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The Paradox of Knowledge Creation in a High-Reliability Organization: A Case Study

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Abstract

We employed an instrumental case study of a multisystem hydroelectric power producer, a high-reliability organization (HRO), to explore how new knowledge is created in a context in which errors may result in destruction, catastrophic consequences, and even loss of human life. The findings indicate that knowledge creation is multilevel, nested within three levels of paradox: paradox of knowing, paradox of practice, and paradox of organizing. The combination of the lack of opportunity for errors with the dynamism of the HRO context necessitates that individuals work through multiple paradoxes to generate and formalize new knowledge. The findings contribute to the literature on knowledge creation in context by explicating the work practices associated with issue recognition, resolution, and refinement, and the formalization of knowledge in failure-intolerant organizations.

Keywords: case study; high-reliability organization (HRO); knowledge creation; paradox theory

Nestled within the rugged mountains and shielded from the curious eye of outsiders, the power plant can best be described as a truly "elegant, beautiful lady." Upon entering the gates, we saw that what makes it powerful is also what makes it perilous. In front of the main entrance stood a monument dedicated to those who lost their lives to this power plant's construction. And if the exterior left anything uncertain, our first encounter with the massive machines revealed the immense power of this plant. Several events in its history stood as a reminder that a failure to appreciate the plant's power may result in catastrophe. Thus, mistake- free operation of this plant is a continuous objective—and one that can be supported only by knowledge shared and created by those working in it amid massive, powerful, and at times dangerous machines. To operate reliably in such a context is to understand how knowledge expands and shapes every thought and action.

Knowledge in high-reliability organizations (HROs) takes a different form due to their ambiguous, continuously evolving, and dangerous nature (Bierly & Spender, 1995; La Porte & Consolini, 1991; Weick & Roberts, 1993). Weick and Roberts (1993: 357) describe HROs as organizations that require "nearly error-free operations all the time because otherwise they are capable of experiencing catastrophes." In HROs, emphasis is placed on enacting repositories of knowledge and reinforcing established procedures and routines (McIver, Lengnick- Hall, Lengnick-Hall, & Ramachandran, 2013; Roberts, 1990). Individuals rely on an existing repertoire of routinized behavior to act swiftly, yet mindfully, when faced with a potentially dangerous problem (Levinthal & Rerup, 2006).

However, the dynamism of the HRO context often generates unpredictable and nonroutine problems where previous knowledge is insufficient and new knowledge must be created. Extant research suggests that in the face of nonroutine problems, experimentation and errors catalyze new knowledge creation (McIver et al., 2013; Schulz, 2001). Individuals think through previously made errors to create new knowledge that can then be utilized in similar situations (McIver et al., 2013; Zhao, 2011). Yet relying on errors may be challenging in a context where a misstep can create fatal consequences. That is, "some organizations must not make serious errors because their work is too important and the effects of their failures too disastrous" (La Porte & Consolini, 1991: 19).

Given this, HROs require strict rules and careful enactment of current knowledge to ensure reliability (La Porte & Consolini, 1991; Levinthal & Rerup, 2006). At the same time, these organizations must allow for rule breaking and questioning of current knowledge when faced with poorly understood, nonroutine problems (McIver et al., 2013; Roberts, 1990). In other words, in HROs, individuals must both *enact* and *challenge* current knowledge as they search for solutions to the problem amid potentially hazardous circumstances. Therefore, the process of knowledge creation in HROs seems to be paradoxical: Individuals must enact current knowledge to comprehend a given problem, but also challenge current knowledge because it may not be appropriate for solving the problem (Garud, Dunbar, & Bartel, 2010; Roberts, 1990). The idea of paradoxes in HROs has been suggested (Roberts, 1990), but, to our knowledge, not conceptually or empirically explored.

Building on the paradoxical nature of knowledge in HROs, we ask this: How is new knowledge created in this context? We take an emic approach to explore paradoxes within the knowledge creation process in the dangerous context of HROs. We follow the framework put forth by Nonaka and colleagues (Nonaka, 1994; Nonaka & Von Krogh, 2009), who conceptualize knowledge creation as a process consisting of two interrelated phases—

knowledge emergence and knowledge formalization. Knowledge emergence occurs when existing knowledge boundaries are crossed, facilitating a cognitive change and development of new insights (Tsoukas, 2009). Knowledge formalization involves the reshaping, clarification, and integration of these new insights into the organizational knowledge system (De Boer, Van Den Bosch, & Volberda, 1999).

To further our understanding of knowledge creation in HROs, we apply insights from paradox theory (Poole & Van de Ven, 1989; Smith & Lewis, 2011). Paradox theory recognizes tensions arising from the coexistence of opposing forces in organizations (Leana & Barry, 2000; Smith & Lewis, 2011). Paradox turns one's attention away from simplification toward the relationships between opposing phenomena, creating more complex theorizing. Despite its promise, however, few studies move from recognizing paradoxes in organizations to theorizing about how these paradoxes are experienced and navigated in practice (Lewis, 2000). In this study, we acknowledge paradoxes inherent in our phenomenon of interest and endeavor to understand how individuals *experience* and *navigate* paradoxes to create new knowledge.

Our main contribution is creating a framework of knowledge creation in context that illustrates the interrelatedness of knowledge emergence and knowledge formalization, and embodies the paradoxes that individuals navigate to create new knowledge. Although previous research recognizes the paradoxical properties of knowledge (Kumar, 2011; Leonard- Barton, 1992), to our knowledge no empirical research has explored the nature of these paradoxes and their formative importance to the knowledge creation process. Thus, our findings extend theory in three ways. First, we extend understanding of knowledge in organizations by explicating three levels of paradox embedded within the knowledge creation process: *paradox of knowing* that exists in the tension between the known and the unknown, *paradox of practice* that illustrates the struggle associated with the integration of the new insights, and *paradox of organizing* that encapsulates tensions related to the organizational structure. Second, in providing a clearer, theory-driven definition of HROs, we extend theory by illustrating (a) the nature of interdependencies that make HROs hazardous and (b) the paradoxes embedded in this context. Finally, we interweave our findings with the literature to problematize the current understanding of knowledge in organizations and theorize how insights from HROs may extend to non-HRO contexts.

Using a Paradox Lens to Understand Knowledge Creation in HROS

Paradox Theory

Organizational research tends to favor consistency, linearity, and stability to allow for more elegant theorizing and consequently, more precise implications (Whetten, 1989). Yet, this elegant theorizing is often critiqued for its inability to capture the complexities and paradoxes inherent in social organizing (Eisenhardt, 2000; Poole & Van de Ven, 1989; Smith & Lewis, 2011). To this end, embracing paradox can be useful as it may facilitate generation of new theoretical and practical insight (Farjoun, 2010; Lado, Boyd, Wright, & Kroll, 2006). For example, Smith and Lewis (2011) argue that an organization's survival is partially dependent on its ability to respond to paradoxical tensions; Lado et al. (2006) suggest that the theoretical and practical promise of the resource-based view is

possible only when its inherent paradox is embraced; and Coff, Coff, and Eastvold (2006) emphasize the importance of paradox to the management of organizational knowledge.

Paradox is the coexistence of two opposing states that are logical in isolation but irrational when placed together (Poole & Van de Ven, 1989; Smith & Lewis, 2011). Even a cursory view of organizational literature is sufficient to recognize that this coexistence permeates the most fundamental organizational issues such as the struggle between innovation and efficiency (Andriopoulos & Lewis, 2009; Davis, Eisenhardt, & Bingham, 2009; Tushman & O'Reilly, 1996), change and stability (Farjoun, 2010; Leana & Barry, 2000), or the known and the unknown (Bass & Chakrabarty, 2014; Lewis, 2000; O'Reilly & Tushman, 2008). For example, the paradox of change and stability allows researchers to transcend the question of whether organizations are stable systems or a result of emergent activities (Poole & Van de Ven, 1989; Uhl-Bien & Marion, 2009) by interrelating the tension between regularity (stability) and adaptability (change) (Eisenhardt, 2000; Leana & Barry, 2000). Embracing paradox provides insight into how moderate experimentation (change-oriented activities) can foster increased reliability (stability-oriented activities) (Farjoun, 2010) and why routine procedures may be critical for working through the nonroutine (Pentland, Feldman, Becker, & Liu, 2012).

