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A Framework for Adaptive Capacity in Complex Systems

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A FRAMEWORK FOR ADAPTIVE CAPACITY

IN COMPLEX SYSTEMS

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ABSTRACT

A FRAMEWORK FOR ADAPTIVE CAPACITY IN COMPLEX SYSTEMS

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Complex systems are characterized by their high level of inter-connectivity, ambiguity, and emergence. Therefore, a failure in one element of a system (e.g. cyber layer) due to external or internal disturbances can lead to a cascade effect that may influence all elements of the system. Consequently, the complex system will not be able to perform its functional performance. Threats related to complex systems are very dynamic, fast, complex and damage can be severe. Thus, to respond to the dynamic and unpredictable nature of these threats, complex systems need to be highly adaptive to survive and thrive in the face of adversity. Adaptive capacity gives the system the ability to adjust and cope with the new circumstances and conditions resulting from an adverse event.

This research addresses the gap in the literature by developing an assessment instrument that captures the key organizational factors necessary for developing and monitoring adaptive capacity in complex systems. These organizational factors serve as criteria to measure the adaptive capacity and improve resilience as well. The presence of these criteria is critical to any complex system, without which resilience is unlikely to be maintained.

To develop the assessment instrument, a four-phase research design approach was developed and executed. A grounded theory approach was employed to establish organizational criteria for the adaptive capacity assessment. More than one hundred diverse data sources were analyzed and coded to identify organizational factors that determine adaptive capacity in complex systems. After deriving the organizational criteria, an assessment instrument was developed. The assessment instrument consists of thirty-eight organizational criteria grouped into nine categories. This assessment instrument was then validated by subject matter experts. The experts have provided positive feedback that the proposed instrument is viable and adequate to accomplish its stated purpose.

This dissertation is dedicated to my mother, Moziah, and my father, Saleh. To my wife, Layla, and my daughters, Yara, Sarah, and Laura. To my brothers and sisters.

You are all the love of my life.

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CHAPTER I

INTRODUCTION

BACKGROUND

"Complex systems almost always fail in complex ways" (Columbia Accident Investigation Board, 2003, p. 6). Accidents and disturbances in complex systems do not usually happen due to one single cause, but a combination of various issues that occur in a more complex manner. In complex systems, unanticipated threats that may disrupt a system's functions and normal operations are common. Therefore, care must be taken to address the underlaying flaws and the inherent characteristics of the system that contribute to any complex disturbance. Without a comprehensive analysis of the whole system and understanding of all its technical, organizational, and cultural elements, there will be little to achieve in mitigating potential adverse events.

Enhancing a system's resilience is a keystone when dealing with complex disturbances. Disasters in complex systems happen through a chain of signs and symptoms of flaws and weaknesses in the system. Stead and Smallman (1999) discussed the crises cycle that consists of five phases (Figure 1). It starts with a *pre-conditions* phase that includes incubation of some unnoticed signals and flaws. This phase is followed by a noticed *triggering event* that directly leads to the occurrence of the real *crises*. After that, the organization tries to respond to these crises and manage the situation to recover to its normal operations. Once the *recovery phase* is achieved, the organization reaches the process of assessing lessons learned from the crises.

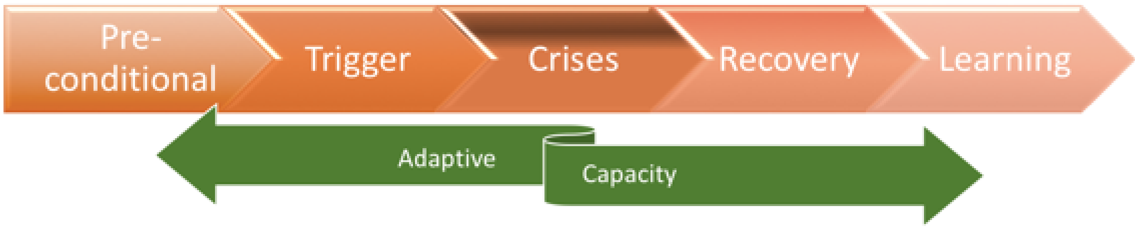

Figure 1. Disaster Life Cycle and Adaptive Capacity (Stead & Smallman, 1999)

Since it is almost impossible for complex systems to identify all risks before an occurrence, the question remains: how can complex systems deal with unanticipated threats? Mayntz (1997) provided an imperative analysis of disasters in complex systems where he developed his analysis based on four pillars. He argued that all complex systems are 1) vulnerable to internal and external adverse events, 2) complex systems must respond to these events, 3) complex systems will fail if they cannot cope and adjust their internal dynamics to the consequences of the crises, and 4) a balance between the system's requirements and the adverse event facing the system is important to achieve an effective response. Further, he emphasized that the ability of complex systems to cope to the new consequences following a disturbance is key in enabling the system to survive any crises.

Adaptive capacity as a mature concept is more commonly used in ecological and environmental change research (Engle, 2011; Gallopín, 2006; Nyamwanza, 2012; Smit & Wandel, 2006). The notion of adaptive capacity can be described as the ability of a system to quickly adjust to change and cope with the new circumstances resulting from a disturbance.

A system’s adaptive capacity to disturbances comes in two forms: first and second-order adaptive capacity (Lee et al., 2013; Woods & Wreathall, 2008). First-order adaptive capacity manifests once a system experiences a disturbance, and this reaction is based on predetermined planning. Second-order adaptive capacity becomes apparent when new capabilities emerge from the system in response to a crisis (Woods & Wreathall, 2008).

As systems advance and become more complex, the need to assess and enhance their resilience and adaptive capacity in the face of disturbances becomes more critical. This research focuses on identifying the organizational characteristics that are necessary to enable adaptive capacity in complex systems. The outcome of this research will help a wide range of complex systems to evaluate their adaptive capacity and boost their ability to adapt and cope with change and become more resilient systems.

The following section provides an overview of this study. It starts with explaining the significance of the study, its purpose, as well as the research questions. At the end of this chapter, definitions of the key concepts related to the study are presented.

RESEARCH SIGNIFICANCE

With the exponential increase in complexity and disturbances, organizations need to constantly monitor and enhance their resilience capabilities to withstand any adverse event. However, building resilient systems is challenging, especially with today's interrelated and dynamic business environment. Due to their nature, complex systems are prone to internal and external disturbances, and there is no system fully immune to face these threats. One of the great challenges facing decision-makers is how to prepare for unknown and unanticipated risks. The traditional risk management approaches that focus on a myopic identification, assessment, and mitigation of risks is not sufficient to deal with complex problems (Sikula et al., 2015). Therefore, it is important to augment the traditional risk management approaches with a new model that focuses on preparing the system to successfully deal with unanticipated risks.

All planning efforts that aim to respond to and manage risks and crises will not succeed without effective enablers and strong systems' qualities. These enablers and qualities are usually organizational elements that reflect the well-being of the system. Building system resilience through focusing on these enabling components is a cornerstone in this process, as resilient systems need to adapt to and cope with disturbances once they occur.

Recently, the concept of resilience has been increasingly used to describe the behavior of systems under disruption, and several measures of resilience have been offered (Park, Seager, Rao, Convertino, & Linkov, 2013; Sikula et al., 2015). Resilience is an essential property in every successful organization. It represents the ability of the system to withstand and respond to any disturbance while quickly recovering its normal operations. Complex systems are attributed to a high level of uncertainties, emergence, and ambiguity. Resiliency provides organizations with the necessary capacity to handle any challenge that may emerge. One of the main components of the system's resilience is the system's adaptive capacity. The notion of adaptive capacity is not as widely discussed in many disciplines as in environmental research (Engle, 2011; Gallopín, 2006; Nyamwanza, 2012; Smit & Wandel, 2006).

Although adaptive capacity is an essential component in every resilient complex system, the existing literature lacks any tool or method to assess an adaptive capacity in complex systems. This research contributes to the body of knowledge by expanding the discussion around adaptive capacity into the engineering management, systems analysis, and risk management landscape.

Table 1 provides an overview of the main contribution of this research on three levels: theoretical, methodological, and practical.

Table 1. Research Contribution Dimensions

Level	Research Contribution
Theoretical	- The notion of adaptive capacity is still an under-researched area in many disciplines. This research expands the discussion of adaptive capacity into the field of engineering management and systems engineering through a rigorous research design which uses the grounded theory approach to establish new determinants of adaptive capacity in complex systems.
Methodological	- This research uses grounded theory in analyzing datasets from diverse sources, including journal articles, government publications, technical white papers, and investigative reports; - The identification of organizational criteria that are suitable to assess complex systems; - The development of an adaptive capacity instrument that is validated by subject matter experts to measure adaptive capacity.
Application	- The results of this study will be useful to many organizations, as they provide: - An assessment instrument that can be applied in various industries as it captures key organizational factors that exist in all modern organizations; - A critique of the weaknesses and highlight of the strengths of adaptive capacity in complex organizations; - A guide for decision-makers to make informed decisions in light of their assessment results.

