A PURSUIT TO RELIABILITY – TOWARDS A STRUCTURAL BASED RELIABILITY FRAMEWORK (FSR)

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Abstract
Purpose – High-reliability performance and high-hazard are intertwined in High-Reliability Organizations (HROs) operations; these organizations are highly safe, highly hazardous and highly significant for the modern society, not only for the valuable resources they have, but also the indispensable services they provide. This research intend to understand how HROs could produce high quality performance despite their challenging and demanding contexts. The research followed an emic approach to develop an organizational framework that reflects the contribution of the seeming traits of the organizations to the operations safety based on the workers point of views about the safety of workstations.
Design/methodology/approach – This research adopted mixed methods of in-depth interviews and literature review to identify the structural characteristics of high-reliability organizations (HROs) embedded in the organizations studies and developed a theoretical based structural framework for HROs. Furthermore, a systemic literature review was adopted to find the evidence from the organizations literature for the identified characteristics from the interviews from the first stage. The setting for this study is six Chinese power stations, four stations in Hubei province central China and two stations in the southern China Guangdong province.
Findings – The organizational framework is a key determinant to achieve high-reliability performance; however, solely it cannot explain how HROs manage the risks of hazard events and operate safely in highhazard environments. High-reliability performance is attributed to the interaction between two sets of determinants of safety and hazard. The findings of this research indicate that HROs systems would be described as reliable or hazardous depending on the tightly coupled setting, complexity, bureaucracy involvement and dynamicity within the systems from one hand, and safety orientation, failure intolerance, systemwide processing, the institutional setting and the employment of redundant systems on other hand.
Originality/value – The authors developed an organizational framework of organizing the safety work in HROs. The applied method of interviewing and literature review was not adopted in any other researches.

Keywords Organizational performance, High-reliability organizations, Organization safety, Organizational Framework

Paper type Research paper

INTRODUCTION

Operations in modern organizations involve high complexity and tightly coupled technologies, the consequences of failure in such organizations would travel outward to influence wide urban societies. Therefore, high-reliability performance becomes one of the key assets the organizations could own. Being an HRO has been an interest of many organizations due to the high-reliability standards which draw the operations in the direction of safety. Reliability performance permits the organizational framework to approach the organization objectives without disappointments (Milosevic, Bass, & Combs, 2018). HROs systems utilize complex machineries in tightly coupled setting within high-hazard environments, according to Normal Accident Theory (**NAT**), HROs are considered stereotypically High-Hazard Organizations (HHOs) (Charles Perrow, 2011). Although the risk of hazard events in HROs operations makes the systems skeptical to large-scale disasters, HROs could obtain nearly full control over the errors and near misses which could lead to wreaking havoc and disastrous consequences including major system failures, massive destruction, and even loss of human life (Bierly & Spender, 2016). Moreover, the entitled risk of HROs operations is very low and the accidents are rarely occurring owing to the organizational capabilities to manage complexity and uncertainty in workplace by preserving safety and maintaining the reliability performance which emphasizes the error-free operations. The main guiding principle of HROs work is to assure the error-free operations (LaPorte & Consolini, 1991; Leveson, Dulac, Marais, & Carroll, 2009; Roberts, 1990; Karl E Weick & Roberts, 1993).

Giving the significant role of HROs to provide wide variety of indispensable services such as electricity, transportation, firefighting, healthcare, chemicals and defense, HROs are compelled to preserve safety of the systems and keep a deep sense of the potential risks no matter what conditions the operations go through. HROs systems are often holding extremely valuable resources, which are required to mindfully use to provide the significant services that cannot be afforded from elsewhere efficiently and effectively (Farjoun, 2010; Leveson et al., 2009). The reliability performance denotes that, the organization has maintained efficient control systems. The safety performance in HROs focuses on failures more than success, the systems are designed around the safety goals and measures in order to pay full attention to errors and navigate the operations towards reliability rather than uncertainty and predictions (K. E. Weick, 2016).

1.1 The Theoretical Contribution

Over the years, the research interest in organizations safety has been shifted from what makes organizations risky from the standing point of **Safety I** to consider what makes them safe from the standing point of **Safety II** (Haavik, Antonsen, Rosness, & Hale, 2016). This research adopts the **Safety II** approach to identify the characteristics of HROs and develop a framework for the organizations working in high-hazard environments. This research contributes to the High-Reliability Theory (**HRT**) by developing a framework that can be used to determine if an organization can produce safety performance under high-hazard environments and the convenience of applying a systematic process to develop the safety performance based on the characteristics of the organizations. Further, the research contributes to the theoretical debate of **HRT-NAT** by consolidating the reasoning of both theories into a framework of HROs. In this research, **HRT-NAT** are considered either complimentary or compatible with each other. The findings of this research expand the understanding of researchers and practitioners about a possible mechanism to improve the organizational performance by adopting the characteristics of HROs as a benchmark in non-HROs to prevent accidents under the challenging conditions.

1.2 Research Statement

The unavailability of a standardized framework of HROs illustrates the lack of empirical research on high-reliability research about how to develop the organizational performance to the reliability level (Agwu, Labib, & Hadleigh-Dunn, 2019). Different from the Structural reliability assessment which concerns assessing the probability of hazard event in extreme conditions (Zuniga, Murangira, & Perdrizet, 2020), this research inspired by the theoretical debate of **HRT-NAT** about the ability of organizations to produce high quality performance despite the challenging and demanding environments. This research develops an organizational framework based on how the theories appreciate the hazard nature of organizations and the managerial aspects of operations in high-hazard environments. While **HRT** has faith in organizations to adopt the right capabilities to prevent the accidents in complex and tightly coupled systems, **NAT** believes that the accidents are inevitable no matter how good the capabilities organizations have. Theoreticians are either optimistic as for **HRT** (Reason, 2016; K. M. Sutcliffe, 2011; Karl E Weick, 1987) or pessimistic as for **NAT** (Charles Perrow, 2011; Rijpma, 1997; Sagan, 1995). In this research, a realistic approach was adopted to understand how the two theories can be reconciled since both theories could be considered valid at different points of time, while **NAT** is valid at the time of accidents, **HRT** is valid at the time of normal operations. Regarding the organizational structure, this research overlooks the tensions between the theories to understand what makes the performance safe from **HRT** point of view and hazardous from **NAT** point of view. This approach enable us to identify the characteristics that make the complex and tightly coupled systems operate safely in HROs.

1.3 Past and Pioneering Work

In the mid-eighties, scholars at University of California, Berkeley, have introduced HRO to the organizations research; La Porte, Gene Rochlin, Paul Schulman and Karlene Roberts have presented their insights in numerous publications. The group identified four organizations that meet and even exceed the established standards of reliable performance set by the society. The four organizations are operating in high-hazard environments with complex technologies nearly accident-free; The Air Traffic Control System (ATC), The Electric Operations and Power Generation Departments, The peacetime flight operations of the US Navy's Carrier Group 3 and its two nuclear aircraft carriers and the PGE's Diablo Canyon plant have set the model for the reliable organizations. In the 1990s, HROs became a so-called area of organizations research, theorizing of high-reliability and high-hazard organizations were often conducted within the scope of safety management. ATC performance has been thoroughly investigated under the HRO trending theme. (Morris & Moore, 2000; O'Neil & Krane, 2012; Karl E Weick, 1987) studied the ATC and Air Operation's high-reliability within the Federal Aviation Administration (FAA). (O'Neil & Krane, 2012; O'Neil & Kriz, 2013) focused on the ATC's policy, structure and protocols of (FAA) in the environmental system and the collective influence of the policy and Aviation agencies on the ATC.

Over the time, research became more concerned about the non-operational aspects, (Morris & Moore, 2000) assessed the learning process of the aviation pilots and the ATC organizational accountability system. Moreover, (LaPorte & Consolini, 1991) investigated the complexity and tight coupling within two aircraft carriers, US air traffic control, utility grid management and firefighting teams. (Karl E Weick, 1987) studied the U.S. Navy culture and the decision making process in high-hazard environments, Weick underlined the significant role of reliability culture in maintaining high-reliability performance. Furthermore, (Bierly III & Spender, 1995) deliberated that, despite the tensions between the traditional naval culture and nuclear submarine framework, the culture on the nuclear submarine is a key source of reliability. The study concluded that, the nuclear navy meets the criteria for HROs due to the strong organizational culture (C Perrow, 1984). Gradually, the research interest diverted to the principles of HROs, the research from (W. Sutcliffe, 2006; Karl E Weick, Sutcliffe, & Obstfeld, 2008) provided a conceptual framework for incorporating the cognitive mindfulness principles into the organizational practices to achieve reliability performance. Recently, (Agwu et al., 2019) build a maturity framework based on the five mindfulness principles proposed by (Karl E Weick et al., 2008) to prevent disasters in high-hazard environments.

