales was evaluated using Cronbach's α with a threshold of $\alpha \geq 0,7$ (Kaplan & Saccuzzo, 1997).

Hypotheses

The central hypothesis of the authors was that although many asset-intensive organizations operate in lower risk environments and deal with less complex systems compared to 'traditional' HROs, they can benefit from a mindful infrastructure for high reliability to manage uncertainties as a result of an increase in the complexity of physical assets in Industry 4.0. Therefore, based on the assumption that asset-intensive organizations, in general, operate in lower risk environments, the authors expected to find lower scores on the five principles of HRO. Furthermore, the authors expected to observe a positive relationship between the five principles of mindfulness and asset performance.

RESULTS

This section presents the results of the survey. The sample of the survey included active members of the NVDO. The survey was administrated by the NVDO and had been accessed online by 133 respondents After removing outliers and other inconsistencies, 90 surveys were fully completed. The first part of this section includes the results of the general questions and the second part comprises the 8 sections on assessing organizations' mindful infrastructure for high reliability. For illustration purposes, some

typical examples have been included from the Netherlands Railways (NS), which can be considered as an asset-intensive organization.

In general, 6 out of 8 sections proved to be reliable in terms of internal consistency (Cronbach's $\alpha \geq 0,7$), indicating that two sections need further considerations when optimizing the survey.

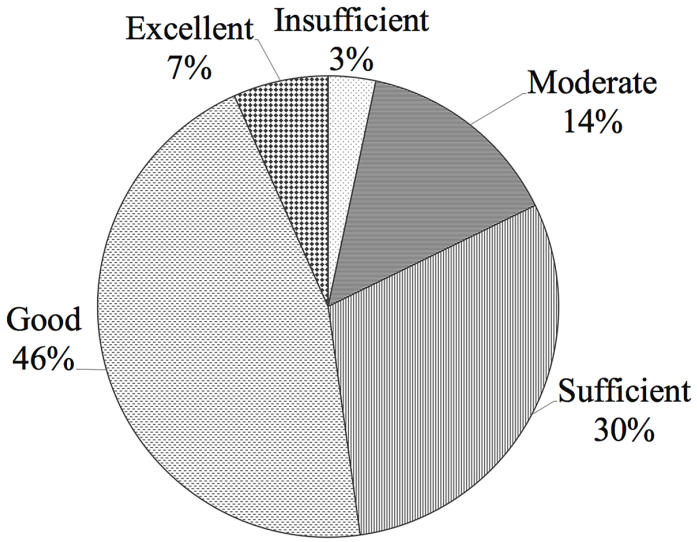
The results of the general section showed that 46% of the respondents were active in the process industry. Other respondents were engaged in sectors like food and pharma, building and construction, infrastructure, fleet and manufacturing. 24% of the respondents were employed in large organizations with more than 2.000 employees, and 60% of the respondents were directly involved in the role of asset owner, asset user, asset manager or service provider. 40% of the respondents were indirectly involved, mainly as a consultant.

Figure 4 shows the results of the perceived asset performance. 14% of the respondents perceived their asset performance as moderate, while 46% of the respondents perceived their asset performance as

Table 1. Internal consistency of the eight survey sections

Section	Cronbach's α
The organization's mindfulness (M1)	0.83
The organization's vulnerability to mindlessness (M2)	0.53
Where mindfulness is most required (M3)	0.60
Preoccupation with failures (P1)	0.82
Reluctance to simplify (P2)	0.90
Sensitivity to operations (P3)	0.83
Commitment to resilience (P4)	0.88
Deference to expertise (P5)	0.83

Figure 4. Perceived asset performance



good. 3% of the respondents perceived their asset performance as insufficient. The question related to the Overall Equipment Effectiveness (OEE), one of the key performance indicators for production, was not fully understood by all respondents. 46% of the respondents were unable to answer this question.

The following subsections summarise the results of the areas of mindfulness, which determine the capability of asset-intensive organizations to discover and manage unexpected events. The items of each section can be found in the Appendix.