The following elements summarize the importance of assessing adaptive capacity in complex systems.

1. Adaptive capacity is usually treated as one component of resilience without clear determinants and indicators that makes it unmeasurable. This research contributes by operationalizing the notion of adaptive capacity into a more meaningful concept through decomposing the broad concept into specific core elements that can be measured and tested.
2. Identifying and characterizing the adaptive capacity criteria is essential for examining whether a complex system can adapt to internal and external disturbances.
3. Providing criteria to assess the level of preparedness and readiness to adapt to unanticipated disturbances and sudden changes in the system.
4. Guiding decision-makers to adaptive capacity's areas of strengths and weaknesses for proper actions. Testing the organizational capabilities through the application of an assessment instrument during the normal times can have great impact on improving the deficiencies within the system.
5. Helping decision-makers to efficiently allocate their resources to improve adaptive capacity and mitigate negative consequences of future disturbances.

RESEARCH PURPOSE

The purpose of this study is to develop an instrument to assess the organizational factors that enable and promote adaptive capacity in complex systems. This study will tackle the issue of adaptive capacity in complex systems from an organizational perspective. The research builds upon the previous resilience literature to develop a new instrument to measure the ability of complex systems to navigate adverse events through adaptive capacity.

The intended users of the suggested instrument are policy and decision-makers, practitioners, researchers, and any entity that is concerned with adaptive capacity, resilience, and complex systems. The next section discusses the research questions that guide this study, followed by the definition of the main concepts.

RESEARCH QUESTIONS

For the purposes of this research, there are two primary research questions:

Question 1: ***What criteria are needed to assess adaptive capacity in complex systems?***

Before assessing adaptive capacity in complex systems, it is important to explore and identify the criteria that can be used in this process. The literature lacks any metrics that can help in assessing the ability of complex systems to show adaptive organizational behavior during crises. This question focuses on capturing the organizational factors that are critical to achieving adaptive capacity.

Question 2: ***How can an instrument to assess adaptive capacity in complex systems be developed?***

This question builds upon the outcomes of the first question. After identifying the criteria, the next step is to develop an instrument that can assess adaptive capacity and highlight the strengths and weakness of the system. This step is imperative in translating the results of this research into a practical instrument that can be used in the real-world, particularly in the Engineering Management and Systems Engineering (EMSE) fields. Figure 2 shows the basic research inquiry structure that highlight the research significance, research purpose, and research questions.

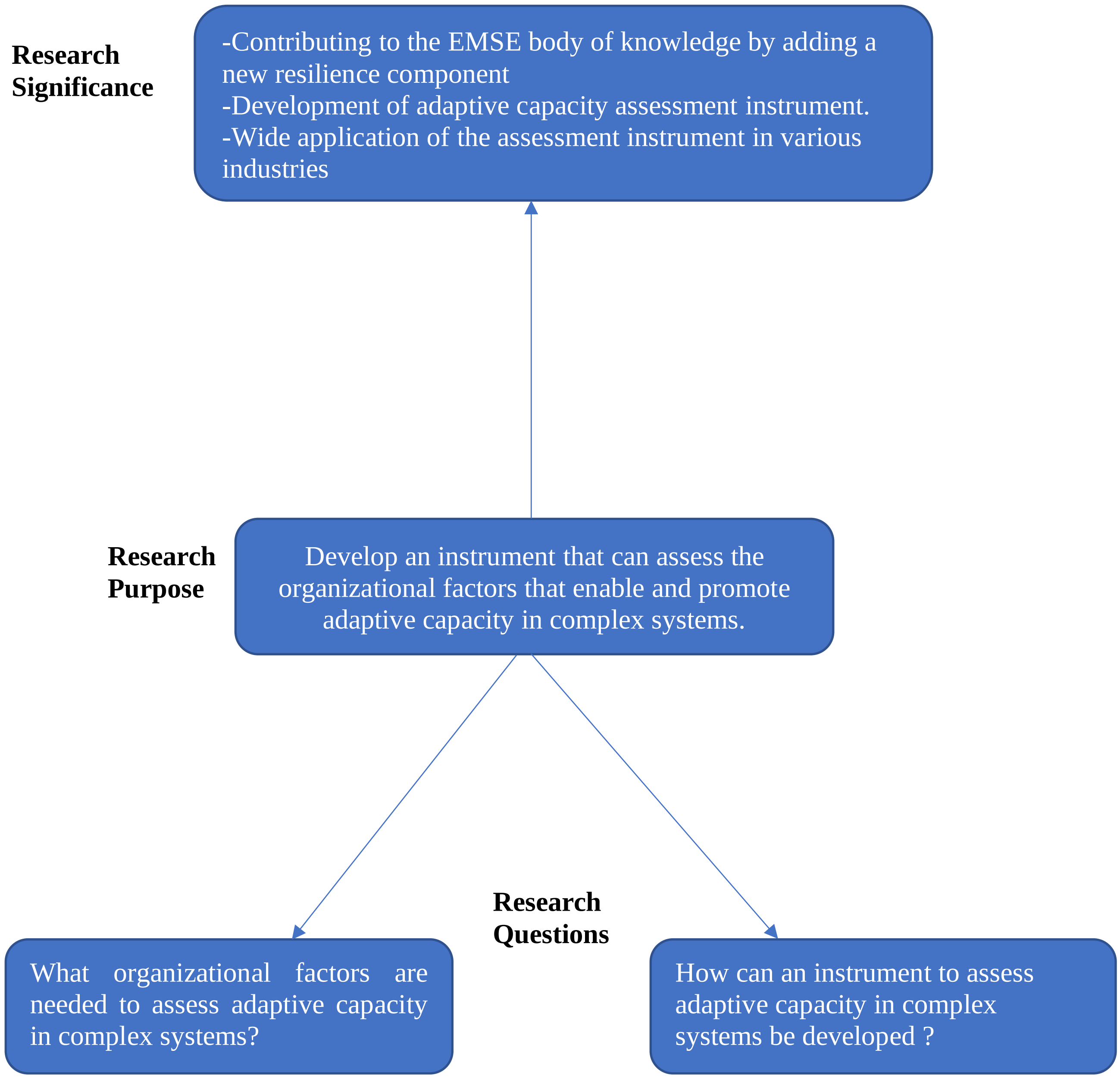

Figure 2. Research Inquiry Structure

DEFINITIONS OF KEY TERMS

Scientific terms and concepts have multiple definitions in the literature depending on the field and context. In this research, terms, such as disturbances, adverse events, crises, stresses refer to the same meaning and are used interchangeably. For the purpose of this research and to provide clarity in the research contexts, these definitions are provided.

Adaptive Capacity

Multiple definitions of adaptive capacity in the literature mostly emerge from the environmental research and ecology fields. Table 2 elaborates on these definitions. For the purpose of this research, the concept of adaptive capacity is defined as the ability of a system to quickly adjust to change and cope with the new circumstances resulting from a disturbance.

Resilience

Erol et al. (2010) define resilience as “the capacity to decrease vulnerability, the ability to change and adapt, and the ability to recover quickly from disruption.” Using this definition, the following metrics were identified: “(1) an enterprise’s capability to decrease its level of vulnerability to expected and unexpected events, (2) its ability to change itself and adapt to changing environment; (3) its ability to recover in the least possible time in case of a disruptive event” (p. 1).

Complex Systems

Keating et al. (2005) provided a comprehensive definition of a complex system as "a bounded set of richly interrelated elements for which the characteristic of structural and behavioral patterns that produce system performance emerge over time and through interaction between the elements and with the environment" (p. 200).

CHAPTER SUMMARY

This chapter introduces this research by discussing the background of the study, explaining the importance of resilience in complex systems and the key role of adaptive capacity in enhancing the ability of these systems to survive and thrive. Moreover, this chapter discusses the significance of the study from three perspectives: theoretical, methodological, and practical. Besides, the main research questions developed for this study are introduced along with a discussion of the purpose of developing an instrument to assess organizational factors of adaptive capacity in complex systems. This chapter concludes with an overview of the definitions of the main concepts used in this study.

The next chapter will examine the related literature around the concept of adaptive capacity, its themes and assessment methods, as well as complex systems' characteristics.

CHAPTER II

LITERATURE REVIEW

The literature review is divided into five sections. First, this chapter starts with a review of the concept of adaptive capacity in the literature. Second, a discussion of the key related concepts to adaptive capacity, including resilience, vulnerability, and robustness are presented. Third, common themes of adaptive capacity are reviewed. Fourth, existing adaptive capacity assessment methods are covered. And finally, a detailed discussion of complex systems and their characteristics are included.

The sources of the literature review come from various disciplines, including but not limited to risk management, organization theory and management, systems theory, disaster planning, and environmental research (refer to Figure 3).