Reliability was introduced in the field of engineering for the purpose of assessing the efficacy of the systems structures and infrastructures to handle the complexity and uncertainty (Pan & Dias, 2017). Several approaches were followed to quantitatively analyze the risks integrated in operations in high-hazard environments, structural reliability methods (Ditlevsen & Madsen, 1996), Monte Carlo simulation, Bayesian Monte Carlo (BMC) (Rasmussen & Ghahramani, 2003), Petri Nets (PN) (Cavone, Dotoli, & Seatzu, 2017; Chen, Li, & Zhou, 2013; Kabir & Papadopoulos, 2019; Weber, Medina-Oliva, Simon, & Iung, 2012), enhanced Bayesian network (eBN) (Straub & Der Kiureghian, 2010). Regarding the role of human error in accidents, the eBNs contributed to developing the Human Reliability Analysis (HRA) which concerns the causes and effects relationship between the human errors and accidents in high-hazard environments (Kabir & Papadopoulos, 2019). HRA has emerged as a hot topic over the past decade (Groth & Mosleh, 2012; Mkrtchyan, Podofillini, & Dang, 2016; Podofillini & Dang, 2013; Su, Mahadevan, Xu, & Deng, 2014).

2. METHODOLOGY

2.1 Research setting

General HRO Context. The setting for this study is Six Chinese Power stations, four stations in Hubei province central China and two stations in the southern China Guangdong province. Two hydroelectric stations, three thermal power stations and one nuclear station.

During the first stage of this research, two safety personnel were interviewed from each of the stations, at least one of them is an engineer in charge of the safety of the station (12 interviews). The safety engineers represent key informants because they are highly knowledgeable about the systems. The interviewees were predominantly males (11 males and 1 female as observed the workforces were predominately males), the average work experience is 15 years among the interviewees. The semistructured interviews represent the primary data source, the interviews were conducted on one-on-one sessions to present the open-end questions which were utilized to identify the key features of the organizations with the intent to understand how the interviewees describe their organizations. The emic approach was followed to understand the seeming traits of the organizations based on the workers point of views about the safety of workstations. The interview questions were ***Safety II*** driven to emphasize the success tendencies which employ the reasoning to study their performance under HROs theme. The key informant in this study is coded as informant 1, works for a nuclear power station. The second author carried the task of translating the questions into Chinese and checked the accuracy of the answers in addition to conducting the two pilot interviews.

In the second stage, a systemic literature review was adopted (Tranfield, Denyer, & Smart, 2003; Tsoukas, 2009) to find the supported literature for the characteristics identified from the first stage which best describe HROs structures. These characteristics are Hazardous, Tightly coupled, Complex, Dynamic, Bureaucratic, Safety Oriented, Failure Intolerant, Systemwide processor, Institutional and Redundant. The peer-reviewed literature published before October 2020 was explored. The search was conducted using five electronic databases (Elsevier, Science Direct, EBSCO Host – Business Source Complete, SCOPUS, and ABI – ProQuest) for academic publications in relation to the search string combination developed in Table 1. The characteristics represent the core of the structural framework together with the representative data from stage 1 in Table 2. A consecutive search was conducted to find the relevant articles in leading journals (e.g., Safety Science and Academy of Management Review, Organization & Environment, Journal of Organizational Behavior, Academy of Management Journal, Journal of Risk Analysis, Journal of Management and Journal of Contingencies and Crisis Management). The search process consisted of two successive stages, the first stage involved searching the titles or abstracts for the keywords of High-reliability Theory, High-reliability organizations, Normal Accident Theory, High-hazard organizations, Resilience Engineering and their acronyms HRT, HRO/s, NAT, HHO/s and RE. The second stage involved searching for the strings of the characteristics identified through the observations from stage one, Table 1 includes the key words of stage two, which included the terms of main interest such as reliable and tight coupling, their synonyms such as Sustainable and interdependence, and the alternative words such as trustworthy and connected.

2.2 Data Analysis

The primary task of the systemic literature review is to find the scholarly papers in relation to the characteristics of HROs, the researches on HHOs and resilience engineering was considered in terms of the similarity of working in high-hazard environments. Including HHOs and resilience engineering provided the search with insightful discussions about organizing safety. On the next stage, the thematic content analysis was used

(Krippendorff, 2004). Firstly, the theoretical aspects of literature were coded, and then coding the identified characteristics from the previous stages so the search process run on a systematic basis. The qualitative data analysis software NVIVO 12 was used for coding. Since the objective of this research is to develop a general framework, it was necessary to avoid any potential industry or organizational biases in stage two, in order to ensure the diversity and generality of the identified characteristics, there were no preferences for research papers about certain type of organizations or industry line.

Table 1

Characteristics and Representative Literature

Characteristic	Keywords	Benchmarks from literature
Hazardous	Hazard, Hazardous, Risk, Risky, Disaster, Catastrophe, Catastrophic, Fail, Failure, Unpredictable and Uncertain	(Bourrier, 2011; Erin Bass & Milosevic, 2018; Ford, 2018; Leveson, Dulac, Marais, & Carroll, 2009; Perrow, 2011)
Tightly coupled	Coupled, Tight Coupled, Coupling, Interconnected, Interdependent and Interdependence,	(Erin Bass & Milosevic, 2018; Ford, 2018; Hopkins, 2001; Perrow, 2011; Rijpma, 1997)
Complex	Complex, Interdependence, Interdependent, Intricacy, Intensive-Technology and Interconnected.	(Bierly & Spender, 2016; LaPorte & Consolini, 1991; Leveson et al., 2009; W. Sutcliffe, 2006; Weick, Sutcliffe, & Obstfeld, 2008)
Dynamic	Dynamic, Dynamicity, Change, Robust Actions, Interactions, Flexibility, Evolving, Impulsive, Developing and Responsive	(Casler, 2014; Enya, Pillay, & Dempsey, 2018; Farjoun, 2010; Ivana Milosevic & Erin Bass, 2014; Morris & Moore, 2000; Perrow, 2011; K. M. Sutcliffe, 2011)
Bureaucratic	Bureaucratic, Bureaucracy, Control, Structure, Restrict, Constrains, Rigidity, Obeying, Routine, Policies, Norms, Standard and Procedures	(Bass & Chakrabarty, 2014; Bierly III & Spender, 1995; Catino & Patriotta, 2013; Erin Bass & Milosevic, 2018; Feldman & Pentland, 2003; LaPorte & Consolini, 1991)
Safety Oriented	Safe, Safety, Error-Free, Mistake-Free Clear Record, Efficacy, Cognitive Processing, Correct, Supportive, Firmly, Acceptable Levels, Containment, Survive, Safety Measurements and Safe Environment.	(Catino & Patriotta, 2013; Ford, 2018; Peiró Silla, Gracia Lerín, & Martínez-Córcoles, 2018; Perrow, 2011; K. M. Sutcliffe, 2011)
Failure Intolerant	Fail, Failure Intolerance, Failure Unforgiven, Technical Failure, Risk, Risk Intolerant, Secure, Securely, Disorder,	(Lekka & Sugden, 2011; I. Milosevic, Bass, & Combs, 2018; Perrow, 1994, 2011; Reason, 2016; W. Sutcliffe, 2006)

	Mess, Correct, Preoccupation With Failure, Incidents, Prevention, Mistake-Free, Accident And System Error	
Systemwide process	Systemwide, System-Wide, Broad Scale, Wide-Manner, Large Scale, Common Procedures, General Procedures, Extensive, Cognitive Processing, Strategy, Strategic, Strategic Coordination And Centralization	(Andriulo, Arleo, de Carlo, Gnoni, & Tucci, 2015; Roberts, 1989; Vogus & Rerup, 2017; Weick & Roberts, 1993)
Institutional	Learning, Continuous Learning, Knowledge, New Knowledge, Cognition, Repertories, Trialing, Training And Experience	(Catino & Patriotta, 2013; Ford, 2018; Levinthal & Rerup, 2006; Macrae & Draycott, 2016; I. Milosevic et al., 2018; Ron, Lipshitz, & Popper, 2006; Weick et al., 2008)
Redundant	Redundant, Redundancy, Backup, Substitution, Replicate, Corrective, Secondary, Alternative, Additional, Substitutes.	(Bourrier, 2011; Busby & Iszatt-White, 2014; Perrow, 1994; Pillay, 2014; Weick et al., 2008)