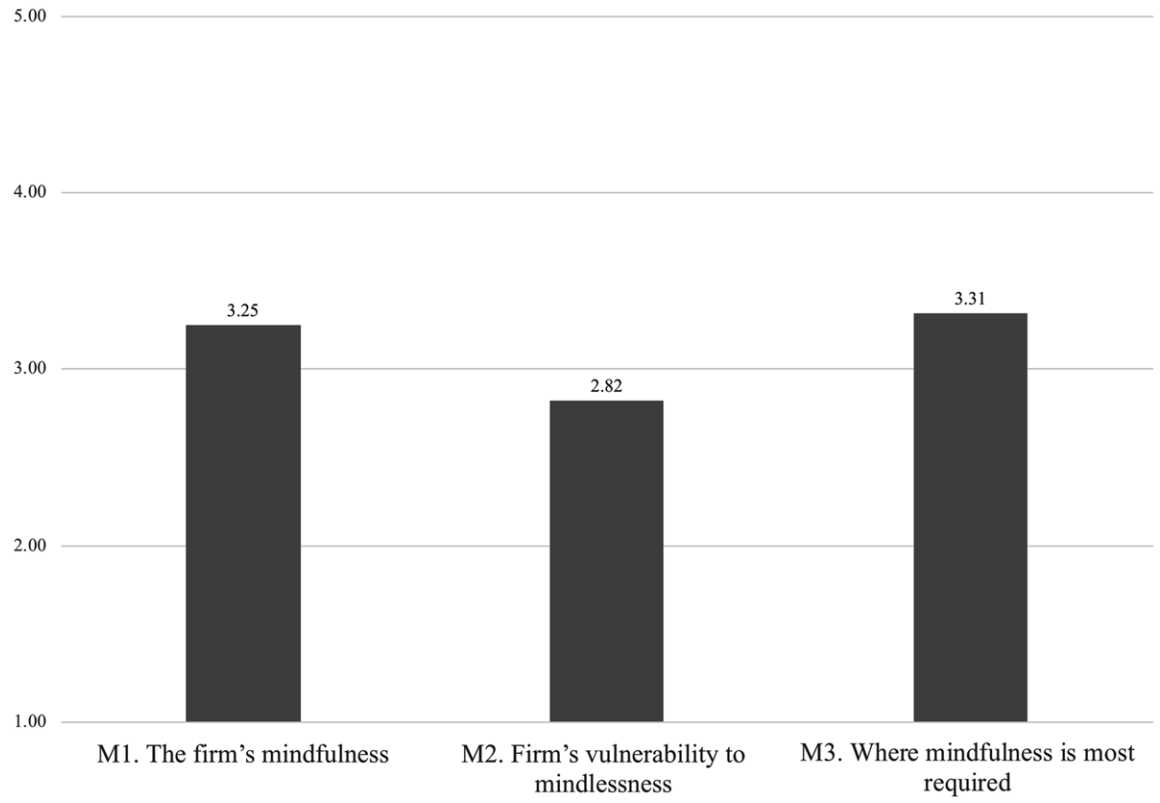
The Need for Mindfulness

The first three sections include the results which determine the need for asset-intensive organizations for a mindful infrastructure for high reliability, although they operate in lower risk environments compared to HROs. Figure 5 includes the mean scores of the sections M1-M3 based on a 5-point scale.

The Organization's Mindfulness

The first section (M1) can be considered as a starting point for assessing the organization's mindfulness, and it will provide insight into whether people are conscious of potential problems and issues and how open they are in finding out. The internal consistency of the scale was high with $\alpha = 0.83$. Results showed that the percentage of answers above the threshold of 28 was high (66%), indicating a strong

Figure 5. The need for mindfulness (mean values on a scale from 1 to 5)



mindful infrastructure for high reliability based on nine items in this section. Nevertheless, the analysis also showed that three items with a mean value of $\mu \leq 3.0$ need further attention from asset-intensive organizations. These items concern the identification of events (26% of the respondents), the specification of events (27% of the respondents), and the understanding of events (22% of the respondents). A typical example from the NS is the need for the rolling stock control centre to gain a thorough understanding of the events that caused failures to a train in operations for the right diagnosis and repair. Is it, for instance, technical failure, or is it the unfamiliarity of the train driver that may have caused the disruption?