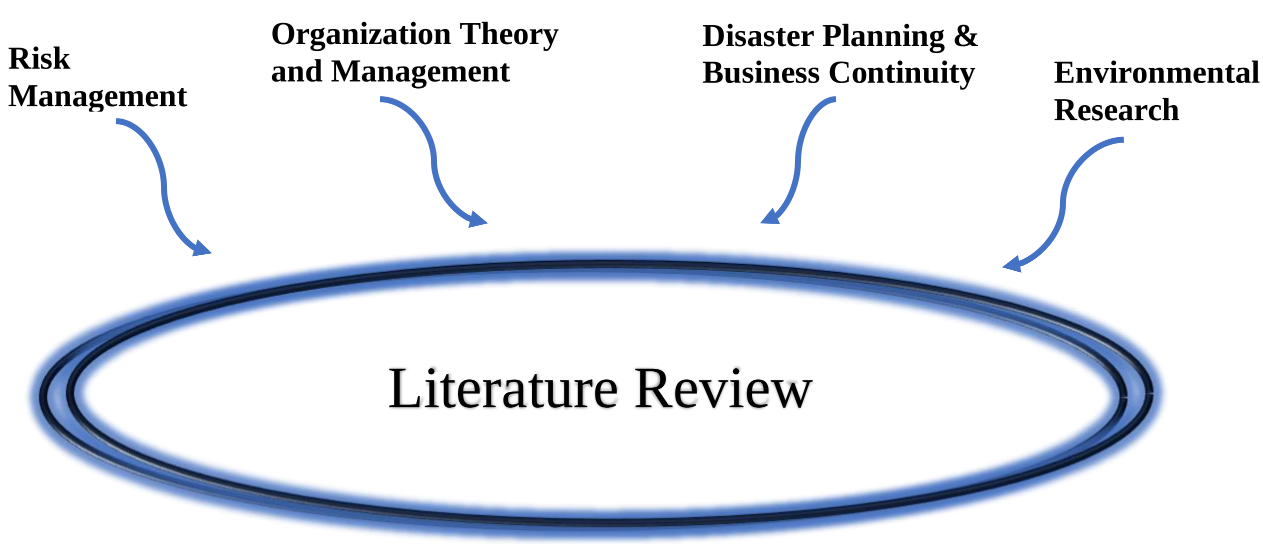

Figure 3. Literature Review Field Sources

Adaptive Capacity

The notion of adaptive capacity is widely used in ecological and environmental research. There are multiple definitions of adaptive capacity in the literature (refer to Table 2). The concept of an adaptive capacity can be described as the ability of a system to quickly adjust to change and cope with the new circumstances which resulted from a disturbance.

The conventional engineering approach is to design systems that are robust and less vulnerable to adverse events (Dalziell & Mcmanus, 2004). The resilience of systems can be boosted by increasing their adaptive capacity. According to Dalziell and Mcmanus (2004), there are three ways to improve a system’s adaptive capacity:

- Leveraging the existing resources in the system. This would allow the system to utilize its available capabilities to respond to any disturbance.

-Leveraging the existing resources in the system but with a new context to address any emerging event.

-Using novel and innovative approaches to tackle the emergent problem.

A system that is constantly exposed to complex problems and uncertain conditions should focus on how to self-organize its internal components and build its capacity to adjust to any adverse event. For example, Justice et al. (2016) tackled the issue of the U.S. container ports’ related risks. The key objective of their work is "how U.S. container ports may adapt to changing circumstances through innovation and the emergent outputs of self-organized agents (components) of their port organizations" (p. 179). Therefore for complex systems problems, the best approach to deal with uncertainty is to adapt and adjust the system's internal components to handle the threats and opportunities (Jansen et al., 2011).

Table 2. Definitions of Adaptive Capacity in the Literature.

Study	Definition of Adaptive Capacity
Smit et al., 2001, p. 881	"the potential or ability of a system, region, or community to adapt to the effects or impacts of climate change."
Walker et al., 2004, p. 1	"Adaptability is the capacity of actors in the system to influence resilience."
IPCC, 2001, p. 982	"The ability of a system to adjust to climate change (including climate variability and extremes), to moderate potential damages, to take advantage of opportunities, or to cope with the consequences."
Dalziell & McManus, 2004, p. 6	"Adaptive capacity reflects the ability of the system to respond to changes in its external environment, and to recover from damage to internal structures within the system that affect its ability to achieve its purpose."
Adger, 2006, p. 270	"Adaptive capacity is the ability of a system to evolve in order to accommodate environmental hazards or policy change and to expand the range of variability with which it can cope."
Vugrin, et al., 2010, p. 7	"Adaptive capacity is the degree to which the system is capable of self-organization for recovery of system performance levels. It is a set of properties that reflect actions that result from ingenuity or extra effort over time, often in response to a crisis situation. It reflects the ability of the system to change endogenously during the recovery period."
Cutter et al., 2008, p. 600	"Adaptive capacity is defined in this literature as the ability of a system to adjust to change, moderate the effects, and cope with a disturbance."
Proag, 2014, p. 374	"Adaptive capacity is the ability to adapt to the event."
IPCC, 2007, p. 869	"The ability of a system to adjust to climate change to moderate potential damages, to take advantage of opportunities, or to cope with the consequences."
Staber & Sydow, 2002, p. 410	"Adaptive capacity refers to the ability to cope with unknown future circumstances."

It is important to distinguish between adaptive capacity and complex adaptive systems (CAS). The distinction is drawn based on the following two aspects:

- **The description and the structure**: CAS is a system that reflects high patterns and self-organization processes among its constituents, while adaptive capacity is a property of a complex system with certain core elements necessary for its viability.

- **The context**: Adaptive capacity in hand is a property that complex systems should possess in order to boost resiliency in the face of disturbances. Therefore, the context here is about resilience and risk management.

Adaptive capacity is especially suitable for organizations with a complex nature and predisposition to unanticipated adverse events. For example, Staber and Sydow (2002) indicated that building adaptive capacity is the most appropriate approach to achieve organizational effectiveness in volatile and dynamic environments. They identified three structural elements of adaptive capacity: 1) multiplexity, 2) redundancy, and 3) loose coupling.

One of the common challenges that researchers face is that the terms of adaptive capacity resilience and vulnerability are often used by different disciplines with different meanings (Dalziell & McManus, 2004). Vulnerability is one of adaptive capacity's related concepts in the literature. Vulnerability is a state that is rooted in the structure of the system, while adaptive capacity is a property of the system with specific characteristics/factors that enables the system to move to less vulnerable conditions. The more adaptive the system, the less vulnerable it becomes (Erol et al., 2009). According to Luers et al. (2003), a system's adaptive capacity can reduce its vulnerability in three ways: 1) decreasing the sensitivity to serious disturbances, 2) less system exposure to disturbances and 3) shift in the system's position relative to the threshold of damage.

According to Dalziell and McManus (2004), the system reflects a high vulnerability as it moves from its stable state once it is hit by a disaster. Following the disaster, the system exhibits a large envelope of adaptive capacity to return to its original stability. The large envelope of adaptive capacity required an investment of large resources due to the low level of adaptive capacity prior to the event. On the other hand, the system exhibits low vulnerability as the system's adaptive capacity was able to bring it back to its equilibrium position with a lessened investment of resources. Both situations indicate that systems with high adaptive capacity before the emergent event can return to their normal operations more quickly and with a lessened use of resources. Another important takeaway is that adaptive capacity should be an inherited quality of the system that manifests once the system is impacted by a disturbance.

There are three metrics related to adaptive capacity in enterprise systems. First, the ability of an enterprise to reduce its vulnerability to anticipated and unanticipated adverse events. Second, the ability to adjust and adapt to the dynamic environment. And third, the ability to recover in the shortest time possible following a disturbance (Erol et al., 2010).

Scholars in the environmental change literature discussed some factors that can influence adaptive capacity. These factors include but are not limited to technology, communication, financial and economic resources, infrastructure, information and skills, equity and quality of institutions (Adger, 2006; Cutter et al., 2008; Engle, 2011; Engle & Lemos, 2010; Nyamwanza, 2012; Smit et al., 2001; Smit & Wandel, 2006).

RELATED CONCEPTS TO ADAPTIVE CAPACITY

This section discusses three main concepts related to adaptive capacity in the literature, namely vulnerability, resilience, and robustness.

Vulnerability

The most common description of vulnerability is the susceptibility of a system to harm (Burton et al., 2002; Luers et al., 2003; Proag, 2014; Smit et al., 2001; Smit & Wandel, 2006). The notion of vulnerability started with social science, yet the application of this concept has made its way to various disciplines and traditions, including organizational management, engineering, and systems analysis, economics, geophysical sciences, information systems, psychology, environmental science, and politics (Adger, 2006; Dalziell & Mcmanus, 2004). All these disciplines have contributed to the evolving understanding of vulnerability. In the disaster research, for example, vulnerability means the physical exposure to harm with a combination of the human capacity to withstand and recover from the disaster (Dalziell & Mcmanus, 2004). While in engineering, vulnerabilities represent weaknesses in the design, requirements, and implantation through which the system can be compromised (Elahi, Yu, & Zannone, 2010).