Table 2

Structural Framework of High Reliability Organizations (FSR)

Dimension	Characteristics	High Hazard organizations HHO An organization working in high hazard context, Consequently, the organization failed to sustain error-free operations and accidents and disasters are inevitable.	High Reliability Organizations HRO An organization which is well financed and boosted to have the right capabilities to prevent failures and disasters under high hazard conditions. Although the operations are nearly error-free, a small fault amid such hazard contexts would lead to a disaster.
Hazard	**Hazardous**	Failures and accidents are unpreventable and The organization does not employ the competencies and expertise needed to response to contingencies events.	The high hazard challenge the organizational capabilities to balance the forces of high hazard and safety and sustain performance by means of accident prevention.
	Tightly Coupled	Tight coupling and interdependences makes the more skeptical to accidents and disasters. Tight coupling spread the failures between the interdependent systems.	Tightly coupled systems are convenient for centralized control and keep the systemwide commands more efficient. Tight coupling endorse accident prevention by spreading transmitting the perturbations and prevent developing errors.
	Complex	Tight coupling contributes to the system complexity which is already exist because of the multidimensional relations between the organization system and surrounding environment. Categorization and simplicity makes the system	The system ensures that, the complex interrelations are well-understood and the complex of hazard operations are well attended and the implications of which, are accounted for.
	Dynamic	Dynamicity requires high responsiveness and timely interactions which are not afforded due to the complexity of operations that creates difficulty to timely adjust and adapt to change.	The system is very sensitive to change in surroundings and actions are migrating to expertise where they are. Furthermore, at the time of nonroutine, the system allows considerable flexibility to neutralize the hazard events.
	Bureaucratic	The practices are pre-established and the hazard consequences cause the system to be crumbling since complex tight coupling technologies are not appreciated as they should be.	The operations are executed following to the operations manual which accounted for relatively all possibilities of hazard events and the prescribed procedures are extensively reviewed. Moreover, reasonable flexibility are allowed at the nonroutine time.
Safety	**Safety Oriented**	The organization would experience tension of competing organizational goals and interests such as production size, and safety goals which make the activities less focused on safety.	Maintaining reliable performance is the main objective of the organizations and all the activities navigate towards the direction of safety. Safety principles govern the operations to ensure that the operations remain error-free and the cognitive processing endorses the decision making processes.

	Failure Intolerant	The organization would be more tolerant to the errors and there is a tendency to find someone to blame for failures which weaken the accident prevention policies and create a tendency to be insensible to problems if they are not directly concern to the individual mission.	In the core of the organizational culture, the failure intolerance is central to preserve the reliability performance, at the time of nonroutine, problems are accurately addressed and resolved with no blame on individuals. At this time, the system takes the opportunity to review the operations procedures and learn new lessons.
	Systemwide processing	While the systems are managed separately, centralization enables the system to deal with the interdependences but still complexity are difficult to be understood in the absence of systemwide processing function.	The system can adjust between centralized control, which fits well with the tightly coupled technologies and decentralized control that facilitates managing the complexity.
	Institutional	The organization benefits from errors as opportunities to learn and create knowledge, these errors are often joined by disastrous consequences. Although the system is luckily engaging in knowledge creation practices, the information accessibility is challenging owing to the dynamicity.	The organizational learning, training, continuous learning and knowledge creations stand as a backbone of the reliability performance, the knowledge system works alongside with the communication channels to provide individuals with the information needed for preserving the reliability performance. The system relies on simulations owing to the failure orientation and intolerance.
	Redundant	Redundant systems increase the probability of disasters owing to the difficulty to control the system since the organization is already experience an overwhelming structural complexity coming from the tight coupling .	At the time of nonroutine, redundant systems are substituting the failed components to preserve the performance, redundancy is significant principle of HROs operations to reduce uncertainty.

3. THE FINDINGS

For more than three decades, organizations reliability has been an emerging research domain, the research expanded the body of Management Science, Sociology, Political Science, Psychology, Anthropology, and Public Administration (Haavik et al., 2016). Yet, there is a lack of consensus on the meaning of reliability and how reliability performance could be maintained and sustained in high-hazard environments, which make it hard to adopt a general definition of the phenomena (Rochlin, 1993). Within the discourse of organizations safety, there are three theoretical streams were underlined; Normal Accident Theory **NAT** (C Perrow, 1984), High-Reliability Theory **HRT** (LaPorte & Consolini, 1991; Karl E Weick, 1987) and Resilient Engineering **RE** (Hollnagel & Woods, 2006). The current study draws on the highlighted theories to identify the common characteristics of HROs structures and develop the structural framework whereas **NAT** and **RE** could operate under the **HRT** umbrella.

3.1 Characteristics of HROs

Reliability performance is produced on the basis of safety and trust in the organizational capabilities, excellence in safety is pronounced to be the distinguishing feature of HROs. (Bourrier, 2011) emphasized on the significant role of HROs in the modern societies, HROs contribute essentially to the economic and social systems by providing a requisite variety of vital and indispensable services thanks to their enhanced performance. Research on HROs has attracted considerable attention since the services provided by HROs are of high demand such as electricity production, health care and firefighting. Scholars tend to be rigorous to describe an organization as HRO, given that high-reliability is meant to be an extraordinary merit that assures that an organization meets high safety standards and could maintain outstanding safety records over long periods

(Bourrier, 2011). Assessing the organizational reliability is inspiring for both researchers and practitioners to understand how HROs obtain such high level of trust, credibility and influence on substantial sectors of the economic and social systems.

Reliability performance permeates through the organizational structure to shield the operations against the potential hazards. Reliability performance endorses the organizational capabilities to prevent failures and disasters (Erin Bass & Milosevic, 2018). Yet, researchers suggested several explanation for reliability performance, (LaPorte & Consolini, 1991; Roberts, 1990) attributed reliability performance to the deference to the technical expertise, continuous learning, and systemwide processing. Correspondingly, (Farjoun, 2010; Ramos, Droguett, Mosleh, & Moura, 2020) indicated that organizations rely on the experienced workers to achieve reliability performance; the meaningful experience fosters the individuals understanding of complex situations. According to (Milosevic et al., 2018), the efficient knowledge system is believed to be a key source of reliability. (Bigley & Roberts, 2001) highlighted that the adoption of a refined bureaucracy as one of the reasons behind reliability performance however, (Milosevic et al., 2018; Karl E Weick et al., 2008) suggested that reliability performance comes from the careful attention to failures and error leaden actions that stems from the strict adherence to the safety protocols in the routine time, and the considerably flexible control at the time of nonroutine time.

The former director of U.S. Naval Reactors office, Admiral Hyman G. Rickover stressed on the significant role of individuals in achieving reliability performance, discipline and training allow individuals to neutralize the small incidents before developing bigger disasters (LaPorte & Consolini, 1991; Wilson, Burke, Priest, & Salas, 2005). The job training promotes the individuals characters to match the requirements of HROs personality. In addition, the mutual-auditing function, criticism and rational guidance are central to preventing failures at the proper time (Bierly

& Spender, 2016). (Milosevic et al., 2018) emphasized that, sustainable reliability requires continual awareness of the workplace safety and collective engagement in safety practices, well attendance to the operations events to apply the needed adaptations is essential to accommodate the nonroutine event and timely adapt to it (Turner & Rindova, 2012). With a reference to the government role in supporting organizations to achieve reliability, (Tolk & Cantu, 2018) believe that, reliability performance cannot be sustained in long-term without a well-established policy that enforces safety standards in all organizational aspects. To conclude, safety performance in HROs requires a strict adherence to the safety standards and principles and prioritizing the safety goals which can be achieved by following the comprehensive operations manual that underlines safety and risk possibilities in the workplace. Individuals are required to mindfully proceed with caution under the stressful circumstances to prevent disasters and achieve the organizational objectives.