Vulnerability to Mindlessness

The organization's vulnerability to mindlessness (M2) assesses how strong people tend to ignore the disruptions that unexpected events cause. The internal consistency of the scale is low with $\alpha = 0.53$ based on 8 items in the scale. Results showed that the percentage of answers below 24 was 41%, indicating that 59% of the asset-intensive organizations have a potential for vulnerability to mindlessness and have the tendency to ignore disruptions caused by unexpected events. Two items need particular attention with a mean value of $\mu \geq 3.0$ (reversed scale). The first item is that people are expected to perform their jobs in a particular way without deviations (46% of the respondents). This makes them vulnerable in responding to unexpected events in operations. For example, sticking to the standard railway schedule will contribute to a reliable performance up to the point where unknown failures occur. Then railway operations will adapt the schedule to absorb the failures to return to the original railway schedule. The second item of vulnerability is caused by severe production pressures (time, costs, growth, profits, or other) on people's work (38% of the respondents).

Where Mindfulness Is Most Required

This last section describes where mindfulness is most required (M3). The items in this section support organizations to start thinking of ways where to improve the capacity for mindfulness. The scale consists of 9 items and has an internal consistency of $\alpha = 0.60$. Results confirm the assumption that asset-intensive organizations operate systems which are less complex and tightly-coupled compared to HROs. 83% of the answers are above the threshold of 27, indicating that in these organizations, mindfulness is less critical due to lower perceived complexity. Nevertheless, analysis also showed that two items with a mean value of $\mu \leq 3.0$ need further attention to strengthen the capacity of mindfulness. The first item is the need for the coordination of working activities (56% of the respondents agrees on this item). The second item concerns the necessity to do things right the first time because work processes cannot always be corrected. 59% of the respondents agree, indicating that for many work processes, there is no opportunity for corrections. The term "First time right" has also been introduced in the maintenance department of NS. It refers to a standard way of working to prevent recidivism by preparing, diagnosing and repairing rolling stock the first time right when it arrives in the maintenance depot.

In summary, 83% of asset-intensive organizations operate in lower complex and tightly-coupled systems, 66% is conscious about potential problems and issues, and 59% of the organizations have a potential for vulnerability to mindlessness. The following sections indicate possible directions for improvements based on the insights to which extend current practices of asset-intensive organizations incorporate the five principles of mindfulness.