Resilience

The concept of resilience made its first appearance in ecological research by Holling (1973). He defined resilience as ‘‘a measure of the persistence of systems and of their ability to absorb change and disturbance and still maintain the same relationships between populations or state variables" (p.14). Understanding resilience has evolved over time as it has gained more attention from different scholars in different contexts. For instance, Walker et al. (2006), defined resilience as the capacity of a system to experience disturbances while maintaining the original structure, functions, feedbacks, and thus, identity. Most of the resilience definitions across different disciplines highlight two themes: 1) the ability of a system to withstand risks and disturbances, and 2) the ability of the system to quickly recover to its original state. Some scholars perceive resilience as the opposite of vulnerability in which more resilience means less vulnerability and vice versa (Erol et al., 2010; Erol et al., 2009).

Some scholars indicated that there are two kinds of resilience in the literature: ecological resilience and engineering resilience (Dalziell & Mcmanus, 2004; Gallopín, 2006; Gunderson & Pritchard, 2002). Engineering resilience focuses on the speed at which something recovers from a disturbance. On the other hand, ecological resilience focuses on maintaining the system's functionality. Therefore, the ecological resilience approach is the most suitable type of resilience for complex organizations as it allows the system to function in the face of disturbances even without full performance and efficacy (Dalziell & Mcmanus, 2004).

Robustness

Robustness is an antonym of vulnerability (Aven, 2011; Scholz et al., 2012). Robustness is the system's property to account for all known threats during the planning and designing phase. In other words, robustness is a proactive quality of a system that makes it strong in the face of variations and perturbations that can lead to system failure.

After introducing these concepts and their definitions, the next section discusses the relationship between adaptive capacity and these three concepts in more detail.

THE RELATIONSHIP BETWEEN ADAPTIVE CAPACITY, RESILIENCE, ROBUSTNESS AND VULNERABILITY

Adaptive Capacity and Resilience

Adaptive capacity gives the system the ability to quickly adjust to emergent changes (resulting from internal dynamics or external perturbation) and if needed modify and transform its structure, relationships, operations, management systems, and governance to withstand any disruption risk. On the other hand, resilience gives the system the capacity to absorb shocks while maintaining the same structure, functions, and feedback (Walker et al., 2006). Resilience - in its fundamental definition - means to bounce back, where the system, after a perturbation, should recover to its original state (Engle, 2011; Hashimoto et al., 1982; Nyamwanza, 2012).

Adaptive capacity can accommodate the system's transformability, and thus, a system with a higher adaptive capacity has more flexibility and adaptability in dealing with stresses as it can modify and transform its structure to cope with the new emergent changes. For example, some scholars argue that the notion of resilience is not always desirable as compared to adaptive capacity (Engle, 2011; Walker et al., 2006). This is because the system-maintaining property (resilience) is not always a positive property, especially at times when it is necessary for the system to transform to a new state when the original state is undesirable.

Adaptive capacity and resilience are two concepts that overlap and intersect based on how they are defined and perceived (Fiksel, 2006). Scholars, like Folke (2006), expanded the definition of resilience to include system's transformability as a property of resilience if the original state is not desirable. His new definition makes adaptive capacity a key component of resilience. However, there is no consensus among resilience scholars on the expanded definition of resilience (Engle, 2011). Erol et al. (2009) suggested that enhancing a system's adaptive capacity automatically means enhancing the resilience of the system.

Robustness and Resilience

Contrary to resilience, robustness accounts for the known threats, while resilience deals with unknown threats and uncertainty of the system (proactive and reactive) (Aven, 2011). Robustness, therefore, is seen as a key component during the planning and designing phase of a system. It is also considered a static property of a system that does not have the dynamic quality of resilience (Scholz et al., 2012).

Vulnerability and Adaptive Capacity

One of the definitions of adaptive capacity is the extent to which the system can modify itself to less vulnerable conditions (Luers et al., 2003). In other words, more adaptive capacity means less vulnerability. The Intergovernmental Panel on Climate Change (IPCC) (2001) explained vulnerability as a function of exposure, sensitivity, and adaptive capacity.

According to Cutter et al. (2008), relationships among vulnerability, resilience, and adaptive capacity are still under-researched and not well articulated. There is no consensus among scholars about the boundaries and relationships between these concepts, particularly resilience and adaptive capacity (Cutter et al., 2008).

COMMON THEMES IN ADAPTIVE CAPACITY

When reviewing adaptive capacity related literature, there are some common themes that can be observed across various fields. These themes include dynamic learning, flexibility, adaptation, self-organization, and transformation (Figure 4). The following section provides an in-depth discussion of these common elements in more detail.

Figure 4. Common Themes in Adaptive Capacity in the Literature

Dynamic Learning

Dynamic learning plays an important role in enhancing the system's adaptive capacity and preparing it to respond to any stressor. Effective communication is an essential mechanism within dynamic learning that enriches the system's adaptive capacity. Hence, effective communication should be practiced in all system's phases: before, during, and after any system's disturbance. The importance of effective communication stems from its ability to create a common knowledge base among all entities about the system's dynamics and operations.

People send thousands of messages and signals every day in different forms with the perception that they are clear and understandable. In fact, it is not always the case. Many of these messages are not accurately interpreted and, in some cases, are misunderstood. A similar perception occurs in complex systems communication mechanisms. The message that is collected by the receiver is not necessarily the same message that was intended to be delivered by the sender (Dekker, 2003). Without a well-structured communication system, it is difficult to detect potential risks, convey intended instructions, and eventually achieve dynamic learning.

The misunderstanding or misinterpretation arises from a problem in the communicative exchange process. Wold and Laumann (2015) argue that "in a professional organization it is plausible to assume that there will be asymmetry between the codes of “source”" and “receiver” – in other words, the top level of the organization might not share the same codes as the lower level, or the lower level might understand and interpret these codes differently" (p. 24). The communication process is usually governed by constructed procedures. According to Dekker (2003), there are two models that can address communication procedures. The first one assumes that procedures are perceived as the best and the safest way to perform the required task. Therefore, employees who precisely follow the procedures achieve a high level of risk management. In the second model, procedures are perceived as a *resource of action*. These types of procedures do not discuss all the details of the tasks as in the dynamic environments of complex systems where it is difficult to specify all the task aspects. Therefore, they are adopted in an interactive manner where risk managers interact with other system entities for further assessment of when and how to apply a specific procedure based on the current behavior of the system.

In many cases, major disturbances can be prevented by effective communication and a well-organized reporting system. Having such a system would effectively detect the potential risk, adequately report it to top management and successfully fix the issue before the loss event occurs and propagates to other system's entities.

Safety Performance Solutions Inc. (SPS) (cited in Williams & Geller, 2008) conducted a safety culture survey of hundreds of organizations. The results of the survey showed that 90% of the respondents think that employees should warn others when they observe unsafe acts. Yet, only 60% of the respondents said they would provide such feedback when they notice that someone was operating at-risk. In the same survey, 74% of the respondents stated that they welcome getting safety-related feedback as a result of peer observations. However, only 28% think workers will have the same feeling in accepting safety-related feedback. The results of this survey show the gap between *knowing what should you do* and *doing what should be done*. To understand the existence of this gap, Geller and Williams (2008) emphasized that "[p]articipants respond that giving safety-related feedback will create interpersonal conflict" (p.1). Also, they stated another cause of this gap, which is that some employees feel they are not qualified to provide safety-related feedback. This survey shows a lack of a well-designed communication and a reporting system that is capable of addressing the issues mentioned in the survey.

All complex systems are prone to internal and external disturbances that may disrupt the whole system. In his discussion of different types of disturbances that may lead to system's failure, Mayntz (1997) stated that there are unrealized threats within the system that are neglected until they become an acute danger and, consequently, cannot be properly handled. To ensure a continuous process of detecting, analyzing, and correcting any system's errors, it is imperative to practice the notion of dynamic learning as part of the system's adaptive capacity. The complex system must continuously learn and generate knowledge and experience about system behaviors and dynamics (Folke et al., 2005).

Dynamic learning is a continuous process targeting the entirety of a system's entities and their behaviors. It involves the case where the system is experiencing certain crises. Hence, it should be ongoing learning of the system's response toward the stressor or risk and how each entity is reacting. The dynamic learning provides risk managers with fast and continuous flow of information about the system's dynamics so that they can achieve thorough and instantaneous knowledge about the behavior of different system entities. Having the risk managers informed and continuously updated about the system status can significantly assist in making the right decisions at the right time. Dynamic learning should be built on instantaneous, accurate, and comprehensive information. Delayed, incomplete, inaccurate, or lacking information about the system's performance during crises will certainly obstruct the risk managers from seeing the real status of the system and will eventually lead to misinformed decisions.