Organizations also tend to experience a continuous struggle between what is already known and what needs to be discovered. This paradox of known and unknown emerges as contexts change and new problems arise, making previous knowledge obsolete (Kumar, 2011; O'Reilly & Tushman, 2008; Smith & Lewis, 2011). Knowledge that once enabled success may subsequently play a role in organizational failure through galvanized "core rigidities" (Leonard-Barton, 1992). To this end, previous research emphasizes errors as triggers to break rigidities imposed by previous understanding (Catino & Patriotta, 2013; Zhao, 2011). New knowledge is created as errors are detected, corrected, and analyzed, thus expanding the repertoire of available responses (Farjoun, 2010; Madsen, 2009).

Although new knowledge creation through the analysis of errors is useful in "failure-tolerant" organizations (Edmondson, 1999), this may not be viable in contexts in which errors generate hazardous consequences, such as HROs (Bierly & Spender, 1995; La Porte & Consolini, 1991). Thus, a tension exists in the need to create knowledge via exploration and discovery (both of which are often error-laden) while maintaining error-free, reliable operation. Recognizing this, Roberts (1990: 160-161) asks, "How adequate can such a literature [based on trial and error] be when addressing phenomena at least partially derived from precisely the opposite conditions?"

High-Reliability Organizations

Research on HROs stems from work on high-risk systems (Bierly & Spender, 1995; Perrow, 1984), or systems that (a) have potential to create hazardous consequences such as large-scale accidents and fatalities, (b) are characterized by complex interactions, and (c) are tightly coupled. Complex interactions are "of unfamiliar sequence, or unplanned and unexpected sequences, and either not visible or not immediately comprehensible" (Perrow, 1984: 78). Tightly coupled entails the proximity between interacting components so that what happens in one affects what happens in another. In essence, risk is created in this context because of the existence of interacting components that can produce unplanned or nonroutine events that are difficult to immediately comprehend.

Although Perrow (1984) did not differentiate among hazard, risk, and reliability, subsequent research recognized that although high-risk organizations are capable of catastrophes, rarely does one in fact occur (Leveson, Dulac, Marais, & Carroll, 2009; Roberts, 1990; Weick & Roberts, 1993). Indeed, although these organizations are high-hazard in the sense that they have high potential to generate catastrophic events, the risk is low because the probability that such event will take place is minimized through emphasis on reliability (La Porte & Consolini, 1991; Roberts, 1990). This insight shifted exploration from what makes these organizations risky to what makes them reliable (Bierly & Spender, 1995; Weick, Sutcliffe, & Obstfeld, 2008). Reliability in HROs expounds from technical expertise, systemwide processes, and a strong focus on learning (La Porte & Consolini, 1991; Roberts, 1990). Weick et al. (2008) further suggest that what makes HROs reliable is full attention on failure and emphasis on complex understanding, resilience, and appreciation of experience when faced with potentially catastrophic events.

Despite this focused description, the HRO term has been applied in less precise ways—many complex, tightly coupled systems are in fact not hazardous, and many hazardous systems are loosely coupled with low accidents rates (Leveson et al., 2009). We build on previous HRO research and define HROs as organizations that are capable of producing catastrophes (not just errors but consequences that can endanger multiple constituents) but are also characterized by systemwide processes (i.e., knowledge creation) that help maintain mistake-free operation despite their hazardous nature (Farjoun, 2010; Leveson et al., 2009).

Knowledge creation in HROs. The HRO context requires individuals to oscillate between applying knowledge in predictable, routine events and creating new knowledge in unpredictable, nonroutine events (Bigley & Roberts, 2001). Although previous research recognized that knowledge facilitates reliability in HROs (La Porte & Consolini, 1991; Weick et al., 2008), insight into how this occurs is fragmented at best. For example, studies suggest that when prior experience is relevant to a problem, individuals rely on that experience to generate a timely solution (Levinthal & Rerup, 2006; McIver et al., 2013). An assumption is that individuals have complete knowledge and are able to enact that knowledge appropriately (McIver et al., 2013). However, this assumption may not hold for several reasons. First, individuals may lack the relevant knowledge due to deficiencies in training or preparation (Leveson et al., 2009). Second, the problem may not be part of the current organizational knowledge repertoire (i.e., the problem is unknown) (La Porte & Consolini, 1991). Third, the context may be dynamic, requiring more variety in response to generate the solution (Farjoun, 2010). Here, we focus on the creation of new knowledge when faced with unknown problems in the dynamic HRO context.

Circumstances often arise in HROs where unknown problems necessitate the creation of new knowledge. In non-HRO contexts, small errors and near misses are often useful in creating new knowledge in response to unknown problems (Carroll, Rudolph, & Hatakenaka, 2002; Dillon & Tinsley, 2008; Farjoun, 2010; Morris & Moore, 2000). However, errors and near misses may produce catastrophic consequences in HROs due to their dynamic nature. In HROs, new knowledge must be created through the focus on reliable, error-free operation. Therefore, we have somewhat contradictory understanding of (a) how individuals work through problems without errors to generate new knowledge and (b) how new knowledge is formalized and integrated into the organizational knowledge system. In this article we illustrate a two-phase process through which new knowledge is created in an HRO.

Research Method

Research Setting

 General HRO context. The setting for this study is a hydroelectric energy producer, "Marion," located in Southeastern Europe. Marion is composed of four units comprising nine hydroelectric energy power plants that are functionally interconnected and interdependent with one another: Unit "BB," Unit "LIM," Unit "ZB," and Unit "CAC." At the time the BB unit began operation in 1966, it was one of the largest hydroelectric power producers in the region. Over time (1974-1982), a series of additions and reorganizations (CAC and ZB merged with BB in 1992 and the LIM system was added in 2005) increased Marion's size, but also facilitated knowledge sharing and reliable operation across all plants. Cross-plant meetings and integrated reliability procedures increased Marion's production capability as well as ensured a more standardized approach to safety.

 Marion is an HRO because, on one hand, it is capable of experiencing hazardous events, but on the other, it maintains relatively reliable performance through systemwide processes. The potential to produce hazardous events stems from the dangerous materials individuals work with and the large machines that are interconnected and can, as our participants indicated, act unpredictably. To maintain reliable performance, Marion has specific procedures for operation, extensive training and debriefings, and invited safety inspections. This preoccupation with reliability (Weick et al., 2008) ensures the most appropriate conduct permeates all organizational levels—from engineers working directly with the machines to executives overseeing the organization.

 Local context. Nested within the general HRO context is the event-specific local context. Due to the hazardous and continually changing nature of the plants in the Marion system, events occur that, if not immediately attended to, could create systemwide failure. In some instances, those events are *routine* in the sense that individuals have encountered them before and can utilize current knowledge to neutralize them. In other instances, the events are *nonroutine* with unknown causes, rendering current knowledge incomplete and requiring the generation of new knowledge.

 Routine events (such as precautionary adjustments, fine-tuning, or minor problems) are important because they prevent serious consequences from occurring. Although routine events are often viewed as stable and repetitive activities that ensure consistency in organizing, they are also dynamic, thus precluding the existence of any two perfectly similar routine events and inciting slight adjustment and adaptation of individuals' responses and actions (Cohen, 2007; Pentland et al., 2012; Turner & Rindova, 2012). Due to the dynamism embedded in the routine events, knowledge created through them entails a refinement and/or augmentation of current knowledge.

 Nonroutine events often arise as small, controllable problems but have the potential to escalate into systemwide catastrophes because the nature of the problem is not immediately known. As such, relying on existing knowledge is insufficient in this situation. New knowledge must be created to define the event and neutralize it to avoid error and maintain reliable operation of the plant (Garud et al., 2010; Tsoukas, 2009). To contextualize our findings, we begin with a description of an instance in which a routine event rapidly transformed into a nonroutine event.

During a scheduled inspection of the BB power plant, a mistake triggered a series of unexpected, catastrophic events. During this inspection, an individual's continual awareness of the equipment sparked observation that oil levels in the power switch were low. Rather than initially inquiring into why this was occurring, this individual reached over for closer inspection. In doing so, the routine event (low oil levels) escalated into an extremely hazardous nonroutine event. The supervisor yelled out to get the individual's attention. However, it was a matter of seconds before the individual closed the electric circuit, resulting in electric shock and serious bodily injury.

The supervisor and two other employees rushed to the individual and immediately administered first aid. Other workers, though visibly disturbed by the event, had to refocus their attention and tend to the malfunctioning machine that now was acting completely erratically. At this point, standard procedures did not aid in the analysis and response to the problem. This was because the problem, at this point, was nonroutine. The workers engaged in initial inquiry to discover distinctive characteristics of the event and coordinate insights by sharing and recombining their experiences. The next 10 hours were critical. The team stayed on the premises, carefully adjusting the machine through knowledgeable action, while simultaneously tending to the accident. Once a preliminary solution was generated, the supervisor immediately contacted BB plant executives to arrange a localized meeting so that the emergent insights could be refined and integrated into the formal knowledge structure. We utilize this event in the coming paragraphs to contextualize our findings.