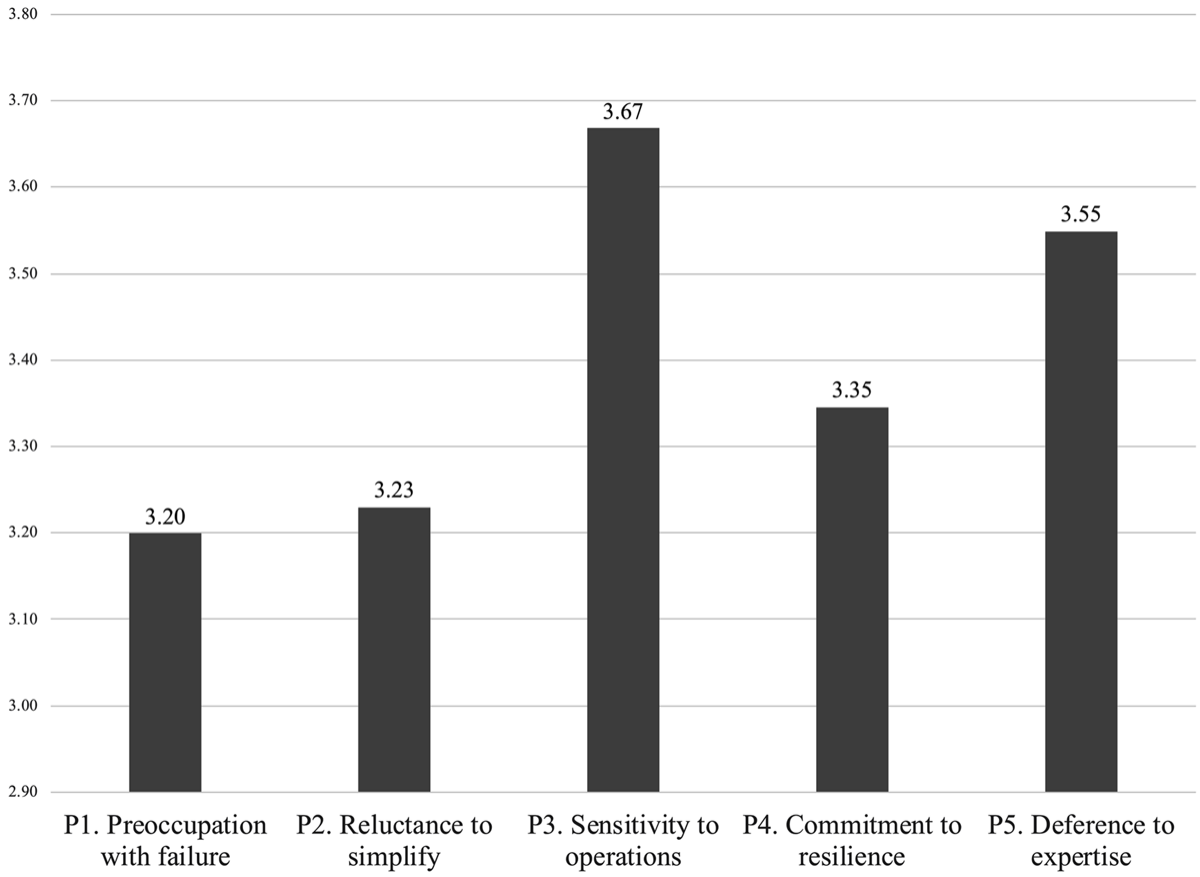
The Five Principles of Mindfulness

This section includes the results of the five principles of mindfulness (P1-P5). Figure 6 shows the mean scores of asset-intensive organizations on a scale from 1 to 5, indicating the average rating for asset-intensive organizations compared to HRO's.

Preoccupation With Failure

Preoccupation with failures (P1) refers to HROs' constant preoccupation with potential errors and failures. The items in this section determine the degree to which asset-intensive organizations have a healthy preoccupation with failure. Asset-intensive organizations need a strong preoccupation with failure to anticipate possible failures of their critical assets. The scale consists of 10 items and has an internal consistency of $\alpha = 0.82$. 31% of the answers were below the threshold of 27, indicating that almost a third of the organizations focus more on success than on failures. Results showed that near-misses were often (61%) regarded as successes that show the organization's capability to avoid disaster rather than failures that reveal potential dangers. Imagine a mechanic in a maintenance workshop, who just managed

Figure 6. The five principles of mindfulness (scale 1-5)



to avoid an accident while repairing a pantograph. By pro-actively sharing his experience (near-miss) with other colleagues at other workshops, he contributes to the identification of potential dangers which increases the preoccupation with failures of the organization. Enabling the mechanic to share his experience easily would promote a more reliable culture in the organization.

Reluctance to Simplify

Reluctance to simplify (P2) relates to HROs' ability to collect, analyse and prioritise all warning signs that something may be wrong and avoid making any assumptions regarding the causes of failure. Seeking out reluctance to simplify, means that organizations want to find how the system socializes people to make fewer assumptions, notice more, and ignore less. Keep it simple is an established management paradigm in practice but does not always contribute to the reliability of the organization. If reality is complex, a simple representation may not be a fair reflection of reality anymore. The internal consistency of the scale was high with $\alpha = 0.90$. Results showed that the percentage of answers above the threshold of 37 was high (54%), indicating a strong focus on collecting, analysing and prioritising warning signs, based on 12 items in this section. The nature of the work, including diagnosing and analysing possible asset failures and applying root cause analysis, may be an explanation for this result. Nevertheless, the lower average score on the item of valuing sceptics within the organization ($\mu = 2.6$) indicates that asset-intensive organizations need to improve organizational conditions for appreciating sceptics.