The role of dynamic learning becomes vital once the disturbance is under control. The importance of dynamic learning at this stage emerges from two areas: 1) understanding of what went wrong, and 2) taking corrective measures based on a new and deep understanding of the system behaviors to mitigate future risks. This process involves some formal procedures of inquiry or internal investigation. Choularton (2001) defines learning at this stage as "the adjustment of coping mechanisms based on a new understanding of the world" (p. 64). This new understanding of the world requires not only investigating the immediate causes, but also the root causes of the disturbance.

To achieve high adaptive capacity through dynamic learning, it is important to adopt the notion of double-loop learning proposed by Argyris (2002). Double-loop learning is designed to deal with complex system problems operating in a highly dynamic and emergent environment. It is centered around changing the structure and challenging the common assumptions, values, and norms of the system in light of experience (Argyris, 2002). Double-loop learning goes in line with adaptive capacity that accommodates desirable fundamental changes to the system's structure, relationships, and operations through the notion of transformability. Choularton (2001) noted that "learning means the adjustment of coping mechanisms based on a new understanding of the world" (p.64). In the context of complex and dynamic systems, Sterman (1994) views learning as a "feedback process in which our decisions alter the real world, we receive information feedback about the world, and using the new information we revise the decisions we make and the mental models that motivate those decisions" (p. 1).

Flexibility

Flexibility is one of the essential attributes of adaptive capacity that any complex system should be equipped with. While complex organization is exposed to internal and external risks that may disrupt or restrain its performance and operations, it is proven that a system's flexibility can help the organization to effectively deal with unpredicted events, such as disturbances and disruptions (Skipper & Hanna, 2006; Fredericks, 2005; Swafford et al. 2006). The adaptive capacity of a system implies designing a system with flexible qualities and properties that can strengthen its ability to address and handle any abrupt event. For the system to be flexible in the face of unpredictable crises, it must be open to learning (Folke et al., 2002). Openness to learning can be attained through a flexible system structure, mechanisms, and dynamics (Folke et al., 2005). Furthermore, flexible system structure should be designed with the least bureaucracy possible. A bureaucracy that is characterized by a high level of standardization, formalization, specification, and hierarchy can limit the system's ability to respond quickly to the surrounding dynamic environment.

The relationships among different systems' entities should allow for flexibility through which they pave the way toward the innovation and novelty that are necessary to navigate complex system disturbances. Moreover, novelty, innovation, and flexibility are imperative keys to avoid surprise and handle ambiguity (Folke et al., 2005).

Flexibility reflects the system's ability to respond quickly and effectively to changing mechanisms, relationships, environments, and contexts. Not only can flexibility enrich the system's adaptive capacity before the crises, but also, it can significantly help the system to rapidly respond to change during the unpredicted event. Smit and Wandel (2006) operationalized the notion of flexibility during disturbances through four elements: 1) decentralization in decision making, 2) low levels of formalization, 3) low degrees of embeddedness to a system's macro culture and 4) establishment of collaborative partnerships.

From an organizational perspective, enterprise flexibility can be defined as a function of three important system's qualities: agility, efficiency, and adaptability (Erol et al., 2009). These qualities can be defined as follows:

- Agility reflects the system's quick responses to the changing and dynamic business processes.

- Efficiency represents the optimal use of available resources.
- Adaptability reflects the system’s ability to adapt and change its business process when necessary to cope with dynamic business requirements.

Skipper and Hanna (2006) studied the possibility of minimizing supply chain disruption risks through improving the system's flexibility. They designed and tested a model to identify the attributes that have the strongest relation to flexibility. They found that top management support, resource alignment, information technology usage, and external collaboration demonstrate a high influence on flexibility. The study concluded with the assertion that flexibility fosters the ability of supply chain systems to mitigate disruption risks.

Adaptation

Adaptation reflects the ability of the system's entities (including humans) to adjust to change. The term adaptation has its roots in evolutionary biology (Smit & Wandel, 2006). According to Kitano (2002), adaptation in biology means the ability to cope with environmental variations. There are different applications of the concept of adaptation in various fields, such as cultural adaptation, ecological adaptation, and organizational adaptation (Dutton & Dukerich, 1991; Smit & Wandel, 2006; Guillemin et al., 1993).

Complex systems adapt to and change their environment by interpreting and responding to the variations (Dutton & Dukerich, 1991). Dynes and Aguirre (1979) tackled the issue of organizational adaptation to face crises and highlighted that crises push organizational structures to move in the direction of coordination through feedback (a high volume of horizontal communication) as opposed to coordination by the plan.

Once the system is experiencing disturbances, the system entities should show a high level of adaptation through the harmonization of internal policy relationships and other mechanisms to cope with the new realities of the system. Oh (2010) conducted a study on organizational adaptation to face disasters and suggested three policy implications for improving effective organizational adaptation: 1) the importance of collaboration and coordination among different entities to create mutual trust, 2) institutionalization of joint operations and retaining of experienced core personnel to foster collaboration, 3) integration of advanced information technologies to enhance effective communication and learning.

Building sound adaptive capacity should not be limited to initiating reactive responses but also involve developing anticipatory adaptation to potential disturbances, including extreme weather conditions. For instance, Linnenluecke et al. (2012), argued that “anticipatory adaptation to extreme weather events contributes to building organizational resilience if it creates resources and capabilities that allow an organization to be more resistant to or recover more quickly from impacts of more frequent and/or severe extreme weather events” (p. 24). The adaptation usually reflects a state in the system. However, adaptive capacity involves different factors that can be measured and reflects the quality of the system in dealing with uncertainties (Ford & King, 2015).

Self-organization

Self-organization is one of the attributes that features the system's adaptive capacity. It reflects the system's impulsive emergence of order (Adams, 2011). In other words, it represents the ability of the system and its entities to determine its structure and qualities (Hester & Adams, 2014). In self-organizing systems, interrelated entities continuously communicate, and based on their exchange of information and feedback, coherent behavior is achieved even in the absence of top-down imposed plans (Ashmos et al., 2002).

According to Ashmos et al. (2002), internal self-organization occurs due to variation in the external system's environment or changes in the interrelated system's elements. Therefore, self-organization is related to the principle of emergence as one of the main attributes of complex systems. Emergence in complex systems incorporates events, structures, and behaviors that cannot be predicted prior to the system's operation (Keating, 2009). Self-organized systems show some resistance to being managed from outside of the system, and any attempt to externally control it may lead to undesirable results (Hester & Adams, 2014). In the complex system domain, it is vital to enhance self-organization of subsystems through maximizing autonomy (more decisions and actions freedom) (Keating, 2008).

It can be argued that self-organization is a function of adaptability to the disturbances and changes in the system. According to Oh (2010), self-organization arises from the necessity of the system to adapt to abrupt crises and, therefore, it creates new operational procedures and collaborative partnerships. He demonstrates that during times of crises, organizations build collaboration with other organizations that may have different properties and, consequently, create a heterogeneous system that limits their self-organization capabilities.

ASSESSMENT OF ADAPTIVE CAPACITY

There are different methods and approaches to measure and characterize adaptive capacity (Engle, 2011; Erol et al., 2010; Ford & King, 2015; Luers et al., 2003; Mcmanus et al., 2007; Staber & Sydow, 2002). These methods include case studies, surveys, frameworks, modeling, and mapping. Engle (2011) indicated that adaptive capacity is difficult to measure due to its latent nature. To address this problem, he suggested that researchers should empirically study past adverse events and their surrounding conditions and contexts.

In the context of quantifying vulnerability, adaptive capacity can be measured as “the difference in the vulnerability under existing conditions and under the less vulnerable condition to which the system could potentially shift” (Luers et al., 2003, p. 259). On the other hand, Ford and

King (2015) suggested a framework to examine the readiness of human systems for the adaptation process. In their framework, Ford and King (2015) outline six elements that are necessary for adaptation to take place. The six elements include political leadership, institutional organization, adaptation decision making, and stakeholders' involvement, availability of usable science, funding for adaptation, and public support for adaptation. For each element, authors identify indicators, potential analysis methods, and data sources. The final phase includes quantitative scoring and qualitative analysis.

Gupta et al. (2010) developed a metric to assess the institution's ability to promote the adaptive capacity of society to withstand any adverse environmental event. Institutional assessment should be performed through assessing the institution's inherent characteristics, which includes formal and informal rules and regulations as well as norms and beliefs. The developed tool, which is called an *adaptive capacity wheel* consists of six dimensions as the main categories and twenty-two criteria associated with these dimensions as subcategories. These dimensions are variety, learning capacity, room for autonomous change, leadership, resources, and fair governance (refer to figure 5).