HROs are described as reliable, hazardous, tightly coupled, complex, dynamic, bureaucratic, safety oriented, failure intolerant, systemwide processor, institutional, and redundant in Table **3**. While there is an agreement between **HRT**, **NAT** and **RE** on three distinctive characteristics of organizations working in high-hazard environments; hazardous, tightly coupled and complex, there are other characteristics, which represent obvious sources of conflict between theories such as safety oriented and failure intolerant. These characteristics are distinguishing features of HROs, which they outperform other organizations on acting on them, however there are fault tolerant systems which share some of the characteristics and could possibly employ them in an efficient manner throughout their operations such as high-hazard organizations, which also could execute HROs principles in their practices (Enya, Pillay, & Dempsey, 2018; Karl E Weick et al., 2008). In practical terms, replicating the identified characteristics to the organizational structures would facilitate the process to synergize, learn, and successfully enforce HROs practices within workplace. Developing organizations performance to HRO level will definitely create a safer future for organizations with little or no social and economic devastating consequences.

3.1.1 Hazardous

HROs are prone to large scale disasters and their operations entail high public and private risks (M. Bourrier, 2011). Controlling hazard events within HROs systems is crucial for the business survival (Lekka & Sugden, 2011; Pillay, 2014; Karl E Weick et al., 2008). Although the missions of HROs are essential, the attached economic and social costs of their failures outweigh the expected benefits (Erin Bass & Milosevic, 2018). The consequences of failures are not limited to the equipment but also, serious injuries and loss of human lives may result from the escalation of hazard events (Bass & Milosevic, 2018; Bierly & Spender, 2016; Charles Perrow, 1994). Failures could lead to major breakdowns of essential services and possibly entire sectors. Consequently, HROs systems are required to sustain the error-free operations because failure is too disastrous to be endured or tolerated (LaPorte & Consolini, 1991; Milosevic et al., 2018).

On one hand, HROs are likely to develop hazard events owing to the system's complexity and dynamicity of operations, on the other hand, the reliability performance stands as a firewall, which blocks the potential failures and safeguard the systems against disasters. Lack of appreciation of the hazard nature at the time of nonroutine events could produce impulsive behaviors that lead to failures (Erin Bass & Milosevic, 2018). NAT theorist (Charles Perrow, 2011) emphasized that, the complex and tightly coupled systems are likely to develop accidents within the high-hazard environments, these accidents are considered inevitable. Perrow highlighted that, high-hazard operations may lead to severe environmental despoiling with serious consequences, which affect large populations. Complexity fuels the hazard inclinations of HROs; the poor understanding of the interdependences between systems would lead to disasters. Although, complexity contributes to creating disasters, it also denotes valuable lessons for organizations to pay more attention to prevent accidents and improve safety in operations, complexity inspires organizations to be more prepared and attentive to disasters.

Moreover, the deeply entrenched bureaucratic control contributes to the hazard events in HROs by allowing the individuals to disregard potential risks and stick to certain procedures at the time of nonroutine events (Ford, 2018), underestimating the potential risks would probably constraint the individuals readiness and responsiveness to the changes in the environment (Kapucu, Berman, & Wang, 2008). (Bierly & Spender, 2016) indicated that, hazard restricts HROs ability to benefit from trial/error learning and the use of empirical science techniques to create new knowledge. Moreover, according to Rickover, the use of technologies and automation carries risk for HROs operations, system design must avoid automation unless the absolute necessary since the constant attendance of well-trained staff is essential to manage the operations consistently with the safety measures (Busby & Iszatt-White, 2014; Karl E Weick, 1987).

3.1.2 Tightly Coupled

HROs operations are known as time-dependent and time-honored processes, of which the highly interdependent technologies have invariant sequences and limited slack resources (Karl E Weick et al., 2008). In such interactively complex environment, anticipating the consequences of errors becomes more problematic since failures are cascading through the coupled systems in nearly invisible manner. (Buldyrev, Parshani, Paul, Stanley, & Havlin, 2010) emphasized that, tightly coupled systems are more vulnerable to failures, high interdependence between the system components and between the events would significantly contribute to propagating the failures to the general systems (Kabir & Papadopoulos, 2019). From **NAT** perspective, tightly coupled systems which combine lack of control with high uncertainty are more likely to develop accidents, giving the inability to control the complex systems in the long run because these systems require a centralized control over their tightly coupled setting together with a decentralized control needed to handle complexity (Charles Perrow, 2011). In contrast, **HRT** highlighted that, tightly coupled systems become manageable if organizations could afford the appropriate capabilities (Leveson et al., 2009), systems should be able to adapt to wide variety of situations and reconfigure accordingly, so it could be possible to provide centralized or decentralized control over their operations (Haavik et al., 2016). However, with the political incentive attached to maintaining success and error-free operations, HROs allows the systems to relocate the available resources to support efficiency goals rather than improving safety (Pettersen & Schulman, 2019).

HRT is based on the fact that, under certain conditions, interactively complex and tightly coupled system will not fail (Karl E Weick et al., 2008), the implementation of redundant systems together with considerate managerial practices guided by mindful organizing will promote the operations safety to the level of reliability. Furthermore, (Bierly III & Spender, 1995) indicated that, tightly coupled systems are more efficient in transmitting the perturbations between subsystems to prevent the development of consecutive failures. For HROs, interdependence denotes that reliability performance is a joint achievement rather than sum of localized achievements (Timothy J Vogus, 2011), all procedures and activities in the system are required to be functioning simultaneously to produce the error-free performance. (K. M. Sutcliffe, 2011) suggested that, in HROs, the small incidents have high potentials to be transformed into a complex disaster owing to tight coupling, accumulation of trivial incidents would increase the probability of disasters since the circumstances that produce these incidents may get along quickly without a sound understanding about what they will develop. Building on these, the following proposition was established:

Proposition 1: In HROs, the tightly-coupled setting increases the possibility of errors and demotes reliability.

3.1.3 Complex

HROs as yet known exhibit complexity in many aspects; tightly coupled structures, complex operations and practices, and entangled relations with the surroundings including the counterparts and environment (Charles Perrow, 2011), systems complexity decreases the dependability of systems (Kabir & Papadopoulos, 2019). Analyzing the complexity is vital to understanding how the systems may fail and consequently decide which preventive action to control the potential failure. The system design emphasize on the safety measures to tackle the complexity, being attentive to the potential risks allows the systems to manipulate the operations and produce safety performance (K. M. Sutcliffe, 2011). Owing to the significant role of HROs, the complexity attached to the systems must be well-understood and the lure of simplicity become the last concern for organizations. From structural perspective, complexity comes from high interdependence of the internal systems and it also extends to the operations and behaviors. Moreover, complexity is embodied in the external environment such as the relationship with other organizations, government agencies and their policy systems which regulate the industry activities (Sagan, 1995), HROs are required to account for the influence of the externals since their systems cannot preserve own isolation (O'Neil & Krane, 2012).

(Karl E Weick et al., 2008) believed that, HROs must dodge the inclinations to simplicity in the workplace by leaning to expertise and avoiding the categorization and typologies that blur the decision-making, such practices contempt for the risk signs in hazard environments (Milosevic et al., 2018). Giving the complexity of systems, recklessness and risk-taking behaviors would produce disasters (Feldman & Pentland, 2003; Maglio, Scott, Davis, Allen, & Taylor, 2016), instead, individuals are required to develop a reactionary and flexible mindset that maintains continuous awareness and favor intricacy over simplicity while coping the potential failures (Kendra & Wachtendorf, 2003). The developed HROs mentality underlines the mindfulness behaviors such as analyzing and questioning the evidences rather than taking risks to apply prescribed actions without firm consideration of the consequences. Furthermore, leaning to the known procedures would create blind spots on possible failures (Milosevic et al., 2018), the tension between obeying the standardized procedures and the flexibility needed for managing the unexpected events embraces a temporal paradox within HROs operations. Building on these, the following proposition was established:

Proposition 2: In HROs, the complexity of interrelations within the systems and in the surrounding environment increases the possibility of errors and demotes reliability.