Sensitivity to Operations

Sensitivity to operations (P3) refers to the ability to obtain and maintain the bigger picture of operations that enables organizations to anticipate potential future failures effectively. Diagnosing sensitivity to operations helps organizations appraise how prepared they are to prevent the accumulation of small events that can grow into bigger problems. The section consists of 9 items, and the internal consistency of the scale was high with $\alpha = 0.83$. Results showed that 10% of the answers are above the threshold of 36, indicating a very strong ability to avert the accumulation of small events into bigger problems. 84% of the responses are between 28 and 36, indicating a strong ability. Nevertheless, two items with a value of $\mu \leq 3.1$ on a 5-point scale can be considered for further improvements. The first item relates to the question of whether people are familiar with operations beyond their own job. Results indicated that 30% of the respondents consider this item as insufficient in their organization. Knowing how other experts and departments operate will increase individuals understanding of how (related) processes and procedures are executed and to what extent they contribute to operations. The second item is the question of whether managers constantly monitor workloads and reduce them when they become excessive. 26% of the respondents disagree, indicating the second area for improvement in this section.

Commitment to Resilience

Commitment to resilience (P4) is concerned with the ability of organizations to not only effectively anticipate errors but also to cope with and bounce back from errors and unexpected events. The capability for resilience, even if it is not exercised, aids diagnosis and detection of unwarranted simplifications

and a cumulative trend in a series of errors. This section consists of 10 items, and the internal consistency of the scale was high with $\alpha = 0.88$. Results showed that the percentage of answers above the threshold of 31 was 76%. This indicates a strong commitment to resilience. A possible explanation for this high percentage is the high valuation of firefighting within asset organizations when things go wrong. Nevertheless, the continual devotion of resources to training and retraining people to operate the technical system should be taken into consideration for further improvements. Results showed that 21% of the respondents disagreed with this item. Technical systems will become more complex when information technology merges with operational technology. This will further increase the need for training, retraining and simulation. A better understanding of the system helps the organization to bounce back from errors and to cope with unexpected events. When introducing new trains, simulations are used to predict future performance and to identify possible failures to increase the response repertoire, which contributes to the resilience of the organization.

Deference to Expertise

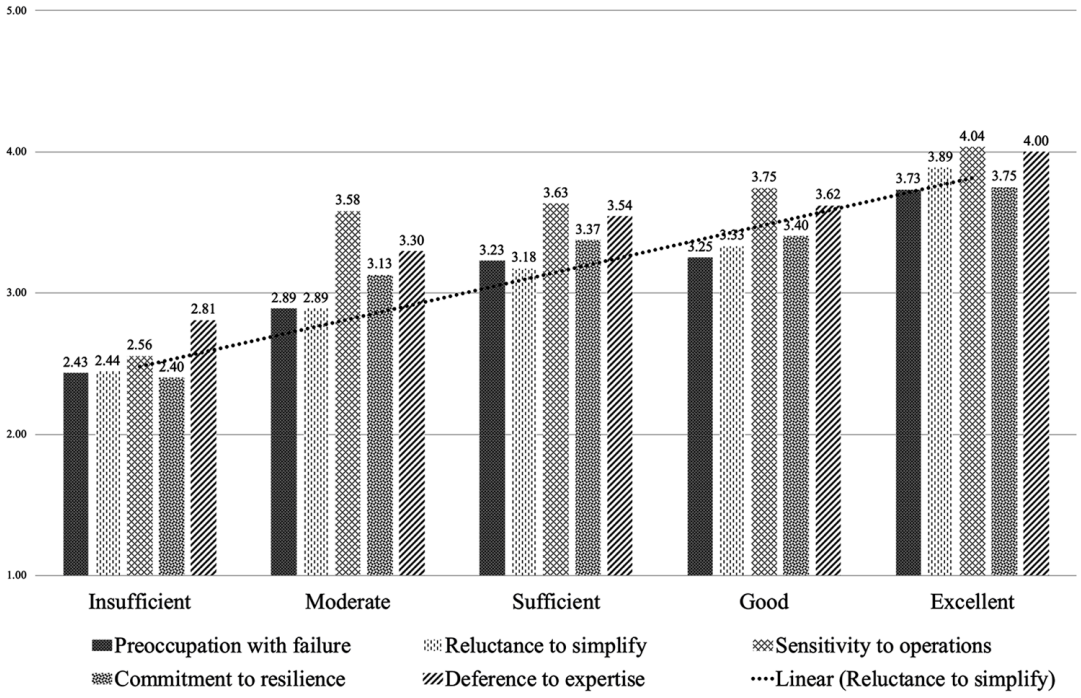
Deference to expertise (P5) refers to deferring decision-making in case of emergencies to individuals with the expert knowledge to deal with a specific problem, irrespective of their status within the organizational hierarchy. This section consists of 7 items, and the internal consistency of the scale was high with $\alpha = 0.83$. Results showed that the percentage of answers above the threshold of 22 was 83%, indicating a strong ability to localize problems and limit spreads. Nevertheless, one item with a value of $\mu = 3.1$ on a 5-point scale can be considered to further strengthen the principle of deference to expertise. 23% of the respondents disagree that people in their organization typically "own" a problem until it is resolved. Ownership and clear responsibilities are essential for an adequate response in case of unexpected events.