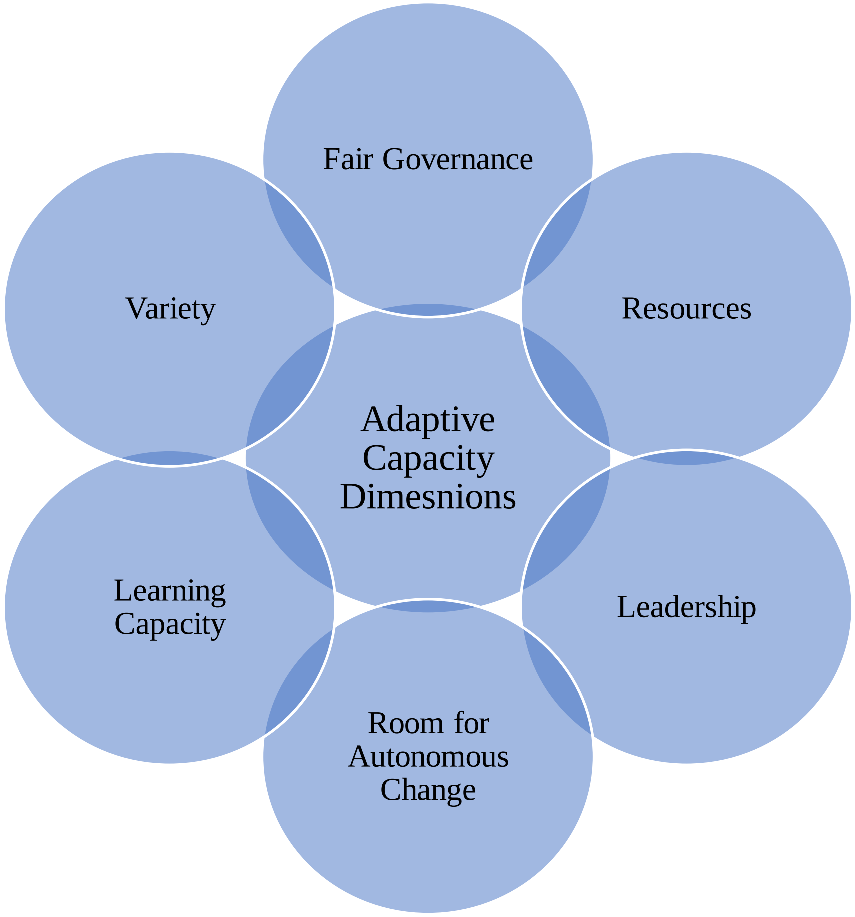

Figure 5. Adaptive Capacity Wheel Dimensions (Gupta et al., 2010)

In the organizational context, Staber and Sydow (2002) suggested that building organizational adaptive capacity is an effective method to deal with dynamic, volatile, and complex environments. Subsequently, they outlined three structural dimensions necessary to build organizational adaptive capacity: multiplexity, redundancy, and loose coupling. Utilizing a similar meaning of adaptive capacity, Erol et al. (2010) defined enterprise flexibility as "the ability of enterprise to adapt to changing business and stakeholder requirements more efficiently, easily and quickly" (p. 4). They consider enterprise flexibility and enterprise resilience as a function of adaptability, efficiency, and agility. The authors identified three metrics to evaluate enterprise resilience: 1) ability to decrease the system's vulnerabilities 2) ability to adapt to the changing environment, and 3) ability to quickly recover from a disturbance.

By the same token, Erol et al. (2010) emphasized that adaptive capacity is an essential determinant of resilience as it is not static and constantly changes with time. Therefore, time becomes an important dimension in measuring adaptive capacity and resilience due to the volatile and dynamic environment of complex systems (Dalziell & McManus, 2004) (e.g. the time between the starting point of a disturbance and the first response).

Many researchers identified governance arrangements and indicators as critical elements in building adaptive capacity. Some evaluate the system’s adaptive capacity based on the existence or absence of these indicators (Clarvis & Engle, 2013; Folke et al., 2005; Lee et al., 2013). For example, Engle and Lemos (2010) conducted an empirical study to investigate the relationship between water governance mechanisms in Brazil and adaptive capacity to climate change. They constructed governance indicators, tested the validity of these indicators (reliability test), and then used qualitative data (interviews) to study the relationship between the adaptive capacity and the indicators. He found that the relationship is positive.

There are various indicators and determinants of adaptive capacity used in previous studies (Luers et al., 2003; Mcmanus et al., 2007; Stephenson, 2010; B. Walker et al., 2006). Examples of these elements include information and knowledge, experience and expertise, networks, transparency, trust, commitment, leadership, accountability, connectivity and collaboration, flexibility and leadership (Clarvis & Engle, 2013).

The next section discusses complex systems in the literature, followed by an examination of their main features.

COMPLEX SYSTEMS

This section focuses on the nature of complex systems and their key features. A better understanding of complex systems and their interactions will allow us to suggest better solutions. Complex systems operate in a dynamic business environment with a high level of emergence and uncertainty (Backlund, 2002; Beer, 1979; Jackson, 1991; Keating et al., 2001). Due to the nature of complex systems and their volatile environments, it is difficult to identify and anticipate adverse events before their occurrence. Therefore, it is important to prepare the complex system and assess its capacity to adapt to any disturbance.

Keating et al. (2005) provide a comprehensive definition of complex systems as "a bounded set of richly interrelated elements for which the characteristic structural and behavioral patterns that produce system performance emerge over time and through interaction between the elements and with the environment" (p. 200). Additionally, they provided a list of complex systems characteristics, which includes the following: A large number of highly interrelated complements.

- Very dynamic emerging behavior
- Constant and dramatic changes in the system's structure
- Uncertain predicted outcomes
- Incomplete understanding of the system's behavior
- Many stakeholders with possible divergence among them
- Limited resources and changing requirements/expectations

High need for immediate responses with a high risk of catastrophic ramifications in the case of mishandling.

FEATURES OF COMPLEX SYSTEMS

The best approach to find out if a system is a complex system is to investigate if it possesses the core features of complex systems. There is no consensus among scholars on a full list of complex systems attributes. Yet, there are key features highlighted by many scholars who tackle the subject of complex systems (Anderson, 1999; Ayyub et al., 2002; Bar-Yam, 1997; Gorod et al., 2014; Groš, 2011; Hester & Adams, 2014; Jaradat, 2014; Keating et al., 2005; Keating et al., 2003; Pinto & Mcshane, 2012; Pinto et al., 2015)

The key features of complex systems that will be discussed in this research are complexity, emergence, autonomy, ambiguity, interconnectivity, and uncertainty.

Emergence

Our knowledge will always fall short of fully understanding and accurately predicting the behavior of a complex system prior to its operation. Rather, our knowledge and understanding of the system increases as the system starts to operate. This does not indicate poor analysis capabilities, however, this is a real phenomenon that is embedded into a complex system problem domain. Keating et al. (2011) indicated that the concept of emergence is part of the complex system's nature that influences the structural and behavioral patterns of the system and will be exhibited over time during the system's performance. They added that systems' analysts could not know when, where, or how the emergence will occur. However, one of the important actions that needs to be taken to respond to emergence is that any system solution or approach needs to deal with any emergent disturbance. In other words, the system should possess the necessary mechanisms to identify, analyze, respond, and therefore adapt to any emergent circumstances. Table 3 presents some definitions of emergence in the context of complex systems.

Table 3. Definitions of Emergence in the Context of Complex Systems

Study	Definition/perspective
Keating (2008)	The structural and behavioral patterns of a complex system will come about through the operation of the system and cannot be known, or predicted, in advance of system operation.
Jaradat (2014)	Emergence can be described as unpredicted behaviors/patterns resulting from the integration and the dynamic interaction between the constituent systems, their parts, and the surrounding environment (open systems). These behaviors/patterns cannot be anticipated beforehand and cannot be attributed to any of the constituent systems.
Hester & Adams (2014)	Emergence is expressed simply by the statement that the whole is more than the sum of the parts. Accounting for emergence means accepting that there will be uncertain, unpredictable phenomena occurring within our mess.
Pinto, Magpili, & Jaradat (2015)	Unforeseen behaviors (risks) that occur because of the integration of multiple complex systems or components.

Jaradat (2014) views emergence (unforeseen and unanticipated events) as a key feature of complex systems that occurs due to a high level of uncertainty, interaction, ambiguity, and complexity and as a result of an integration of multiple systems within the large complex system. To deal with emergence as a risk management problem, Pinto et al. (2015) suggest that emergence is one of the major challenges that face risk managers and safety professionals. Therefore, it requires deep systemic thinking about the problem, such as treating the risk problem from a holistic perspective to adapt to any unexpected behavior or disturbance. Also, it is imperative to design a flexible and resilient system to withstand any unpredicted event.