3.1.4 Dynamic

Operations in HROs are constantly evolving in a relatively unpredictable manner (Karl E Weick & Sutcliffe, 2015). HROs dynamic nature stems from the continuous interactions between the interdependent system components (Milosevic et al., 2018). In such dynamic environments, hazard in operations is continuously redefining the system status, which make the system constantly striving to be technically corrected and comprehended. Individuals deal with the system as a living thing, they are often encountered by unknown problems that require timely actions (McChrystal, Collins, Silverman, & Fussell, 2015). Given that the impulsive interactions would quickly develop a disaster, all events must be well-attended and appropriately responded to. At the time of nonroutine, owing to the functional dependencies in HROs systems, it would be a matter of hours or minutes or even seconds to transform the small incident into a complex disaster with fewer or no options to resolve it (K. M. Sutcliffe, 2011).

(Thiry, 2002) suggested that, HROs tend to be more flexible to accommodate the external environmental changes than other organizations working in high-hazard environments. The dynamics in HROs internal operations such as interdependences of the systems increase the likelihood of hazard events, therefore, HROs systems are needed to be rather responsive and moderately flexible to cope and react to the evolving events and be able to create new solutions to the new problems (Drucker, 1992; Nonaka, 1991). In the meanwhile, there a reasonable concern for the flexibility tendencies, at the time of nonroutine, flexibility would carry high risk and make individuals less focused on the strategic safety goals (Denyer, Kutsch, Lee-Kelley, & Hall, 2011). The systemwide monitoring task is crucial to handling dynamicity, the monitoring system is required to address all component of the systems to resolve the new problems at the most convenient time by determining and applying the suitable solutions (Ford, 2018). Moreover, the voluntary error reporting systems in HROs is considered a key risk mitigation tool, it promotes the system defenses to keep alert to changes in operations (Bourrier, 2011). Building on these, the following proposition was established:

Proposition 3: In HROs, the operations dynamicity increases the possibility of errors and demotes reliability.

3.1.5 Bureaucratic

HROs bureaucratic control represents a profound organization convention, the reliability performance stems from the standardized operations and prescribed procedures which follow a well-established and instructive operations manual (Milosevic et al., 2018). HROs systems are based on a bureaucratic control mode in which, strictly adhering to the rules becomes a must, owing to the high-risks convoying any inconsiderable flexibility (Bierly III & Spender, 1995; K. M. Sutcliffe, 2011). The operations must be executed and thoroughly managed according to the bureaucratic hierarchy which shows a great respect to expertise and experience (Karl E Weick et al., 2008), the strict utilization of the predetermined procedures endorses reliability performance, adherence to the rules preserves operations safety (Yassin & Martonik, 2004). The bureaucratic control moderates the interactions between the technical and cultural systems to produce reliability. Vital system functions rely heavily on the bureaucratic rules such as safety check-ups and performance auditing to avoid the deviations which are strongly uninvited (Bierly & Spender, 2016).

Obeying the bureaucratic orders and appropriately applying the prescribed procedures are central practices to eliminate the potential risks (Milosevic et al., 2018). HROs count on the comprehensive operations manual which accounts for the possibilities of risk to reallocate the system resources when needed and preserve the reliability performance at the time of nonroutine (March, 1991; Roberts, 1990). Furthermore, reliability culture supports the bureaucratic control by implementing high centralization and wide processing into activities through training and learning processes (Bierly & Spender, 2016). Yet, the systems strive for stability is restrained by the considerable flexibility needed for managing the dynamic nonroutine event, (Thackaberry, 2004) suggested that, the safety norms are not necessarily bureaucratic while going through nonroutine events. Under very limited conditions, HROs systems would permit flexible control to manipulate and cope the nonroutine situations, in which flexibility would be considered beneficial for keeping the higher level system of knowledge updated. Building on these, the following proposition was established:

Proposition 4: In HROs, the bureaucratic control increases the possibility of errors and demotes reliability.

3.1.6 Safety Oriented

In the pursuit of reliability, safety represents a strategic goal and a condition of business survival, preserving safety comes ahead of any other objective, HROs are required to continuously commit to safety measures and risk management tools such as: incident and near miss reporting, permit-to-work and job safety analysis (JSA) (Boin & Schulman, 2008). The label of HRO is implicitly assuring that, the organization has an outstanding safety record and a set of basic safety principles for operations (Rochlin, 1993). HROs operations are oriented to safety, the system control is committed to high cognitive processing and application of predetermined procedures that ensure the error-free performance and prevent accidents (olde Scholtenhuis & Dorée, 2014). HROs operate within high-hazard environments with exceptionally safe performance shielding by means of reliability performance and demonstrate safety by experiencing few or no accidents under extremely hazardous conditions (Samuels, 2010; Saunders, 2015).

(Karl E Weick et al., 2008) argued that, the reason behind HROs superior performance is the enactment of mindfulness, which endorses the individuals to manage uncertainty and maintain focus on the present moment by being more attentive and aware about the workplace (Timothy J. Vogus & Rerup, 2017). HROs systems rely on the role of top management to enforce safety principles, alongside an extraordinary safety culture of HROs that guides individuals to achieve reliability performance. (Samuels, 2010) indicated that, performance auditing and the strong supportive reliability culture endorse HROs to handle hazard situations at acceptable levels of performance (Youngberg, 2004). Moreover, HROs design is based on accident-prevention to eliminate accidents that may be caused by errors in the design which accounts for 60 percent of accidents in high-hazard environments (Bhattacharjee, Ghosh, & Young-Corbett, 2011). Building on these, the following proposition was established:

Proposition 5*:* In HROs, safety orientation endorses reliability performance and decreases the possibility of errors.

3.1.7 Failure Intolerant

HROs are highly susceptible to dreadful and large-scale events with social and economic devastating consequences of errors (Erin Bass & Milosevic, 2018). Consequently, the social and political setting in which they operate is unforgiving and demanding persistent safe operations to avoid such events, small incidents or bigger crashes would trigger the failure alarm (Leveson et al., 2009). (Charles Perrow, 2011) emphasized that, HROs hazard nature dictates the need for an efficient accident prevention program and polices that preserve the reliability performance (Saunders, 2015; Karl E Weick et al., 2008). While reliability performance is based on error-free operations, failure intolerance represents the philosophy of HROs safety work, it serves as the defense mechanism of accident prevention. The preoccupation with failure denotes insightful lessons for safety to decrease the probability of disasters according to organizations scholars and practitioners (Ford, 2018; Jahn & Black, 2017; Karl E Weick & Roberts, 1993; Williams, Gruber, Sutcliffe, Shepherd, & Zhao, 2017).

According to (Karl E Weick, 1987; Karl E Weick & Sutcliffe, 2015), the human error is an explanation for the organizational failures, the accidents occur because workers fail to anticipate the consequences of their actions on operations. Employing error tolerance policies is too risky in high-hazard contexts alike HROs and therefore, organizations rely heavily on failure intolerance to alleviate the manmade errors and avoid ignorance and apathy which lead to accidents. Failure intolerance denotes that, HROs systems prohibit the empirical based training and learning in favor of simulations (Clarke, 1993). Failure intolerance is associated with systemwide processing and tight coupling, the overwhelming systemwide optimization process of the tightly coupled systems could lead to failure which propagates quickly to the interdependent systems concluding by disaster (Bierly & Spender, 2016). Furthermore, according to (Charles Perrow, 2011), failure could be a consequence of the technical problems and/or administrative errors which give way to disorders and possibly develop disasters. Emphasizing on the role of complex technology in failures, Perrow accused the use of intensive-technologies of system failure when accompanied with dynamicity and complexity (Bierly & Spender, 2016; Charles Perrow, 1994), that illustrates why Rickover decided to ban intensive automation while designing the nuclear submarine. Building on these, the following proposition was established:

Proposition 6*:* In HROs, failure intolerance endorses the reliability performance and decreases the possibility of error.