Data Collection Procedures

We adopted an emic approach to explore knowledge creation "from within" and capture the insider's view of the process. We conducted an instrumental case study (Stake, 1995) and used multiple sources of data including formal interviews, informal conversations, observations, and archival data such as internal documents, governmental reports, and news articles. Triangulation of data sources improved the robustness of the findings (Creswell, 2007).

Interviews. The primary data source was 17 semistructured interviews conducted one-onone with participants either in their private offices or in a meeting room in Marion. In addition, we talked to participants informally during observation and transportation to different units in the Marion system (distances ranged from several minutes to 2 hours away). We first interviewed the general counsel and the health and safety manager. These individuals were our key informants because they are highly knowledgeable about Marion, its practices, and events that occurred throughout its history. In the second round of interviews, we spoke with the general managers of each power plant. From there, we used a snowball sampling technique to identify others who were involved with, or had substantial information about, knowledge practices in Marion. The interviewees were predominantly male (15 males and 2 females—the workforce was predominately male), averaging 15 years of experience with Marion.

Observation. The first author spent every work day for the first 4 weeks of the study at the site, traveling between plants and spending time with employees both at and outside

work. During this time, the first author had several opportunities to observe meetings as well as employee interactions. Observation allowed us to gain insight into the regular operation of the organization as well as appreciate its tightly coupled and hazardous nature. Observing the machines and the interaction of engineers with the machines allowed us to further contextualize our findings as well as to experience practice from the view of the participants. An observational protocol was used to record "descriptive" and "reflective" accounts of knowledge- related activities (Creswell, 2007).

Archival data. Though we did not rely extensively on archival data, they provided useful historical information that helped us appreciate Marion's hazardous nature. Particularly helpful was documentation tracing the history of the organization, documentation describing the nature of the equipment, and a book containing performance and safety information for each plant over the past 20 years. Archival data also highlighted the importance and continuous revision of safety procedures.

Data Analysis

Driven by the extant literature, we started data collection with the intent to understand how individuals in Marion make decisions (La Porte & Consolini, 1991; Leveson et al., 2009). However, when we asked if there is anything we need to know that we did not cover in our questions, our key informants replied that to understand Marion we must understand the importance of knowledge for reliable operation. Based on this insight, we revised our research question and successive data collection activities. Subsequent stages were marked with iterative movement between data collection, data analysis, and the literature to refine the logic of our emergent themes.

In the initial stages of our analysis, we focused on three categories of codes: expected codes (e.g., interaction of more and less experienced individuals; the importance of noticing unusual signals), surprising codes (e.g., flexibility rather constancy of experience), and unusual codes (e.g., paradoxes that individuals experience and navigate to create new knowledge) (Creswell, 2007). Initial codes formed the first-order codes in the data structure. In the following stage, we used the coding process to generate a description of the setting and identify researcher-induced themes embodying the knowledge creation process (Creswell, 2007). This gave rise to second-order codes that allowed a more holistic understanding of the data (Bansal & Corley, 2012). Our approach to coding resulted in the data structure reported in Table 1. In the last stage, we interwove the interpretation of the findings with the literature to construct the final narrative.

To confirm the validity of our findings, we utilized triangulation, member checking, and thick description (Creswell, 2007). First, we searched for convergence across different sources by interviewing individuals from different levels of the hierarchy and from different plants. We triangulated our findings with observational and archival data. We also asked our informants if the themes that we identified made sense and whether our overall description reflected their experiences. This resulted in further refinement of our findings. Finally, we employed thick description in the presentation of our findings. We provide rich, detailed, emic insight into the practices that constitute knowledge creation in Marion as experienced by our participants.

Table 1. Data Structure of the Knowledge Creation Process in Routine and Nonroutine Events in a High Reliability Organization

Local Context	Data Description
Routine events	Statements about the importance of preventive maintenance to ensure reliable performance. Planned activities are considered essential in preventing unintended surprises.
Nonroutine events	Statements describing unplanned, emergent events. Informants often described these events as a sense that "something is not right." These events acted as triggers to the process of new discovery.

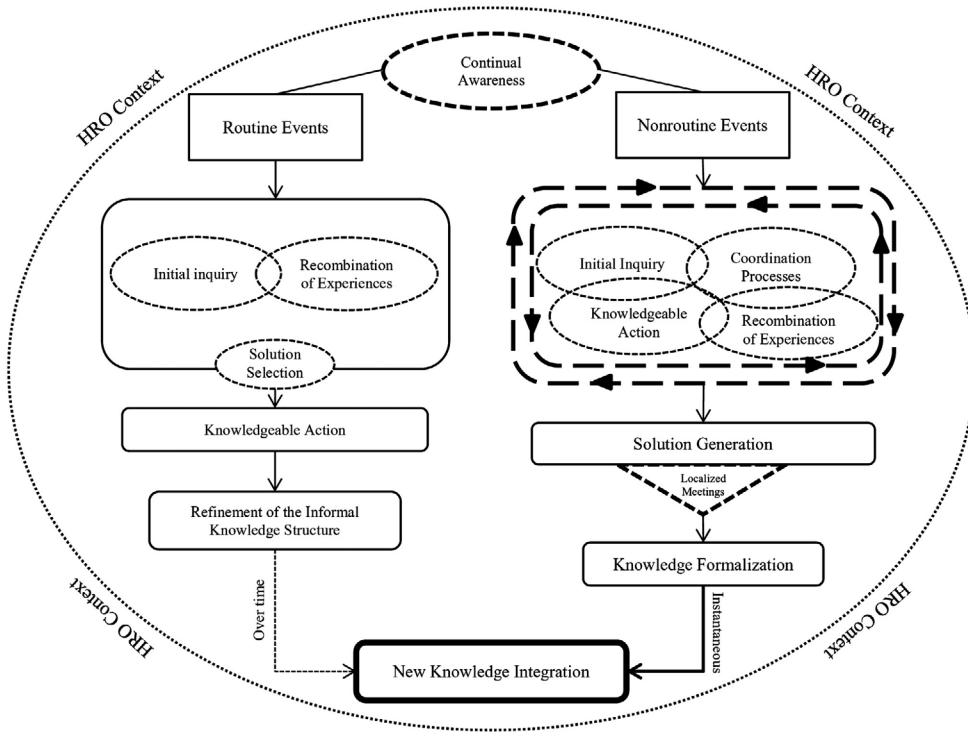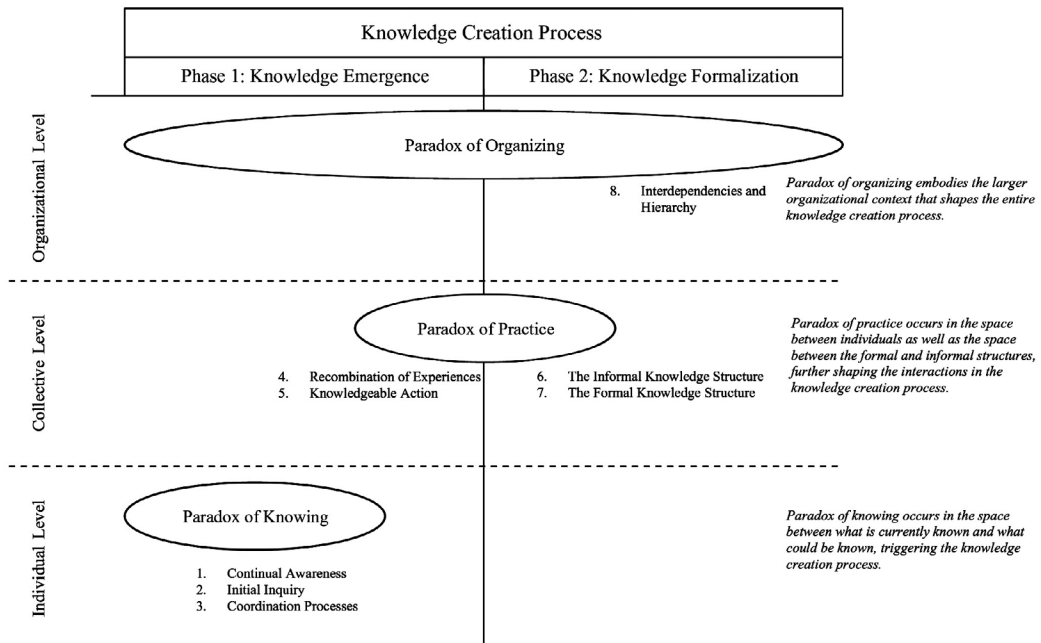| Dimension of the Knowledge Creation Process	Data Description	Local Context		Phase of the Knowledge Creation Process	
		Routine Events	Nonroutine Events	Knowledge Emergence	Knowledge Formalization
1. Continual awareness	Statements indicating the necessity of understanding the plant as a complex system and thus being continuously alert as to what is going on.	✓	✓	✓	✓
2. Initial inquiry	Statements about the questioning process once the trigger has been observed. Informants referred to this process as "consultation" in which they engage to define the problem.	✓	✓	✓	
3. Coordination processes	Statements indicating how engineers adjust to each other's observations and experiences during the questioning process. It is this dynamic adjustment that allows them to integrate diverse viewpoints quickly.		✓	✓	
4. Recombination of experiences	Statements about the importance of long tenure with the organization as well as involvement with various emergent projects. Experience is what engineers rely on to guide their understanding of both emergent and planned events.	✓	✓	✓	
5. Knowledgeable action	Statements describing the actions toward the emergent problem. Informants indicated the need for the "right action at the right time" to avoid mistakes that can "cost human lives."	✓	✓	✓	
6. The informal knowledge structure	Statements indicating the existence of a dynamic understanding of how things should be done that is not yet a part of the formal system. It allows engineers to maintain a degree of flexibility in their actions.	✓			✓
7. The formal knowledge structure	Statements indicating formal rules and procedures that are binding for all. Informants described these procedures as codified prescriptions of how to act in a given situation.	✓	✓		✓
8. The nature of the HRO context: interdependencies and hierarchy	Statements indicating the dangerous and continuously evolving context in Marion. Informants described how even the smallest inattentiveness may result in tragic consequences.	✓	✓	✓	✓