Ambiguity

A complex system problem domain is characterized by being ambiguous. The notion of ambiguity in the context of complex systems is not only influencing the ability to interpret the system's behavior but also the ability to draw the boundaries of the system. A system's boundaries are important to differentiate between what is included in the system and what is not. In other words, it helps in distinguishing between elements that are part of the system and other elements that are part of the surrounding environment as the type of the element dictates the required method of analysis. In complex systems, the system's boundaries are vague, incomplete and may change over time. It is worth noting that as the complex system evolves, our understanding of the system increases. This is also true regarding the ambiguous system's behavior, structure, and boundaries (refer to Table 4).

Pinto et al. (2015) demonstrate that risk managers and safety professionals should take the ambiguous nature of complex systems into consideration when designing a system. For them, a flexible system is needed to accommodate any future adjustments and improvements to cope with the new risk that may arise at any point in time. Appreciating all complex system's attributes and their impacts lead to 1) a better understanding of the systems, 2) more mature analysis of the system problems domain, and 3) avoid solving the wrong problem "type III error" (Mitroff, 1997).

Table 4. Definitions of Ambiguity in the Context of Complex Systems

Study	Definition/Perspective
Pinto et al. (2015)	Ambiguity is the lack of clarity concerning the interpretation of a system's behavior and boundaries.
Ayyub et al. (2002)	The ambiguity stems from the possibility of having multiple outcomes for a process or system. Recognition of some of the possible outcomes creates uncertainty.
Renn et al. (2011)	With ambiguity, we refer to plurality of legitimate

	viewpoints for evaluating decision outcomes and justifying judgments about tolerability and acceptability.

Interconnectivity

Complex systems are usually composed of subsystems and entities that involve humans with different social and cultural identities, information and technology hardware, software as well as many other elements. For the system to operate, many of its components need to interact, collaborate, and communicate with each other to achieve certain goals or execute specific tasks as part of the system's holistic mission. Therefore, interconnectivity in complex systems is exhibited in various forms, including high interrelationships among entities in the system or the metasystem, human interactions, human-machine interaction, as well as interaction among the system's components (software and hardware). Pinto et al. (2015) and Linkov et al. (2013) noted that a high level of interconnectivity among various entities, such as supply chain networks could open many avenues for internal and external vulnerabilities and threats. Studying the internal dynamic of the systems and continuously understanding the interconnectivity among its components will enhance the resilience of the system (Linkov et al., 2014). Cilliers (2002) discussed various characteristics of interactions among the complex systems elements that can be summarized in Table 5.

Table 5. Interaction Characteristics in the Context of Complex Systems

Interaction Characteristics	**Explanation**
Dynamic interaction	The elements in a complex system interact in a dynamic manner with a constant exchange of information. Some elements are constituted by their relationships with others.

Rich interaction	Any element in the system influences and is influenced by other elements. The human dimension in complex systems makes the interaction diverse with various capacities.
Non-linear interaction	This is a precondition for complexity and guarantees that small causes produce a larger impact. Rich and dynamic interactions, along with the competition for resources in complex systems, break the symmetry and does not allow for linearity.
Loops in the interconnections	Feedback is an essential process in complex systems. This means interlinked full and sometimes complicated loops in a large network.

Uncertainty

Due to the nature of complex systems and the surrounding environment, there is a high level of complexity, emergence, ambiguity, and interconnectivity operating in a very dynamic environment. Therefore, it is necessary to acknowledge that uncertainty is embedded in the system. This level of uncertainty impacts our knowledge about the system and therefore, influences our decision-making process (Jaradat, 2014; Keating et al., 2011; Pinto et al., 2015).

In a similar manner, in the context of risk management, uncertainty reflects the lack of sufficient knowledge, data, and information about the probability and severity of potential risk. Therefore, this makes it difficult to provide a clear and accurate risk assessment (Aven & Renn, 2009; Filar & Haurie, 2010; Renn et al., 2011).

Groš (2011) listed uncertainty as the fourth feature of complex systems. For example, in complex systems, there is no absolute information security, there must be some probability that an incident might occur and thus, some uncertainty in the system (Groš, 2011).

Complexity

Complexity can be the first feature one might notice with regards to complex systems (refer to Table 6). According to Justice et al. (2016), complexity emerges due to the high frequency and dynamic interactions among the system components. The system's behavior cannot be predicted or understood if it is solely studied by its individual components without holistic analysis of the entire system and its interactions (Ellis & Herbert, 2011; Schneberger & Mclean, 2003). Contextual factors also play a vital role in shaping the system's behavior in both positive and negative ways. Pinto et al. (2015) indicated that contextual issues, such as political, managerial, social, and cultural factors influence the system's complexity. According to Bar-Yam (1997), the complexity of a system can be measured through the amount of information and data that describes its behavior.

In the context of risk management, capturing complexity is crucial to 1) identify potential risks, and 2) analyze and manage these risks should they occur. The importance of understanding the system's complexity lies in the ability to capture the dynamic interactions and interrelationships among the system's element, which will greatly help in the risk analysis and management process. Additionally, the holistic view in tackling a risk problem is necessary because focusing on one component without tracing its relationships and interactions will not provide any solution, instead, it will constitute a waste of resources.

Table 6. Definitions of Complexity in Systems Theory

Author	**Definition**
(Flake, 1998)	An ill-defined term which means many things to many people. Complex things are neither random nor regular but hover somewhere in between. Intuitively, complexity is a measure of how interesting something is.
(Freniere et al., 2003)	Complexity is a measure of the degree to which a system contains large numbers of interacting entities with coherent behavior. Notionally, one can measure complexity from a value of zero to some maximum number. Zero complexity indicates a completely simple system; few entities have either minimal or no interactions. Generally, one can account for the behavior of such system with a simple set of equations or short description- for example, contemporary military combat models, replete with attrition equations.

(Williams, 1999)	A type of dynamical behavior in which many independent agents continually interact in novel ways, spontaneously organizing and reorganizing themselves into larger and more complicated patterns over time.
(Pinto et al., 2015)	Complexity exists when a situation exhibits a high level of interrelationships among the elements and their parts, a high level of uncertainty and ambiguity, emergence, a large amount and flow of data, incomplete knowledge, and exhibits a highly dynamic nature.
(Hanseth & Ciborra, 2007)	Complexity could be defined in a simple and intuitive way as the "sum" of the number of components and connections between them.
(Schneberger & Mclean, 2003)	Complexity is a function not only of the number of system parts or components but also of the respective number of their interrelations. The higher the combined number of parts and their interactions, the higher the level of complexity.
(Hanseth & Lyytinen, 2010)	Complexity can be defined as the dramatic increase in the number and heterogeneity of included components, relations, and their dynamic and unexpected interactions in IT solutions.

Autonomy

With the high level of complexity, dynamic interactions, and emergence in complex systems, constituents tend to have their purpose and sometimes operate independently (Juarrero, 2009). Hester and Adams (2014) stressed that systems desire to function autonomously to achieve the system's goal and purpose. However, systems do not operate in a vacuum and must interact and co-exist with other constituents. Therefore, there is tension that exists between autonomy and integration, where more integration means less autonomy. Couture (2006) argues that autonomy refers to the extent to which a system's constituent is different from its surrounding environment. He added that "autonomy in this context does not mean that a complex system is separate from its environment; rather, it means that its dynamic structure governs the nature of its interaction with the environment in which it is nested" (p. 33).

Autonomy has three levels in complex systems (Jaradat, 2014; Keating, 2008):

- Operational Autonomy: the ability of each system, as part of the whole complex system, to operate freely to achieve the system's goal and purpose.
- Managerial Autonomy: each system is integrated and attached to the whole complex system, yet it operates independently.
- Geographical Dispersion: while the system shares information and data with the whole complex system, it can maintain a separate physical entity existence

CHAPTER SUMMARY

This chapter has discussed the related literature to adaptive capacity and complex systems. It started with presenting a background of the concept of adaptive capacity and discussed its relationship with other similar concepts, such as resilience, and vulnerability. Then, it provided a synthesis of common themes related to adaptive capacity in the literature, namely: learning, flexibility, self-organization, and adaptation. It also discussed common adaptive capacity assessment methods, highlighting the need to develop an instrument to particularly assess adaptive capacity in complex systems. This chapter has concluded with presenting the main features of complex systems: complexity, emergence, autonomy, ambiguity, interconnectivity, and uncertainty. The discussion of the main attributes of complex systems is imperative in drawing the boundaries and scope of this research.

CHAPTER III

RESEARCH DESIGN AND METHODOLOGY

This chapter is devoted to discussing the research design of the study. The first part of this section starts by restating the research questions, followed by introducing the research design chosen to execute the study, and the data analysis procedure. The following chapter presents the research analysis and findings. The last chapter of this dissertation illustrates the importance of this study, its limitations, implications, and recommendations for future research.