3.1.8 Systemwide Process

HROs operations deploy extensive processing functions which are executed in a widely manner such as monitoring, safety inspections and knowledge creation processes (Bourrier, 2011; Milosevic et al., 2018). Systemwide processing stems from the centralized control of HROs systems, wide processing is associated with the centralized strategic coordination that allows coping operations in a systematic manner and accounting for all possibilities of failures. (Charles Perrow, 2011) indicated that, centralization is merely considered the efficient administrative theme to maintain safety in the complex and tightly coupled systems. HROs operations follow rigorous rules of systemwide command, the systems rely heavily on wide processing to assure that all procedures are executed in the most perfect manner, which mind for all subsystems as a part of the general framework. Owing to the high complexity of HROs systems, understanding the interdependences between components becomes compulsory (Williams et al., 2017). Wide processing endorses HROs systems to be aware of the consequential effects of their actions on the interdependent systems while tuning any of the components (K. M. Sutcliffe, 2011). (Pettersen & Schulman, 2019) emphasized the organizational capabilities to adopt the systemwide processing to adapt to the different stages of operations, systemwide processing supports the interdependent systems to recover at the nonroutine time at the stages of operations disruption, failure and recovery.

HROs operations are based on a centralized system design to prevent accidents and achieve reliability performance, centralized command enhances HROs systems' capacity to respond rapidly and proficiently to the abnormalities, which intimidate the system components (Hopkins, 2009). Despite the benefits of systemwide processing and centralization for HROs safety, systemwide processing causes an overwhelming cognitive processing for senior executives to keep accounting for all the possibilities (Bierly & Spender, 2016; olde Scholtenhuis & Dorée, 2014). The activities of accident prevention and disaster control signify the role of systemwide processing, such practices could be across organizations and even countries to help managing the critical events. Moreover, systemwide processing enhances the system capacity to transmit the perturbations rapidly in between systems (Bierly III & Spender, 1995), which could prevent disasters by applying the centralized commands to appropriately amend the general system motions and apply the needed procedures. Building on these, the following proposition was established:

Proposition 7: In HROs, systemwide processing endorses reliability performance and decreases the possibility of errors.

3.1.9 Institutional

A common denominator of HROs is the ability to sustain an outstanding performance over long periods, which stands as an evidence of a high class institutional setting that endorses the system capabilities to maintain reliability and safe operations. (Catino & Patriotta, 2013) addressed that, HROs institutional setting reflects a pattern of efficient control over interactions between safety culture and values from one side, and cognition and emotions on the other side. HROs knowledge system reinforces the strong safety culture which represents the shared knowledge built up through training and learning process (Bierly & Spender, 2016). (Milosevic et al., 2018) deliberated that, the ability to create new knowledge when needed endorses the HROs systems to keep resourceful knowledge repertories and update the operations manual. Retaining reliability performance within complex and tightly coupled systems confirms the efficiency and supportiveness of the knowledge system and communications channels that facilitate the knowledge flows to combine the individuals' knowledge and shapes reliability performance.

While learning from errors is a fundamental practice among the common folk of organizations to ensure safety and promote their performance, HROs systems give trial-and-error learning a very limited opportunity owing to the disastrous consequences of errors (Karl E Weick, 1987). Giving that the reliability performance is supported by a proactive attitude against failure, HROs rely on simulations to improve the quality of training (Clarke, 1993; Enya et al., 2018). Moreover, HROs developed a continuous learning approach to compensate for the difficulty of learning by trialing (Edmondson, 1999; Karl E Weick & Sutcliffe, 2015). Several studies have suggested that, HROs systems leverage continuous learning as a fundamental function of the systems (Catino & Patriotta, 2013; Reason, 2016; Ron, Lipshitz, & Popper, 2006; W. Sutcliffe, 2006; Karl E Weick, 1987), continuous learning permits the organizational structure to develop new knowledge and produce the reliability performance that guides the actions needed to handle complexity and dynamicity (Milosevic et al., 2018; Reason, 1990; Zhao, 2011). Furthermore, by creating the needed knowledge to support handling the present situations it also supports the system to sustain finer engagement in the future situations (Bass & Milosevic, 2018). Building on these, the following proposition was established:

Proposition 8***:*** In HROs, the institutional setting endorses reliability performance and decreases the possibility of error.

3.1.10 Redundant

HROs represent highly redundant systems, HROs include many redundant systems to substitute the primary systems in case of failure. (LaPorte & Consolini, 1991) believed that, the role of redundant systems is to preserve and foster the reliability performance at the time of nonroutine. Furthermore, (Karl E Weick et al., 2008) suggested that, implementing redundant systems is crucial to keep responsive to the potentially hazardous technical issues and prevent failures (Pettersen & Schulman, 2019). However, redundant systems endorse reliability performance and reserve the capacity to cope with the uncertainty of irregular events, redundancy in HROs may take a different form fault tolerant organizations, the chronic preoccupation with failure is one of the key reasons why redundant systems are exist in HROs (Leveson et al., 2009).

According to (Bierly III & Spender, 1995), moderating the relationship between the need for trust in system in one hand, and skepticism and preoccupation with failure on the other hand is a problematic issue in the high-hazard environments. Regarding theories, HRT trusts redundancy to prevent disasters and enhance the fault tolerance capabilities as HROs follows the reliability oriented design (Burgazzi & Pierini, 2007; Clarke, 1993), still **NAT** believes that redundancy increases the systems complexity, which feeds the hazard nature of organizations. However redundant systems is believed to increase the likelihood of normal accidents according to NAT, the theory considers the implementation of the redundancy as an efficient strategy to deal with the corresponding failures while redesigning the systems in high-hazard environments (Burgazzi & Pierini, 2007; Rijpma, 1997; Karl E Weick et al., 2008).

Although HROs systems rely on redundant systems as second layer of protection against failures, (Clarke, 1993) indicated that redundant systems are also subject to accidents. Failure of redundant systems denotes that, the organization has to deal with interdependence of failure events within two systems and take consequences of two propagative failures (McChrystal et al., 2015), Three Mile Island TMI disaster 1979, Pennsylvania USA, was developed by a consecutive failure of primary and secondary cooling circuits in addition to failure of the relief valve – a redundant system - which led to a severe damage for the water reactor (Broughton, Kuan, Petti, & Tolman, 1989). Moreover, investment in the redundant systems represent a heavy cost to the organization budget. Yet, the criticisms to redundancy are justified; either failure or the high cost of redundant systems, but still the wisdom of HROs trust in redundancy is not a question. Building on these, the following proposition was established:

Proposition 9: In HROs, redundant systems decrease the possibility of errors and endorse reliability performance.

3.2 The Framework of Structural Reliability (*FSR)*

The identified characteristics were used to develop the structural based reliability framework (FSR). The proposed framework provides a measure of the reliability of organizations and makes it possible to properly introduce this phenomenon, the measurable framework enhances the knowledge about HROs. Utilizing the FSR to the organizations facilitates the process of assessing the safety performance of organizations working in high-hazard environments. FSR enables to track the progression of the development efforts towards reliable performance and safer operations. FSR comprises 10 characteristics which shape the organizations safety performance, the characteristics are outlined in Table **3**. Two dominant forces were presented in the framework; hazard and safety, these forces interact with each other to produce the reliability performance.

4. Table 3

5. Structural Framework of High Reliability Organizations (FSR)

Dimension	Characteristics	High Hazard organizations HHO An organization working in high hazard context, Consequently, the organization failed to sustain error-free operations and accidents and disasters are inevitable.	High Reliability Organizations HRO An organization which is well financed and boosted to have the right capabilities to prevent failures and disasters under high hazard conditions. Although the operations are nearly error-free, a small fault amid such hazard contexts would lead to a disaster.
Hazard	**Hazardous**	Failures and accidents are unpreventable and The organization does not employ the competencies and expertise needed to response to contingencies events.	The high hazard challenge the organizational capabilities to balance the forces of high hazard and safety and sustain performance by means of accident prevention.
	Tightly Coupled	Tight coupling and interdependences makes the more skeptical to accidents and disasters. Tight coupling spread the failures between the interdependent systems.	Tightly coupled systems are convenient for centralized control and keep the systemwide commands more efficient. Tight coupling endorse accident prevention by spreading transmitting the perturbations and prevent developing errors.
	Complex	Tight coupling contributes to the system complexity which is already exist because of the multidimensional relations between the organization system and surrounding environment. Categorization and simplicity makes the system	The system ensures that, the complex interrelations are well-understood and the complex of hazard operations are well attended and the implications of which, are accounted for.
	Dynamic	Dynamicity requires high responsiveness and timely interactions which are not afforded due to the complexity of operations that creates difficulty to timely adjust and adapt to change.	The system is very sensitive to change in surroundings and actions are migrating to expertise where they are. Furthermore, at the time of nonroutine, the system allows considerable flexibility to neutralize the hazard events.
	Bureaucratic	The practices are pre-established and the hazard consequences cause the system to be crumbling since complex tight coupling technologies are not appreciated as they should be.	The operations are executed following to the operations manual which accounted for relatively all possibilities of hazard events and the prescribed procedures are extensively reviewed. Moreover, reasonable flexibility are allowed at the nonroutine time.