Asset Performance and the 5 Principles of Mindfulness

The Pearson correlation coefficient is a measure of the linear correlation between two variables X and Y. It has a value between $+1$ and -1, where 1 is a total positive linear correlation, 0 is no linear correlation, and -1 is a total negative linear correlation. The hypothesis was that asset-intensive organizations with a strong mindful infrastructure for high reliability would achieve a higher reliable performance of physical assets. Figure 7 illustrates the correlation between asset performance (horizontal axis) and the five principles of mindfulness as perceived by the respondents. The five principles all have a positive correlation with the asset performance, and all the correlations have a sig. (2-tailed) value of less than .05. Because of this, it can be concluded that there is a statistically significant correlation between asset performance and the five principles of mindfulness, taking into consideration that the population is based on a sample of 90 respondents. Pearson's r is the highest (.447) in the correlation with the performance and the principle of reluctance to simplify. The lowest Pearsons' r value was found (.363) in the correlation between asset performance and the principle of preoccupation with failure.

Investing in a mindful infrastructure for high reliability, especially when facing more uncertainty as a result of more complex systems in the fourth industrial revolution, will positively contribute to the reliable performance of physical assets.

Figure 7. Relation between asset performance and the 5 principles of mindfulness



DISCUSSION AND IMPLICATIONS

The results of this study were presented and discussed at the annual conference of the NVDO in October 2017 with approximately 80 participants from asset-intensive organizations. This section includes a summary of the discussions at this conference to emphasize the relevance of this research and its implications for practitioners. By discussing statements using an online voting tool, further insights were gained to what extent practitioners expect the unexpected in their own organization and if they may benefit from adopting the principles for a mindful infrastructure. Based on the survey results, 5 statements were selected by the expert team consisting of both practitioners of the NVDO and academics from the University of Twente for discussion:

- The first statement raised was endorsed by 98% of the participating voters (39 out of 40) which stated that the complexity is not related to the technology, but to the organization. More awareness (section M1-M3) about the importance of organizational reliability, besides the technical reliability of the asset, to respond to increasing complexity, is therefore essential.
- The second statement was defined as “management is unaware of the issues and problems in operation”. This relates to the principle of sensitivity to operations (section P3) and was confirmed by 27% of the voters (10 out of 37). The existing gap between management and operations is well discussed in literature but remains an important challenge for organizations.
- Expect the unexpected also implies a certain strategy to respond in case of unexpected events (section P4). 40% of the voters (15 out of 37) lacked a strategy to manage the unexpected, while

77% of the voters (30 out of 39) confirmed the statement that they need to pay more attention to the unexpected in their organization.