Figure 1. The Knowledge Creation Process Along Two Paths in a High-Reliability Organization

Findings

To illustrate the knowledge creation process in HROs, we present our findings in two phases: knowledge emergence (Phase 1) and knowledge formalization (Phase 2). Our findings show that the knowledge creation process takes on two separate paths depending on the local context (routine or nonroutine event) (Figure 1). During the knowledge emergence phase (Phase 1) occurring within routine events, individuals rely on their experiences, recombination of those experiences, and localized discourse to *select* the most appropriate solution from an existing knowledge repertoire and adapt it to the contingencies of the situation. Once the solution is selected and adapted, the formalization phase (Phase 2) entails the refinement and/or augmentation of the informal knowledge structure. Conversely, during nonroutine events, the knowledge emergence phase (Phase 1) involves individuals first defining the problem through initial inquiry and coordination then combining their experiences through knowledgeable action to *generate*, rather than select, a solution tailored to the situation. In nonroutine events, the knowledge formalization phase (Phase 2) involves immediate discussion of the solution via localized meetings, leading to prompt integration of the emergent insight into the formal knowledge structure.

Our findings reveal that individuals experience three levels of paradox—individual, collective, and organizational—in the knowledge creation process. At the individual level,

Figure 2. Three Levels of Paradox Existing Within the Knowledge Creation Process in a High-Reliability Organization

the *paradox of knowing* uncovers the struggle individuals experience as they work to categorize an event as routine or nonroutine and generate a preliminary understanding of the problem. At the collective level, the *paradox of practice* uncovers the struggle embedded in the distributed nature of knowledge in action and the coexistence of the formal and informal knowledge structures. Finally, at the organizational level, the *paradox of organizing* uncovers the tension between stability and change that permeates the entire organization, thus shaping the knowledge creation process in its entirety. These paradoxes are depicted in Figure 2. Select participants' descriptions are interwoven throughout our findings, while others are provided in Table 2.

Phase 1 of the Knowledge Creation Process: New Knowledge Emergence

The importance of knowing existing procedures in Marion is exemplified in the written rules and procedures posted on the walls of each plant in view of the employees on their way to the machine area. Employees interweave these procedures in their work to ensure reliable performance. However, the complex nature of Marion occasionally generates unpredictable and nonroutine events in which current procedures may not be applicable. When they occur, individuals heedfully interrelate to connect "sufficient individual know-how to meet situational demands" (Weick & Roberts, 1993: 366), collectively decreasing the possibility of catastrophe. In exploring how individuals in Marion heedfully interrelate to create new knowledge, we discovered five themes: continual awareness, initial inquiry, coordination processes, experience, and knowledgeable action.

Table 2. Themes, Codes, and Data of Knowledge Creation in a High-Reliability Organization

Theme	Code	Representative Data
The process of new knowledge emergence	1. Continual awareness	"Simply put, it is all about monitoring the condition of the machines . . . to know when something can be done by the way the equipment looks like. There are criteria that you have to know and to watch for to know what is going on."
	2. Initial inquiry	"The problem is solved through asking questions. When I am not sure what is going on I ask others."
	3. Coordination processes	". . . when things go wrong, one man even when he has the greatest knowledge of it all cannot solve it . . . there need to be others who will ask questions or subquestions and help find the way that is the best."
	4. Recombination of experiences	"[Experience] is significant. For 37 years a lot to see and learn. . . . It simply means you know how to follow the process, how to manage the production and so on."
	5. Knowledgeable action	"There were some abnormalities in the aggregate and we could not figure out the problem . . . so we decided to stop it and analyze the levels and the problem was solved."
The formalization of new practices	6. The informal knowledge structure	"It is within the organization itself, if we see that something became a practice and it is good . . . it brings good and it is not part of the formal system, we make it a part, we regulate it.
	7. The formal knowledge structure	"They are essential [formal procedures] and you have to know them. The production of electric energy brings with it issues that are dangerous for people and environment . . . and we have to deal with that. We need to know and act according to the procedures in each situation. . . . They help you solve the problems."
HRO context	8. Nature of the HRO context: interdependencies and hierarchy	"There are these demands, pressures stemming from the system [procedures] to operate according to them . . . and there is a question of how to maintain all of it, and still operate by the rules . . . it is a balancing act . . . you need to estimate whether something can pass, skip over some rule. What the risk would be given the problem you are facing and what the constraints are."
	• • Routine events	"We operate under the specifications of the annual plan. In situations where something out of the ordinary happens we deal with that at the spot. . . . When the issue is simple and I have all the information I need, I act in accordance to my experience and procedures."
	• • Nonroutine events	"Not everything can be specified ahead of time . . . the plant is a process, a living thing . . . something is always happening . . . you have to be technically correct and safe and to address each and every element when something does not look right."

Continual awareness (Dimension 1 of the knowledge creation process). HROs are fundamentally dynamic in that even the most routine events and slight irregularities may quickly transform into hazardous ones (La Porte & Consolini, 1991; Perrow, 1984). In this context, changes are seen as warning signs that ought to be evaluated to prevent failure (Dillon & Tinsley, 2008; Farjoun, 2010; Turner & Rindova, 2012). As a consequence, individuals must continually be aware of their surroundings and attune to familiar and less familiar signals.

This awareness coupled with prolonged, careful observation of the behavior of the machines and understanding how the machines should behave (e.g., normal idiosyncratic sounds versus abnormal sounds that suggest immediate correction is needed) enables individuals to anticipate when something is, or could be, wrong. An engineer explained that "incidents may occur out of the blue and many things can be detected earlier if you watch carefully for them." In other words, "watch[ing] for them" allows individuals to anticipate an event and engage in activities necessary to neutralize threats to reliable operation. As such, employees do frequent "rounds of the equipment" to observe their operations. During observations they focus on (a) visual cues, (b) sounds, (c) smells, and (d) movements, relying on their knowledge to differentiate between those that are regular from those that are irregular. The reliance on all senses is not surprising, as previous research implies that acute awareness stems from the senses, enabling individuals to anticipate and respond to situational changes (Cunliffe & Coupland, 2012; Tsoukas, 2009). Acute awareness enables Marion employees to recognize cues that something might be out of the ordinary:

> It started with one man during his regular round of the aggregate . . . he *heard* a sound coming from the turbine that was somewhat different than normal and instantaneously notified others.

However, continual awareness does not, in itself, allow individuals to categorize the event as routine or not. For example, in the event described above, the engineer engaged in continual awareness by noticing that the oil levels in the power switch were unusually low. The awareness allowed the engineer to notice the irregular signal, but was insufficient, as subsequent events indicate, to properly categorize the event. To do so and correspondingly trigger the appropriate set of actions, individuals must engage in initial inquiry.