Safety	**Safety Oriented**	The organization would experience tension of competing organizational goals and interests such as production size, and safety goals which make the activities less focused on safety.	Maintaining reliable performance is the main objective of the organizations and all the activities navigate towards the direction of safety. Safety principles govern the operations to ensure that the operations remain error-free and the cognitive processing endorses the decision making processes.
	Failure Intolerant	The organization would be more tolerant to the errors and there is a tendency to find someone to blame for failures which weaken the accident prevention policies and create a tendency to be insensible to problems if they are not directly concern to the individual mission.	In the core of the organizational culture, the failure intolerance is central to preserve the reliability performance, at the time of nonroutine, problems are accurately addressed and resolved with no blame on individuals. At this time, the system takes the opportunity to review the operations procedures and learn new lessons.
	Systemwide processing	While the systems are managed separately, centralization enables the system to deal with the interdependences but still complexity are difficult to be understood in the absence of systemwide processing function.	The system can adjust between centralized control, which fits well with the tightly coupled technologies and decentralized control that facilitates managing the complexity.
	Institutional	The organization benefits from errors as opportunities to learn and create knowledge, these errors are often joined by disastrous consequences. Although the system is luckily engaging in knowledge creation practices, the information accessibility is challenging owing to the dynamicity.	The organizational learning, training, continuous learning and knowledge creations stand as a backbone of the reliability performance, the knowledge system works alongside with the communication channels to provide individuals with the information needed for preserving the reliability performance. The system relies on simulations owing to the failure orientation and intolerance.
	Redundant	Redundant systems increase the probability of disasters owing to the difficulty to control the system since the organization is already experience an overwhelming structural complexity coming from the tight coupling .	At the time of nonroutine, redundant systems are substituting the failed components to preserve the performance, redundancy is significant principle of HROs operations to reduce uncertainty.

6. DISCUSSION

Much discussions about high-reliability performance fluctuate between very optimistic or pessimistic views about the organizational capabilities to survive accidents in high-hazard environments, the optimistic discussions are often from **HRT** theorists against the pessimistic view from **NAT**. Past research tends to be more biased towards one of the two theories, a lack of cohesion in deliberating the structural features of the organizations hinders the development of a general framework that provides an understanding of how safety performance be produced under the high-reliability theme, and how accidents could be prevented under the trying conditions. Previous discussions have shifted the focus from what makes the organizations risky to what makes them safe regarding the stand point of the researchers from ***Safety I*** or ***Safety II***. However, in this research, the mixed method research was employed to identify the common features of organizations working in high-hazard environments to develop a general framework of HROs. To avoid the organizational bias while developing the framework, the insights from the interviews in stage one were validated by the characteristics of organizations from the literature in stage two.

HROs count on the safety measures of reliability performance to improve safety in operations, achieving high-reliability performance denotes that the organizations have demonstrated the capabilities which enabled preventing the errors that could lead to disasters. Within high-hazard environments, the inherent imperfections of human capabilities could seriously undermine the performance and prevent sustaining reliability performance. Therefore, individuals are required to develop a positive attitude towards failures and bound by the safety codes and afford an active engagement in operations. Giving the fact that, not all hazard situations would present warning signs, instead of relying on expectations, individuals are needed to have an adequate understanding of the challenging conditions of their workplace since relying on expectations would serves as hazardous frame of reference owing to the hazard nature that hinders their abilities to predict and prevent potential disasters.

Regarding the theoretical perspectives, integrating the characteristics into an organizational framework cannot be an instant action, adopting the characteristics of HROs has never been, nor could it be an easy quest but rather the organizations need to scrape through the reliability passage day after day to obtain a safer performance under the risk of hazard events. Regarding the correlation between reliability and resilience, both capabilities stands for significant asset of the organizations, while reliability performance works as a shield that significantly decreases the probability of failures, resilience enhances the ability to survive the disasters and keep moving forward. From NAT point of view, resilience would be more favorable for organizations to survive since organizations could not prevent the accidents. Nevertheless, reliability and resilience are complementary terms and none of them would be a substitute for one another.

6.1 FSR as a Source of High-Reliability

The proposed framework associates the characteristics of the organizations with the determinants of safety and hazard in Figure 1. The interactions between the determinants of safety and hazard promotes the system capability to manage the risk factor attached to hazard events. Further, the structural framework is a key determinant to achieve the reliability performance however, solely it cannot explain how HROs limit the risks of hazard events and operate safely in high-hazard environments. Figure 2 incorporates the hazard and safety forces in relation to the characteristics to illustrate how organizations manage hazard and uncertainty within the framework. HROs are required to consider the impact of hazard events in their operations so as to afford the convenient technical and intellectual capabilities to prevent any developing contingencies and resolve the paradoxical implications which are embraced from the continuous interaction between hazard and safety forces, the interactions shape the practices within the organizational framework. While tight coupling and high complexity of systems feed the hazard forces of HROs, reliability performance significantly benefit from this combination that provides insightful lessons for organizing safety work in high-hazard environments. HROs operations tend to be more committed, attentive and responsive to hazard events owing to the dynamicity and relatively bureaucratic control of HROs systems. On the other hand, the institutional setting and employment of redundancy feed the safety inclinations of HROs systems. Safety orientation and failure intolerance are governed by systemwide processes which endorse the HROs operations.