- One of the identified items that needs further consideration relates to the question of whether people are familiar with operations beyond their own job (section P4). 58% of the voters confirmed that people in the organization are not familiar with other working processes beyond their own job.
- Rewarding people for the identification of issues and problems contributes to the principle of preoccupation with failure (section P1). 55% of the voters (18 out of 33) confirmed the lack of rewarding issues and problems within their organization.

In summary, participants of the conference confirmed to a large extent the results as presented in this chapter and endorsed the idea to adopt HRO practices when seeking reliable performance.

CONCLUSION

The purpose of this chapter was to operationalise the HRO concept in the asset management domain, to measure to what extent the HRO principles are recognised at asset-intensive organizations and identify possible correlations between HRO principles and higher asset performance. In general, results revealed that the HRO principles could be operationalised to the domain of asset management and showed the extent to which the practices of asset-intensive organizations incorporated the five principles of mindfulness. Results showed a strong link between the overall asset performance and the five principles of mindfulness to manage the unexpected and maintain a relatively error-free performance.

The main hypothesis was that although asset-intensive organizations operate in lower risk environments compared to HROs, they can benefit from a mindful infrastructure for high reliability to manage higher levels of uncertainty a result of an increase in the complexity of physical assets due to the fourth industrial revolution. Results confirmed that the majority of asset-intensive organizations currently operates in an environment with lower complexity and less tightly-coupled systems compared to HROs. Nevertheless, only 66% of the organizations are conscious of potential problems and issues, and 59% has a potential for vulnerability to mindlessness. The survey results indicated that the HRO principles are recognised but also identified several items that need further management attention to strengthen the capability of asset-intensive organizations to discover and manage unexpected events. The results showed that there is a positive relation between asset performance and the five principles of HRO (P1-P5), indicating that adopting practices of the 5 principles of a mindful infrastructure for high reliability will benefit asset-intensive organizations in achieving reliable performance. Given these results and the expected increase in complexity in the fourth industrial revolution, asset-intensive organizations should consider adopting practices from HROs to strengthen their mindful infrastructure for high reliability.

The generalizability of this research is limited to asset-intensive organizations but may provide clear directions for organizations in other domains as well. Specifically, those organizations who face more and more uncertainty due to an increase in the complexity of their systems. Future research will be performed in the context of the introduction of new critical physical assets. High levels of uncertainty (e.g. teething problems) characterise critical asset implementations and organizations need to prepare consciously to expect the unexpected when seeking reliable asset performance.

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KEY TERMS AND DEFINITIONS

Asset-Intensive Organizations: Asset-intensive organizations such as utilities, heavy engineering, pharmaceuticals, and transportation rely on physical assets that are expensive, complex, and have a major impact on organizational performance.

Commitment to Resilience: Is concerned with the ability of HROs to not only effectively anticipate errors but also to cope with and bounce back from errors and unexpected events.

Deference to Expertise: Refers to the ability of HROs to defer decision making in case of emergencies to individuals with the expert knowledge to deal with a specific problem, irrespective of their status within the organizational hierarchy.

High Reliability Organizations: High reliability organizations (HROs) are a subset of high-risk organizations designed and managed to avoid accidents in complex, tightly coupled systems.

Preoccupation With Failure: Refers to HROs' constant preoccupation with potential errors and failures.

Reluctance to Simplify: Refers to HROs' ability to collect, analyze, and prioritize all warning signs that something may be wrong and avoid making any assumptions regarding the causes of failure.

Sensitivity to Operations: Refers to the ability to obtain and maintain the bigger picture of operations that enables HROs to anticipate effectively potential future failures.