Initial inquiry (Dimension 2 of the knowledge creation process). Once they notice an irregularity, employees in Marion engage in questioning to generate a preliminary understanding and classify the event as routine or nonroutine. Immersion into a dialogue with knowledgeable others fosters a setting in which individuals question their own assumptions and search for links between contradictions and diverse insights (Ford & Ford, 1994; Smith & Lewis, 2011). These links establish shared understanding that enables context-specific actions (Turner & Rindova, 2012). Initial inquiry is akin to Weick and Roberts's (1993) heedful interrelating in that individuals flip through their mental repositories as well as the repositories of others to form connections between their know-how and the contingencies of the situation. This inquiry is dialectic with questions spiraling out of other questions until the individuals tentatively agree on the categorization of the event.

As demonstrated in Figure 1, when the event is categorized as routine, initial inquiry acts as a recollection mechanism through which individuals exploit collective knowledge and build initial insight necessary to incite the appropriate action. In routine events, individuals transition relatively quickly from initial inquiry to recombination of their diverse experiences to select the most appropriate solution from the repertoire of current knowledge practices (Figure 2). The transition is particularly vague as the recombination of experiences commences almost simultaneously with initial inquiry. The fact that the "solution is never the same" illustrates the dynamism, and at times complexity, of routine events, which consequently creates a space for new knowledge emergence even within a "known" event. A plant manager explained the process:

> When we estimate that the issue is simple, and when there is already a procedure in
> place, we generate several possible solutions . . . we lay them down side by side, and
> analyze how to use them. . . . When this occurs, I rely on workers closest to the issue.
> And you have to understand, the solution is never the same. There always needs to
> be explanation of why this solution was chosen and how it changed.

In contrast, as depicted in Figure 1, when the event is categorized as nonroutine, in-
dividuals utilize initial inquiry to determine "what the event is not and what should not
be done." Individuals make sense of their experiences by engaging in thought experi-
ments, contemplating what could have been and what could happen in the future (Morris
& Moore, 2000). Determining what the event is not is a form of a thought experiment in
which individuals utilize their knowledge not to select the solution (as in routine events),
but to explore the boundaries of the event and discard irrelevant information. By explor-
ing what the event is not, individuals minimize opportunities for inappropriate action
(this process did not take place in our example, resulting in improper action). One engi-
neer explained this as a process of "consultation" with colleagues, while another stated,
"When I am unsure what is happening, I always consult with others."

Coordination processes (Dimension 3 of the knowledge creation process). In routine
events, individuals rely on their experiences and recombination of those experiences to
select the most appropriate solution to resolve the issue (Schulz, 2001). In contrast, dur-
ing nonroutine events, initial inquiry transitions into coordination processes during which
individuals collectively build understanding about the event. They do so by dynamically
iterating between various alternatives (Leveson et al., 2009; Smith & Lewis, 2011), facil-
itating a string of microadaptations in an effort to form preliminary agreement regarding
what the event is. This is in line with what Weick (1987) and Bierly and Spender (1995)
term "rich analysis." Collectives engage in rich analysis because each person in the col-
lective is both an individual observer and a dependent of the collective. As multiple in-
dividuals engage in raw talk and adjust to each other's insights, new knowledge emerges
(Bierly & Spender, 1995). To support this, one of our participants explained that even those
with the most experience cannot know everything. Individuals must ask questions and
listen to others (i.e., adjust to differing insights), "always look[ing] to get mutual agree-
ment" so that new knowledge can emerge:

> When a major intervention is necessary and an action is needed . . . there must
> be coordination between me and the manager, either technical or production
> manager and a few others—mostly those in the plant when the intervention
> is needed . . . and we always look to get mutual agreement.

Individual-level paradox: Paradox of knowing in the knowledge creation process. Contin-
ual awareness is a trigger for the knowledge creation process. Once individuals become
aware of the event, initial inquiry enables them to codify it as routine or nonroutine, thus
activating one of the two paths of knowledge creation (Figure 1). This process also gives
rise to the individual-level paradox: paradox of knowing. That is, the awareness of the
event requires timely action—often within minutes. However, improper action may have
grave consequences, as illustrated in the example above. As such, individuals must simul-
taneously utilize and question their current knowledge to make appropriate distinctions
and generate a preliminary understanding of the event (routine or nonroutine). Previous
knowledge is critical because it allows them to identify known patterns (Farjoun, 2010;

Pentland et al., 2012). At the same time, failure to challenge existing knowledge may result in premature action and potential escalation of the event. Consequently, individuals must resist simplification and remain in a state of paradox between the known and the unknown—that is, paradox of knowing. Given this, we offer the following proposition:

> *Proposition 1a:* In HROs, individuals' reliance on their existing knowledge while simultaneously questioning it builds understanding and decreases the possibility of error during knowledge emergence.

In the context of nonroutine events, initial inquiry acts as impetus for coordination processes. In this transition, individuals open up space for multiple interpretations of what is happening by interweaving their insights with that of others. Individuals rely on their knowledge to critically evaluate the knowledge of others as they identify known aspects of the event and search for ways to infuse new sense into the situation. In doing so, individuals simultaneously reinforce and challenge each other's understanding to, on one hand, solidify what is known and, on the other, prevent previous knowledge from clouding discovery. Given this, we propose,

> *Proposition 1b:* In HROs, when the event is unknown, simultaneous sharing and challenging of insights from multiple individuals through coordination processes expands the knowledge base while decreasing the possibility of error.

Recombination of experiences (Dimension 4 of the knowledge creation process). Experience is a driving force behind initial inquiry and the ability to dynamically adjust to others to comprehend the event. It enables individuals to more clearly articulate what the event is not by comparing it to events that have occurred previously (Morris & Moore, 2000). For example, Langley and Tsoukas (2010: 4) argue that experiences incorporate the past and the present: "Unlike substances, which do not include one another but are seen as nested, standing under one another—sub-stantia—experiences include other experiences and grow out of the integration of bodily and mental events into something new." In other words, individuals recombine their various experiences and make them relevant to the local contingencies (Schulz, 2001). Indeed, recombination of experiences tends to enhance reliability in contexts facing frequent perturbations and unpredictability, such as HROs (Farjoun, 2010).

Bourdieu's (1990: 54) description of experience as "a product of history. . . . It ensures the active presence of past experiences, which, deposited in each organism in the form of schemes of perception, thought and action, tend to guarantee the correctness of practices and their constancy over time" was relevant to our findings. However, rather than *constancy* of practice, experience at Marion enables *flexibility* of practice. Flexibility of practice is evident in the practitioners' engagement with practice, their anticipation of what might happen next, and their adjustment to that anticipation (Lewis, 2000; Sandberg & Tsoukas, 2015). Whether in a routine or nonroutine event, individuals know that they must at least partially adapt (routine events) or critically challenge (nonroutine events) each practice. Flexible experience allows individuals to make the knowledge relevant to a given situation and appropriately react to ambiguous stimuli. It enables them to engage "all [their senses] into the discovery":

> When a malfunction occurs, based on your extensive experience, you know how to react . . . you use all your senses and you know how to react. These experiences are valuable and necessary, without it you cannot work.

Knowledgeable action (Dimension 5 of the knowledge creation process). During routine events, knowledgeable action entails application of the selected solution to neutralize the event. Based on initial inquiry and recombination of experiences, individuals collectively identify the most appropriate solution that is then carefully applied to the problem (Mc-Iver et al., 2013). Thus, there is a distinct separation of thought and action. In contrast, during nonroutine events, the separation of initial inquiry and recombination of experiences is blurred, making it difficult to discern where one begins and the other ends. Questioning and coordination are still occurring at the moment individuals decide to act. It is through "articulation [that] practitioners obtain a clearer understanding of what they do by becoming aware of the distinctions they have been following" (Tsoukas, 2009: 943). Articulation occurring during questioning and coordination allows individuals to more fully comprehend what is transpiring and enact their knowledge in a more mindful manner, thus decreasing the possibility of error. The action, in turn, generates pieces of information to be internalized for new knowledge to emerge. During routine events, the incoming pieces of information reinforce and augment the current knowledge structure. These minor adjustments become a part of the collective understanding. During nonroutine events, incoming pieces of information catalyze new knowledge emergence. The action is needed "at the right time" to generate the influx of novelty necessary to comprehend the situation (Pentland et al., 2012; Sandberg & Tsoukas, 2015). That is, individuals can understand the situation only through their actions, and actions can be known only after they occur (Sandberg & Tsoukas, 2015). The influx of novelty relaxes current understanding, opening up space for knowledge emergence. One of our informants described knowledgeable action as inseparable from problem solution:

> There was this problem with the aggregate . . . we weren't sure what was going on . . . after discussion with the men on the floor we decided to turn the aggregate off, but the problem continued . . . so we turned off all the machines because we realized that there was no more time to wait. We had to act fast.