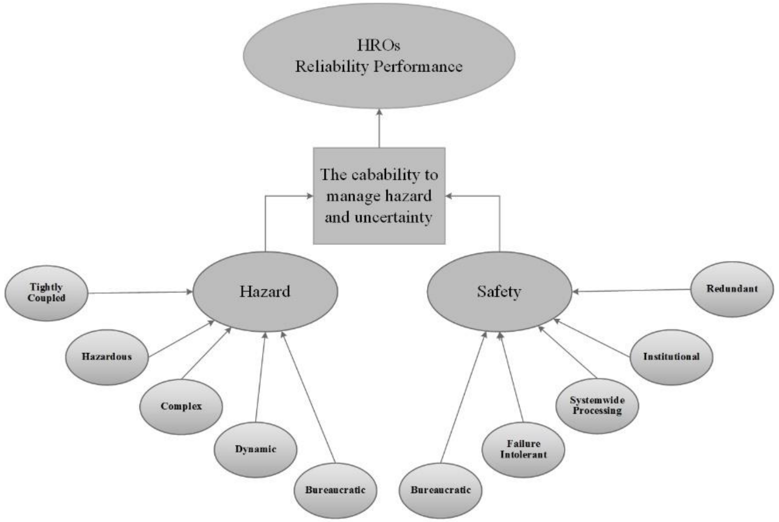

Figure 1

Figure 2

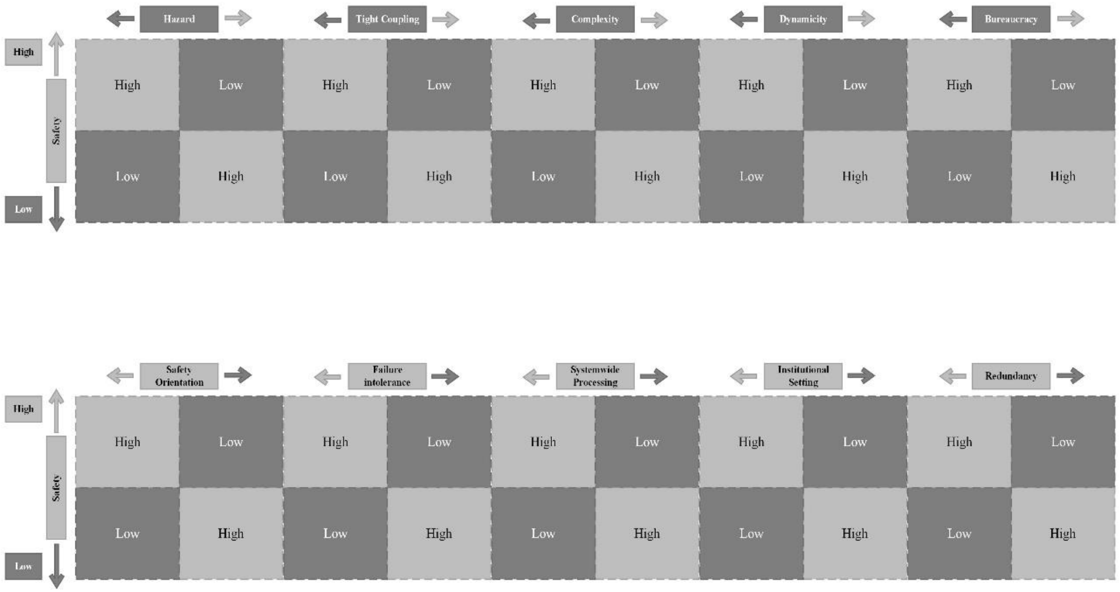

Figure 2

Although the organizational scholars could have a common understanding of what HROs are, to our knowledge there is no unified definition in the literature. In this respect, a common definition of HROs will provide a better understanding for scholars and practitioners. Mostly the researchers define HROs in a narrow sense of their research environments, many definitions are focused on certain features, what makes the definitions incomplete or even have little relation to the theoretical insights or the original objectives of HRT founders. Previous definitions disregard the unique nature of HROs and make it problematic to find a consensus description of HROs. Therefore, FSR framework and HROs characteristics were carefully considered to provide a comprehensive definition of high-reliability organizations. HROs represent the combination of organizational mindful practices, advanced technologies and standardized systemwide processes, which qualify the system to operate reliably under risky, high complex and hazardous environments, the system can predict, prevent and control hazard events in operations at acceptable levels of performance and sustain the availability of services with outstanding safety records over long periods.

The definition highlights five key points, the role of management in operating HROs safely in respect to organizational mindfulness (Karl E Weick et al., 2008), complex technology involvement, high-hazard environment and the safety records sustainability in respect to **NAT** (Charles Perrow, 2011) and the strong organizational culture (Bierly & Spender, 2016). Furthermore, the ability of the systems to foresee the risk sparks together with the ability to engage and correct the hazard events represent significant qualities of HROs operations. HROs systems possess the ability to bounce back quicker and stronger than any other organizations by means of their capacity to manage high complex interdependent technologies under the conditions of high-risk (Charles Perrow, 1994; K. M. Sutcliffe, 2011). the findings of this research inconsistent with (Charles Perrow, 2011) proposal to evaluate the performance of organizations working in high-hazard environments as a binary classification, **NAT** suggests that the systems are either reliable and functional or hazardous which is considered of low credibility.

6.2 The Organizational Forces

6.2.1 Safety Forces

Preserving the high-reliability performance represents a joint venture. At the organizational level, the tightly coupled systems are needed to work in harmony to employ the organizational resources efficiently. The enactment of mindfulness is required to sensibly guide decisions and behaviors towards obtaining reliability performance, the organizational mindfulness govern the practices of recruiting, training, monitoring and maintenance. Mutual auditing is required to assure that individuals comply with the standardized and rigorous procedures to prevent accidents and produce high-reliability performance. Regarding the bureaucratic control, at the time of nonroutine, relatively flexible control is needed whence expertise intervention would prevent developing contingencies and system failures. At the individual level, adequate training and experiences are obligatory for compelling to the prescribed procedures. The knowledge system uses continual awareness as a foundation to learn and generate new knowledge which is needed for understanding the complex system and be able to attune to the customary and unfamiliar signals. At the macro level, the role of government policies is to obligate the HROs to bind with the chains of the laws and standards towards assuring stability of the industries and reliability of operations. Moreover, the government moderates the interrelations between organizations to create a supportive environment to share the knowledge and expertise needed for controlling the dynamic systems and prevent disasters across organizations.

Safety orientation and failure intolerance are two fundamental principles of HROs, these principles outline the activities within the framework. Complying with these principles, individuals utilize the systemwide controls to accommodate routine and nonroutine events and avoid failures. Regarding the institutional setting, the high-risk of hazard events, failure intolerance and safety orientation denote that, trial based learning and training are relatively forbidden due to the high uncertainty accompanying experimentations. Similarly, introducing new technologies to HROs is criticized for the same concerns. Differently, in failure-tolerant organizations, imprinting the key characteristics of HROs to the framework would induce a structural reforming process which inspires technological improvements to achieve reliability performance. Drawing on anthropological perspectives of HROs environments, this research suggests that, a well-built organizational culture underlies the collective efforts to produce reliability performance, augmented practices are being employed into the formal and the informal aspects to make the decisions based on logic. In turn, the well-established institutional setting endorses the reliability culture to handle the process of acquiring the organizational culture throughout stages of training, observing and performing according to the safety standards.

6.2.2 Hazard Forces

The risk of hazard events in HROs operations represents a motivation to achieve the high-reliability performance, paying attention to the severe hazard in operations induces the system to adopt convenient principles and procedures which are needed to control the potential failures. Failure to appreciate the hazard nature of HROs operations carries risks that the powerful tightly-coupled complex systems could be so erratic in the high-hazard environments, the disastrous consequences affecting equipment and individuals. Dealing with high-hazard systems requires interventions from two perspectives; accident prevention and adopting a rigorous attitude towards the inconvenient technologies or practices which are considered unfitting for the hazard contexts and possibly lead to failures. Furthermore, hazard nature motivates the organization to stay continuously striving for safety and maintain reliability performance which would be a major disaster when the organization takes it as a stopping place rather than a way station on the endless pursuit of reliability.

While tight coupling makes the operations more complex and allow failures to spread smoothly between the interconnected systems, it also facilitates the systemwide processing in operations commands which becomes a must within the highly interdependent systems to preserve reliability performance. Furthermore, dynamicity aligns with tight coupling to increase the complexity of systems by speeding up the propagation of errors to develop complex disasters. In the contrary, dynamicity enhances the effectiveness of the knowledge system to create new knowledge and update the knowledge repertories to promptly detect, correct, and carefully analyze errors while going through nonroutine events. In the meanwhile, the bureaucratic control limits the ability to create new knowledge in the routine time since the system trusts the known procedures to respond appropriately and neutralize the hazard. There is tension exists in the system because of the bureaucratic control needed for stabilizing the reliability performance and the urge to disregard the standardized procedures at the time of nonroutine.

7. CONCLUSION AND FUTURE DIRECTIONS

Preserving safety is the ultimate goal for HROs, operations in high-hazard environments are luckily to develop disasters with consequences of massive destruction, and even loss of human life. Giving that the missions of HROs are essential for the economic and social systems, preventing accidents in such organizations attracted high attention from scholars, practitioners and governments owing to the high cost of failures which outweigh the expected benefits. This research adopted mixed method of interviewing and literature review to understand how HROs sustain safety in operations over long periods, and develop the structural based reliability framework FSR which incorporates the seeming traits of the organizations with the organizational forces that shape the reliability performance. The long experiences of interviewees and from the grasp literature provided the empirical evidence needed for validating the characteristics combined in the organizations framework. Based on **FSR**, reliability performance represent a combination of high quality practices of recruiting, training, learning and auditing in presence of supportive policies with reference to the safety measures and accident prevention programs, which provide a solid foundation for consistently safe performance. This research contributes to the organizations literature by defining key characteristics and terms of reliability organizations in relation to the real-world experience of HROs but still not clear how to assess these characteristics. Therefore, the findings of this research suggest that, there is a need for more empirical research to evaluate these characteristics to know to what extent they contribute to the safety of organizations. There is a need for more study about the benefits of mindfulness practices to enhance the self-awareness and attention and how that contribute to the safety of organizations. Furthermore, the structural framework can be standardized and applied across organizations in different industries to anticipate whether the structure of the organization would produce reliability performance or not and also learn about their competitiveness regarding the managerial practices within high-hazard conditions.

8. ACRONYMS

FSR: Framework of Structural Reliability

HRT: High-Reliability Theory

NAT: Normal Accident Theory

RE: Resilience Engineering

HROs: High-Reliability Organizations

HHOs: High-Hazard Organizations

HRA: Human Reliability Analysis

JSA: Job Safety Analysis

ATC: Air Traffic Control

BMC: Bayesian Monte Carlo

PN: Petri Nets

eBN: enhanced Bayesian Network

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