APPENDIX

Figure 8. Survey items adopted from Weick and Sutcliffe (2011)

M1 - Assessing the firm's mindfulness	**P2 - Reluctance to simplify**
1. There is a sense of susceptibility to the unexpected throughout the organization	1. People around here take nothing for granted
2. Everyone feels accountable for reliability	2. Questioning is encouraged
3. Leaders pay as much attention to managing unexpected events as they do to achieving formal organizational goals	3. We strive to challenge the status quo
4. People at all levels of our organization worry constantly about misspecifying events	4. People feel free to bring up problems and tough issues
5. People at all levels of our organization worry constantly about misidentifying events	5. People generally deepen their analyses to better grasp the nature of the problems that arise
6. People at all levels of our organization worry constantly about misunderstanding events	6. People are encouraged to express different views of the world
7. We spend time identifying how our activities could potentially harm all our stakeholders	7. People listen carefully, and it is rare that someone's view goes unheard
8. There is widespread agreement among the firm's members on what we don't want to go wrong	8. People are not attacked when they report information that could interrupt operations
9. There is widespread agreement among the firm's members about how things could go wrong	9. When something unexpected happens, people spend more time analyzing than advocating for their view
	10. Skeptics are highly valued
M2 - The firm's vulnerability to mindlessness	11. People trust each other
1. Exceptions rarely arise in our work	12. People show considerable respect for one another
2. We encounter the same kinds of situations and problems day after day	
3. People in this organization have trouble getting all the information they need to do their work	**P3 - Sensitivity to operations**
4. People are expected to perform their jobs in a particular way without deviations	1. On a day-to-day basis, there is always someone who is paying attention to what is happening
5. People often work under severe production pressures (time, costs, growth, profits, or other)	2. Should problems occur, someone with the authority to act is always accessible to people on the front lines
6. Pressures often lead people to cut comers	3. Supervisors readily pitch in whenever necessary
7. People have little discretion to resolve unexpected problems as they arise	4. People have discretion to resolve unexpected problems as they arise
8. Many people lack the skills and expertise they need to act on the unexpected problems that arise	5. During an average day, people interact often enough to build a clear picture of the current situation
	6. People are always looking for feedback about things that aren't going right
M3 - Where mindfulness is most required	7. People are familiar with operations beyond their own job
1. Work is accomplished through a number of sequential steps carried out in a linear fashion	8. We have access to a variety of resources whenever unexpected surprises crop up
2. Feedback and information on what is happening are direct and simply verified	9. Managers constantly monitor workloads and reduce them when they become excessive
3. The work process is relatively well understood	
4. The work process does not require coordinated action	**P4 - Commitment to resilience**
5. We can directly observe all the components in our production process	1. Resources are continually devoted to training and retraining people to operate the technical system
6. There are many different ways to produce our product or service (for example, items can be rerouted, schedules can be changed , and parts can be added later if delays or shortages occur)	2. People have more than enough training and experience for the kind of work they do
7. There is a lot of slack in our work process	3. This organization is actively concerned with developing people's skills and knowledge
8. In our work process, things don't have to be done right the first time because they can always be corrected	4. This organization encourages challenging "stretch" assignments
9. There is a lot of opportunity to improvise when things go wrong	5. People around here are known for their ability to use their knowledge in novel ways
	6. There is a concern with building people's competence and response repertoires
P1 - Preoccupation with failures	7. People have a number of informal contacts that they sometimes use to solve problems
1. We actively look for failures of all sizes and try to understand them	8. People learn from their mistakes
2. When something unexpected occurs, we always try to figure out why our expectations were not met	9. People rely on one another
3. We treat near misses as information about the health of our system and try to learn from them	10. Most people have the skills to act on the unexpected problems that arise
4. We regard near misses as failures that reveal potential dangers rather than as successes that show our capability to avoid disaster	
5. We often update our procedures after experiencing a near miss	**P5 - Deference to expertise**
6. If you make a mistake it is not held against you	1. People are committed to doing their job well
7. People report significant mistakes even if others do not notice that a mistake is made	2. People respect the nature of one another's job activities
8. Managers actively seek out bad news	3. If something out of the ordinary happens, people know who has the expertise to respond
9. People feel free to talk to superiors about problems	4. People in this organization value expertise and experience over hierarchical rank
10. People are rewarded if they spot potential trouble spots	5. In this organization, the people most qualified to make decisions make them
	6. People typically "own" a problem until it is resolved
	7. It is generally easy to obtain expert assistance when something comes up that we don't know how to handle