Collective-level paradox: Paradox of practice in the knowledge creation process. As much as experience drives initial inquiry and coordination, inquiry and coordination also enrich experience. Our participants described nonroutine events as a "rite of passage" for less experienced employees. To this end, participation in these events provides those with less experience an opportunity to interact with more experienced individuals, highlighting the importance of flexibility, rather than constancy, of practice and appreciation for the ambiguity of their work (La Porte & Consolini, 1991). At the same time, however, less experienced individuals play a key role in facilitating questions and challenging the current understanding. Indeed, the blending of more and less experienced workers aligns with the idea that organizational knowledge can be "increased if more levels of experience are connected, as when newcomers who take nothing for granted interrelate more often with old-timers who think they have seen it all" (Weick & Roberts, 1993: 366). In Marion, the interaction between more and less experienced allows individuals to remain open to new insights and creates a context in which new knowledge can emerge:

> When I started working in the KB plant I had a manager who really helped me and with whom I did all the electrical things, on the same machine . . . he's a man with great experience and knowledge and I owe him a lot, as far as my present experience.

Although experience is critical in nonroutine events, it is through the enactment of that experience that new knowledge emerges. As individuals engage in questioning and coordination, they also consider what an appropriate action might be. Because the problem they face is not fully known, the most appropriate action is often difficult to identify. Individuals must discover the appropriate action based on questioning and coordination, and observe what happens after action occurs. Paradox exists because premature action can lead to deadly consequences. However, without action, only limited insight is possible, constrained by previous knowledge structures that only suggest what the event is not. Thus, in nonroutine events, action changes the nature of the problem. This process of problem solution in the collective-level paradox ultimately shapes knowledge emergence in this HRO:

> *Proposition 2a:* In HROs, the interaction of individuals with diverse experiences creates a paradox needed for knowledge emergence while decreasing the possibility of error.
>
> *Proposition 2b:* In HROs, knowledgeable action triggers the knowledge emergence process while decreasing the possibility of error.

Individuals in Marion have extensive knowledge about most everything they do. However, even a brief moment of inattentiveness and belief that their knowledge is complete can result in catastrophic consequences. Individuals in HROs must be "synoptic while knowing that they can never fully achieve [full knowledge]" (La Porte & Consolini, 1991: 29). In this context, they must proactively analyze, search, and question their knowledge before, during, and after the event has taken place. After the emergence of new knowledge, the formalization stage ensues in which the new knowledge becomes formalized and integrated with the organizational knowledge system.

Phase 2 of the Knowledge Creation Process: Formalization of New Knowledge

The integration of new knowledge into the organization's existing knowledge system is an important step in the knowledge creation process (Coff et al., 2006; Nonaka & Takeuchi, 1995). To leverage emergent knowledge, an organization must be able to scale and formalize it (Coff et al., 2006). As illustrated in Figure 1, in Marion, the knowledge formalization phase of the knowledge creation process follows two paths. New knowledge created during routine events is integrated in the informal knowledge structure of each power plant. We term this knowledge structure informal because it is not formally codified. It exists in a collective understanding of "how things should be done" and entails only minor adjustments to formal procedures. The informal knowledge structure enables individuals to "bend the rules" when needed and adjust formal procedures to the situation (i.e., contribute to and enable flexible experience). Alternatively, new knowledge created during nonroutine events is immediately formalized and becomes a "binding rule for all."

The informal knowledge structure (Dimension 6 of the knowledge creation process) Despite efforts to standardize practices, each plant approaches its activities and operations

somewhat differently. Those variations stem from the unique history of routine events in each plant. Each routine event encompasses natural variations requiring adjustments in the patterns of actions (Pentland et al., 2012; Turner & Rindova, 2012). Consequently, as individuals apply their knowledge in routine events, they also adjust it to the specific circumstances (March, 1991; Schulz, 2001). This adjustment increases flexibility of experience and builds the informal knowledge structure: a collection of well-understood, yet not formally documented, activities for operation. To this end, the informal knowledge structure in the plants and across the system exists within the interplay of past knowledge, present circumstances, and future expectations. An engineer described it as "experience that is transferred through generations and not possible to learn from the book."

Over time, individuals might launch initiatives to formalize useful informal practices, thus expanding the formal knowledge base. Launch of these initiatives by individuals is part of organizational practice. It is the institutionalized manner in which flexibility, changeability, and continuous development of the formal knowledge structure takes place. Procedures, although necessary in this context, must be continuously reevaluated to remain relevant to new contingencies. In Marion, individuals continuously work to bring forward new knowledge and insight and distribute it throughout the organization. Informal knowledge structures are thus an important platform from which individuals challenge the formal knowledge structure:

> The initiative can come from any one engineer to regulate something . . . if that is something that is perceived as important but it is not a part of the procedure currently . . . the engineer would recommend to us to formalize this particular practice.

The formal knowledge structure (Dimension 7 of the knowledge creation process). Procedures that compose the formal knowledge structure are codified activities that guide reliable operation in Marion. Whereas some informants described the procedures as "limiting," all individuals recognized their necessity. In a casual conversation, one engineer even described how he often resisted initiatives for standardization and development of the systemwide formal knowledge structure. He believed that procedures diminish the flexibility necessary for reliable performance. However, he stated that he now understands the importance of the procedures to the everyday operation of his power plant. These procedures facilitate both the awareness of an event, as well as the initial action aimed at solution selection or generation.

In Marion, new knowledge is formalized in one of two ways. In routine events, individuals launch an initiative to formalize practices from the informal knowledge structure and integrate them into the formal one. In contrast, new knowledge stemming from nonroutine events is immediately considered and formalized. Previous research suggests that organizations might not always capitalize on knowledge created during past problems because of hindsight bias, or the tendency to overestimate the amount of information needed to resolve the problem (Dillon & Tinsley, 2008). In Marion, this bias is minimized because once the nonroutine event is neutralized, those involved immediately engage in a series of meetings to dissect the issue and record everything that transpired during the event. For example, after the nonroutine event described above occurred, the plant manager immediately convened a series of meetings with other plant managers and executives. During these meetings, they discussed what happened during the event, whether the action

taken was appropriate, and how to define the issue. An informant from the LIM system described the process to us as "local meetings":

> We hold the local meetings with all four power plants at the [LIM] headquarters. We all have to be present: power plant manager, lead engineer, heads of technical service, as well as technicians . . . we introduce the issue, and the lead engineer clarifies issues from the report. We discuss all the things that happened during the day, what was done, etc. Depending on the issue, we then forward our suggestion to the BB board.

"Local meetings" are a defining characteristic of HROs. For example, La Porte and Consolini (1991) reported that employees conduct reporting sessions (what they term "hot washups") immediately after error identification as well as a series of debriefings during which employees discuss lessons learned. Similarly, Carroll et al. (2002) discussed "problem investigations" as a critical aspect of corrective action programs. Our findings indicate that local meetings are indeed important for the formalization of emergent understanding (i.e., lessons learned) and codification of new knowledge within the formal knowledge structure. Where our findings depart from previous literature is that, in Marion, local meetings are not necessarily error-driven. The most relevant knowledge stems from the nonroutine events that were appropriately handled and were error-free. During these meetings, the nonroutine event is further scrutinized, formalized, and integrated into the formal knowledge structure.

Collective-level paradox: Paradox of practice in the knowledge creation process. Coexistence of the formal and informal structures gives rise to the paradox of practice in the knowledge formalization phase (Figure 2). Individuals incorporate both informal and formal procedures in their practice to have more complete, although often paradoxical, knowledge. The knowledge is paradoxical because the procedures are incomplete, only partially connected, and occasionally opposing. Formal and informal procedures are by definition incomplete because complete knowledge in HROs can never be fully attained (La Porte & Consolini, 1991; Leveson et al., 2009). Furthermore, because informal procedures are more malleable, over time the gap between them and the formal procedures widens. As a consequence, individuals must be mindful of these differences and navigate them with care. Finally, formal and informal knowledge can also be opposing. Partially due to the widening gap and partially due to the rigidity of the formal bureaucracy, informal practices take a different form, thus allowing individuals to "play the system." For example, when asked to describe his activities, a plant manager read his job description, smiled, then asked, "Now, do you want to hear what I really do?" Employees continuously interweave both formal and informal knowledge structures into their activities to preserve the emergent nature of knowledge necessary for reliable operation of their plants. Given this, we propose,

> *Proposition 3a:* HROs are characterized by the interwoven formal and informal knowledge structures that at least partially oppose one another.
>
> *Proposition 3b:* In HROs, interrelating formal and informal procedures facilitates error-free discovery in the knowledge creation process, thus increasing the reliability of HROs.

Organizational-level paradox: Paradox of organizing in the knowledge creation process. HROs are paradoxical because they embody characteristics that are relatively discrete in more mainstream organizations: certainty versus uncertainty, application of current knowledge versus new discovery, hierarchical versus decentralized processes, and so on (La Porte & Consolini, 1991; McIver et al., 2013). HROs have interdependent, tightly coupled structures necessary for reliable application of current knowledge, but are also flexible and able to absorb new insights stemming from nonroutine events. Indeed, individuals in Marion continually oscillate between what they know and what they must discover. To this end, our findings indicate that what makes the knowledge creation process in HROs like Marion unique is that the paradox of organizing shapes the entire process. The paradox of organizing arises from tensions embedded in (a) the pervasive interdependencies of the system and (b) the unpredictable yet hierarchical structure (Figure 2).

Interdependencies of the system contribute to the dangerous nature of HROs (Perrow, 1984). Specifically, because different segments in the system (machines, other equipment, people, and plants) are closely connected and often dependent on each other for proper performance, problems are more likely to escalate. Accidents occur most often not from one malfunctioning part or human error but from the interaction of diverse components that are closely linked (Leveson et al., 2009). However, what remains unclear is the nature of the interdependence in HROs and how that interdependence escalates danger on one hand and shapes knowledge as a reliability-inducing process on the other (Leveson et al., 2009).

Our findings indicate that interdependence is multilevel because it permeates individuals, collectives, and the structure of the organization and paradoxical because it operates in opposing directions depending on the level it permeates. For individuals and collectives, interdependence is embedded in the collective recombination of experiences occurring not just during routine and nonroutine events, but also in everyday practices. Physical separation of offices is practically nonexistent (managers' offices are on the plant floor) and individuals tend to spend more time on the floor of the plant or in communal areas than in their respective offices. For example, one of the engineers made a remark during our conversation: "Earlier today I went to the plant [within the LIM system] that just went through unplanned repairs because one of the aggregates was acting up. I got to see how it worked out." In other words, interdependence at the individual and collective levels facilitates knowledge creation and transfer, increasing the reliability of Marion.

In contrast, interdependence at the structural level increases the complexity of the plants (Perrow, 1999) and contributes to the potential escalation of nonroutine events, decreasing the reliability of Marion. At the structural level, interdependence is reflected in the manner the plants are constructed (physical interdependence) as well as their mutual dependence on natural resources (natural interdependence). Physical interdependence exists in close, daily interaction of machines and employees. Machines are heavy, are large, and have multiple interacting parts necessary for adjustment to the volatility of the demand for energy. For example, the pump-storage plant in the BB system has several interacting parts that take on different roles depending on the demand for electricity. Natural interdependence extends beyond the organization and is embedded within the landscape in which the plants are located. A plant manager explained that understanding natural interdependence is pertinent to the reliable performance of the system:

> All four plants [in the LIM system] are each a story in itself but are all hydrologically related. If one experiences irregularities, the other may not have enough water in the lake. . . . So in the system, [name of the] plant is the most important in terms of power production, but they all need to function properly in order to maintain the voltage in the network.

Building on these findings, we propose,

> *Proposition 4a:* Interdependence between individuals and collectives facilitates the knowledge creation process, increasing the reliability of HROs.
>
> *Proposition 4b:* Interdependence in the structure increases the complexity of the organization and possibility for large-scale errors, decreasing the reliability of HROs.

Tensions also surface from the organizational hierarchy. In its emphasis on high reliability, Marion is organized as a bureaucracy focused on the application of current procedures and top-down control. Individuals in Marion see standardized and strictly prescribed practices as key to reliable performance. Deviation from standard procedure is considered extremely dangerous and strongly discouraged. In this context, focus is placed on structured and rigid routines and repetition of current procedures rather than exploration for novelty (McIver et al., 2013). The standardization of practices and stringent controls ensure that everyone knows "what to do" because failures may "cost human lives." One of our participants explained,

> The most important thing is to know what to do and what not to do, because this is very powerful equipment and any error would cause great damage and possibly stoppage of the whole plant, and if they do not take this into account, people may also lose lives and so we need to take care of people who work here daily.

However, in addition to being dangerous and highly controlled, HROs are also continually evolving and relatively unpredictable. HROs are reliable precisely because they capitalize on the benefits of bureaucracy (i.e., stringent control systems) while avoiding the inertia of continuous restructuring that often accompanies bureaucracies (Bigley & Roberts, 2001). Individuals in Marion often experience multiple issues that interact in a complex manner— complex because the origin of the issue may not be fully comprehendible a priori and because issues surface simultaneously (or almost simultaneously). As one of our participants explained, the plant is "a living thing":

> The power plant is a process, a living thing, always something happening, you should strive to be technically correct and safe and to address each and every element, as well as equipment maintenance, hazardous substances are always an issue. And then there is high-speed, mass, power, it is quite complex.

Our findings illustrate the paradox of organizing in HROs that operate in the tension of a hierarchical, yet adaptive, structure. The paradox of organizing exists because HROs necessarily operate with a stringent rule-based hierarchy despite their continuously changing, unpredictable context (McIver et al., 2013). Individuals in HROs must navigate this paradox of control versus adaptation as they create new knowledge. Building on these findings, we propose,

Proposition 4c: Tensions arising from the rule-based hierarchy and the continuously changing, unpredictable nature of HROs give rise to the paradox of organizing.

Proposition 4d: The paradox of organizing in HROs permeates the organization and shapes the entire knowledge creation process.

Discussion

Contemporary organizations are fundamentally complex and dynamically permeated by numerous nested paradoxes (Coff et al., 2006; Lado et al., 2006; Smith & Lewis, 2011). To understand contemporary organizations is to understand how paradoxical tensions may be nested, how they scale, and how paradoxes at one level (e.g., individual) shape those at another (e.g., collective) (Smith & Lewis, 2011). Problematizing organizational paradoxes allows us to build theories that more fully mirror the complexity faced by contemporary organizations (Eisenhardt, 2000). In this study, we focus on knowledge creation as a fundamental paradox in HROs. Knowledge is created in paradox because, on one hand, it enables one to handle events in the most appropriate manner while ensuring reliability and stability needed for optimal functioning of any organization. On the other hand, however, if not continuously challenged, overreliance on current knowledge may prevent the exploration needed to remain responsive to changes in the internal and external environments.

In this study, we discover a nuanced approach to knowledge creation that incorporates two dynamic paths within three levels of paradox. Whereas previous research has tended to underplay the paradoxical nature of knowledge, our findings indicate that paradox is critical to understanding how individuals transcend the boundaries of current understanding and generate novelty. Perhaps our most relevant contribution is the creation of a framework of knowledge creation in organizations that explicates the paradoxes embedded within. We organize our discussion around (a) insights with regard to the nature of HROs and how those insights may enrich our understanding of non-HROs and (b) insights with regard to the paradoxes in the knowledge creation process and how those insights might extend to non-HROs.

The Nature of High-Reliability Organizations

HROs exhibit a unique organizational context (Roberts, 1990) that may provide theoretical insights applicable to a wide range of complex organizations. Yet surprisingly little empirical research has been devoted to understanding their uniqueness. For example, although their tight coupling and interdependence are identified as key facilitators of hazard (Leveson et al., 2009), there is insufficient understanding of why. Similarly, there is only fractured understanding of what makes HROs reliable. In this study, we empirically illustrate the nature of tight coupling and interdependence in an HRO as well as identify continuous knowledge creation, rather than redundancy, as a key platform for reliable performance.

Our findings illustrate two facets of interdependence—collective interdependence and structural interdependence—that operate in opposition. Collective interdependence enables individuals in HROs to engage in diverse knowledge practices and prevent major failures. In contrast, structural interdependence increases the complexity of the plants (Perrow, 1984) and contributes to the escalation of hazardous events. By explicating the na-

ture of the structural interdependence and providing insight into its two distinct forms—physical and natural—we extend current understanding of HROs (Leveson et al., 2009).

Our findings also suggest that continuous knowledge creation facilitates reliable performance. HROs are strict bureaucracies because this structure allows them to exploit current resources and apply predetermined procedures most appropriately (March, 1991; Roberts, 1990). At the same time, our findings indicate that HROs often experience non-routine events that cannot be resolved using existing knowledge. When this occurs, individuals must generate novel solutions through careful interweaving of current knowledge with tentative exploration. The process of new knowledge creation not only allows individuals to neutralize potential failures before they occur but also permits the collective to build a repertoire of knowledgeable practices that allows them to notice and recognize potential cues to failure. Thus, to understand what makes organizations reliable is to understand how they create new knowledge amid potential danger.

Extension to non-HROs. Non-HROs tend to value reliability and embody paradoxical characteristics as well, although to a lesser degree. To this end, insights from HROs may be useful for theorizing how multiple paradoxes are managed as well as how high levels of reliability are achieved without sacrificing search and exploration. This is important because, as Lado et al. (2006: 115) recognize, "companies may succeed or fail based on differences in their capabilities to manage paradox." We offer two theoretical insights that may extend understanding of non-HROs: (a) the paradox of stability and change and (b) the dynamism of reliability.

We uncover how non-HROs work through the paradox of organizing exemplified in the tension between the need for stability and the need for change (Smith & Lewis, 2011). Similar to HROs, non-HROs struggle with incorporating variance-inducing practices such as innovation and flexibility with variance-reducing practices such as reliability and routines (Farjoun, 2010; Feldman & Pentland, 2003). Simple separation, however, provides only an imperfect solution—bureaucracies can be flexible (Bigley & Roberts, 2001; Milosevic & Bass, 2014) and structures may be instrumental for creativity and innovation (Harrison & Rouse, 2014; Pentland et al., 2012). Our findings contribute to this stream of research by empirically illustrating how bureaucracies achieve flexibility and how constraints facilitate new knowledge creation. We show how individuals interweave standard operating procedures with the discovery process to generate new knowledge and integrate it with the organizational knowledge system. In doing so, we illustrate the nested nature of the stability/change paradox that permeates most contemporary organizations (Smith & Lewis, 2011).

Our findings also provide insight into the concept of reliability. In HROs, reliability signifies failure-free performance. For non-HROs, reliability is evident in consistent service, stability of core activities, or even the ability to bounce back from environmental shocks (Dillon & Tinsley, 2008; Farjoun, 2010; Turner & Rindova, 2012). However, in contrast to research that portrays reliability as a stability-oriented, variance decreasing mechanism, our findings indicate that maintaining reliability is a daunting task requiring continuous awareness and proactive work. Individuals engage in numerous microadaptations to accommodate emergent unplanned events and deliver consistency (Turner & Rindova, 2012). We extend this insight by illustrating how individuals manage paradoxes inherent in these microadaptations through initial inquiry and coordination. Indeed, initial inquiry and coordination may be key facets of knowledge creation even in failure-tolerant organizations

Paradoxes in the knowledge creation process. A critical contribution lies within the discovery of three levels of paradox that individuals experience and navigate to create new knowledge. To this end, our findings align with previous research by showing that the continuous interaction between less and more experienced individuals is important and that continual awareness enables employees to recognize dangerous signals and appropriately classify them as novel or not (Weick & Roberts, 1993). Our findings also align with the notion that new knowledge integration with the current system is integral to the knowledge creation process (Cohen & Levinthal, 1990; Matusik & Heeley, 2005; Nonaka & Von Krogh, 2009).

We extend theory by providing a framework of knowledge creation that explicates three levels of paradox—paradox of knowing, paradox of practice, and paradox of organizing. Paradox of knowing occurs when individuals experience a deviation in their work that requires them to simultaneously utilize their current knowledge, challenge what they know, and engage in initial inquiry to generate preliminary insights into the deviation. Paradox of practice exists in the space between old and new knowledge in both the knowledge emergence phase (between individuals) and the knowledge formalization phase (between the formal and informal knowledge structures). The interplay of formal and informal structures in the paradox of practice gives rise to the overall malleability of the organizational knowledge system, which is necessary for reliable performance.

Finally, the paradox of organizing embodies the larger organizational context in which knowledge creation is situated. Centralization and procedural control at the organizational level can coexist with individual discovery and the ability to change the system at the individual level. They are interrelated, creating the paradox of organizing that individuals experience and navigate to create new knowledge and ensure continuous reliability. In HROs, individuals might ignore prescribed procedures when those procedures are categorized as unsafe or irrelevant to the given circumstances (Leveson, 1995). However, ignoring prescribed rules can lead to a major catastrophe, and the distinction between the two is clear only in hindsight (Leveson et al., 2009). By exploring how individuals interweave contextual contingencies into their knowledge practice, we provide stronger insight into this distinction. Our contribution lies in illustrating the conditions in which ignoring procedures enables new knowledge creation and continuous reliability of HROs.

Extension to non-HROs. Experimentation and errors are often portrayed as instrumental in the knowledge creation process (McIver et al., 2013; Schulz, 2001; Zhao, 2011). In this perspective, new knowledge is created as errors are detected, analyzed, and resolved. However, this perspective implicitly assumes that because non-HROs are more failure-tolerant, the benefits of gaining insight from errors outweigh the costs of making them. As a consequence, non-HROs are required to engage in cost/benefit analysis and choose between their desire for consistency of performance and new knowledge creation. By embracing the paradox perspective, however, organizations may be able to move away from either–or thinking and foster the "ability to recognize and accept the interrelated relationship of underlying tensions" (Smith & Lewis, 2011: 391) for a more holistic, yet paradoxical approach to knowledge creation.

Doing so is difficult, however, because in an effort to comprehend an increasingly ambiguous and ever-changing reality, individuals tend to opt for simplicity, creating polarized either–or distinctions (Lewis, 2000; Smith & Lewis, 2011). As a consequence, when

faced with paradox, they often remove, rather than work through, it. They choose activities that worked in the past, focus on a single choice, and remove opportunities for further exploration. This in turn reinforces the rigidity of action and stifles discovery (Lado et al., 2006; Poole & Van de Ven, 1989). Our findings illustrate that individuals do not simply follow rules and procedures on one hand, and pursue solution generation on the other. Nor do they oscillate between standardized and improvised actions. Rather, through coordination, individuals interweave constraints with their own experiences and knowledgeably act to facilitate discovery. Therefore, we provide a more fine-grained depiction of how individuals work through paradoxes to create new knowledge.

Limitations

Though the topic of this study is timely and increasingly relevant, there are several limitations that should be addressed. First, there are limitations related to the particularities of our research methodology. Though qualitative methods offer robustness in detailed, rich descriptions of organizational life, as observers, immersion in these rich details can never be fully appreciated, explicated, or communicated. With regard to this particular study, a struggle exists between providing rich description of our findings and presenting and connecting them with extant research (Wolcott, 2008). Thus, a limitation of this study, similar to other qualitative research, is achieving "seamless quality" while presenting "an adequate level of detail" (Wolcott, 2008: 107). Rather than imposing analytical elements on our study, we embrace the interplay of individuals and context, which forms the knowledge creation process in Marion. We attempt to describe this interplay to highlight the importance of studying both when seeking to understand knowledge creation in HROs.

Second, in an effort to focus our study, we had to omit several interesting avenues suggested by our data. For example, our findings indicate that "rite of passage" is important to knowledge creation because it enhanced reliability in Marion. Future research could investigate differences in organizational design and strategic human resource practices that facilitate the rite of passage, enabling continuous knowledge-driven interaction among less and more experienced individuals. In addition, our findings indicated that certain individuals took on informal leadership roles in the knowledge creation process and distributed knowledgeable practices across the plants. Our data also indicated that conditions under which individuals tend to ignore prescribed procedures is important (Leveson et al., 2009). To keep focus on the knowledge creation process as a conduit to reliable performance, we could not devote significant attention in our narrative to these elements. However, we do believe these to be fruitful directions for future research. In sum, our findings provide important implications for theory but also highlight several avenues for research to pursue to extend our understanding of knowledge creation in context.

Conclusion

HROs embody a paradox—their dangerous and dynamic context can generate exceptions that require new knowledge without opportunity for learning through failures. And so we ask, how is new knowledge created in the context where opportunities for exploration and learning through errors are absent? In pursuing this question, we challenge linear processes of sequential, identifiable stages of knowledge creation and call for a more

dynamic understanding. Our findings offer that knowledge exists in a dynamic interplay of experience, actions, and interactions that occur organically as individuals struggle to understand problems under intense pressures. In doing so, individuals experience and navigate three levels of paradox occurring along one of two paths in which knowledge is created. We offer an overarching framework of knowledge creation in context in which complete knowledge can never be attained; yet the pursuit of complete knowledge drives continuous action to achieve reliable, mistake-free operation.

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