Review of the Research Questions

There are two research questions that guide this study. These questions are:

Question No. 1. *What organizational factors are needed to assess adaptive capacity in complex systems?*

Question No. 2. *How can an instrument to assess adaptive capacity in complex systems be developed?*

Research Design Approach

The chosen design, to answer the research questions above, is inductive and qualitative in nature and utilizes a grounded theory approach. The qualitative design of this dissertation is a grounded theory study. Generally, grounded theory studies aim to derive a theory from collected data through systematic coding and analysis methods (Leedy & Ormrod, 2010). The most common coding method is the one suggested by Corbin and Strauss (1990) which consists of open coding, axial coding, and selective coding leading to the development of a theory.

The research design involves four phases. The first phase is the grounded theory coding. The second phase is the conceptualization of the identified criteria. The third phase is development of the adaptive capacity assessment instrument. And the final phase is the validation phase (see Figure 6). The following section briefly discusses each of the phases in more detail.

Research Design Phases

Phase I will focus on identifying a set of criteria that are necessary to enable the adaptive capacity in complex systems using grounded theory coding. Identifying adaptive system criteria will be performed through four steps:

1- **Establishing the adaptive capacity data sources** that will be used as an input into the grounded theory coding process.

2- **Grounded theory open coding** from the data available in the adaptive capacity data sources pool. Open coding is an analytic process of coding all concepts related to adaptive capacity without any preconceived idea of the coding outcome.

3- **Grounded theory axial coding** is a process that builds upon the outcomes of open coding where all concepts associated with adaptive capacity criteria is identified. This process aids in building relationships and connections among the identified categories established in step 2.

4- **Grounded theory selective coding** is where axial coding is the final step in the coding process where a new theory will emerge. It is a process of integrating all coded categories under specific adaptive capacity core criteria.

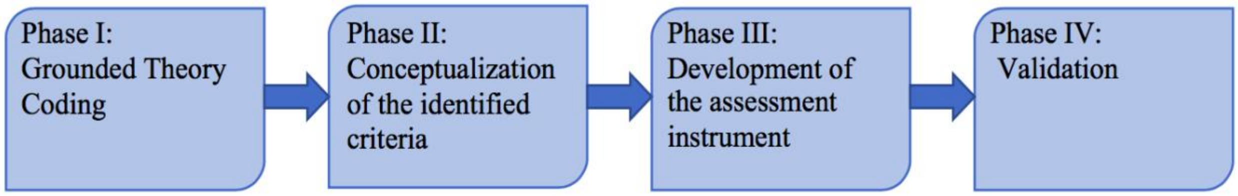

Figure 6. Research Design Phases

In Phase II, following the identification of the adaptive capacity criteria, detailed definitions and explanations will be provided for each criterion. Additionally, the identified criteria will be particularly applied to a complex system domain.

Phase III is crucial as it builds on the previous two phases. The adaptive capacity assessment instrument will rely on the results of phase I and phase II. The instrument will be designed to capture organizational factors that enable or restrict the adaptive capacity in complex systems. Besides, the assessment instrument will be able to show the areas/points of strengths or weaknesses in the complex system under investigation.

In Phase IV, the validation step, the developed assessment instrument will be reviewed by the subject matter experts. The purpose of this step is validating and testing the assessment instrument before it can be deployed and applied to a specific complex system. The instrument will be evaluated based on the following dimensions.

- Value of the instrument in enabling adaptive capacity in complex systems.
- Completeness of the criteria.
- Duplication, redundancy, and inadequacy

The following section discusses the grounded theory coding as the research design chosen to execute this study, followed by a discussion of the data analysis software that will be used to analyze data, which is the QSR-NVIVO. These sections are followed by an elaborated discussion of what the researcher intends to do in each of the four research design phases.

GROUNDED THEORY CODING

The grounded theory was founded by Glaser and Strauss (1967). This approach focuses on discovering a theory via a systematic method. The original purpose of the grounded theory method is to bridge the gap between the theory and the empirical research to produce useful theories (Glaser & Strauss, 1967) (i.e. generating a theory from data). The theory offers systematic inductive strategies to conduct rigorous qualitative research. It starts with identifying a set of data (or area of study) to develop more abstract conceptual ideas and categories. The identified data is then to be synthesized and analyzed to establish a patterned relationship within the chosen data set (Charmaz, 2007; Walker & Myrick, 2006).

Grounded theory is a method that combined two approaches of data analysis (Walker & Myrick, 2006). The first approach focuses on coding and analyzing the coded data to confirm a specific proposition. The second approach does not engage in any coding process but focuses on carefully categorizing and analyzing the data using memos to explore theories. Glaser and Strauss (1967) stated that "a third approach to the analysis of qualitative data – one that combines, by an analytic procedure of constant comparison, the explicit coding procedure of the first approach and the style of theory development of the second" (p. 102). The grounded theory is not meant to prove or verify a preconceived idea, such as hypothesis or any given proposition. However, the primary purpose is to generate a theory.

Qualitative coding involves applying preconceived codes to the data. That is to say; all codes are decided and planned before the research starts collecting the data (Charmaz, 2007).

However, the grounded theory coding entails that the researcher creates codes as the research progresses and without any preconceived ideas about the outcomes of the coding process. Therefore, the output of grounded theory is unforeseen to the researcher prior to the start of the study (Charmaz, 2007).

Glaser and Strauss (1990) suggested two different coding methods and phases. For instance, Glaser's coding method consists of two consecutive processes: substantive and theoretical coding. The substantive coding is aimed at producing categories and their associated properties and is comprised of two phases, open and selective coding. The second process is theoretical coding, which builds on the substantive codes to discover a theory or hypothesis. On the other hand, Strauss’ coding method is divided into three main phases: open, axial, and selective coding. Table 7 demonstrates a comparison between Glaser’s (1978) and Strauss and Corbin’s (1990) coding approaches (Corbin & Strauss, 2008; Glaser, 1978, 1992, 1998; Glaser & Strauss, 1967; Strauss & Corbin, 1990; Strauss, Corbin, 1994; Strauss, 1987; Walker & Myrick, 2006).

Table 7. Comparison between Grounded Theory Coding Approaches

<table>
<tr><td colspan="3">Glaser's (1978) coding approach</td><td colspan="2">Strauss and Corbin’s (1990) coding approach</td></tr>
<tr><td rowspan="2">Substantive</td><td>Open</td><td>- “Coding the data in every way possible”
- No preconceived ideas/concept.
- Analyzing the data line-by-line.
- Writing memos about any conceptual or theoretical ideas that might arise during the coding phase.
- Researcher stops when finding a theory starting to emerge.
- Theoretical sensitivity should be maintained</td><td>Open</td><td>- “Analytic process through which concepts are identified and their properties and dimensions are discovered in the data."
- No preconceived ideas/concept.
- Analyzing the data line-by-line.
- Breaking the data down into categories and dimensions to set the stage for building relationships among the categories.
- Theoretical sensitivity should be maintained</td></tr>
<tr><td>Selective</td><td>- Transitioning from open coding into a more focused process revolving around a specific core category.</td><td>Axial</td><td>- The purpose is to build connections/relationships among identified categories.
- It can be achieved using “coding paradigm.”</td></tr>
<tr><td colspan="2">Theoretical coding</td><td>- Using cues in the data set, theoretical codes are applied.
- The theoretical codes are then used "to conceptualize how the substantive codes may relate to each other as hypotheses to be integrated into a theory."</td><td>Selective</td><td>- The researcher selects one core category where other categories are linked to core one with interrelated relationships.
-Therefore, it is the “process of integrating and refining the theory."</td></tr>
</table>

This research will follow the Strauss and Corbin (1990) approach for the following reasons:

- Corbin and Strauss's (1990) approach offers various analytical techniques to maintain theoretical sensitivity. These techniques include the flip-flop technique, making close-in and far-out comparisons, questioning, and the red flag technique.
- The use of the open and axial coding phase is more appropriate to the research at hand. Researching the existing data and exploring adaptive capacity assessment criteria will be possible using this approach. This will include identifying the adaptive capacity dimensions or criteria followed by building relationships among identified dimensions.
- Building upon the first two phases, the selective phase will revolve around one core element, which is assessment of adaptive capacity in complex systems.

The following section discusses the data analysis software that is used to collect data, followed by a detailed discussion of the four phases of the research design that will be followed to establish the adaptive capacity instrument.

Data Analysis Tool: The Use of QSR-NVIVO in Exploring the Adaptive Capacity Criteria

NVivo is a software tool used in qualitative and mixed methods research. Hutchison, Johnston, and Jeff (2010) wrote an article discussing the benefits of using NVivo in grounded theory research after comparing similar software. They stated that "QSR-NVivo can be used to facilitate many aspects of a grounded theory approach, by presenting a recently worked example of how a grounded theory-based research study developed using NVivo throughout" (p.17).

The rational for using this software can be explained as follows:

- It is a powerful tool as it helps the researcher store, organize, code, categorize, analyze, and visualize the data.

- It helps in navigating a huge amount of data related to adaptive capacity. This includes all activities in the open coding such as categorization and classification.
- Using this software will not weaken the application of Strauss and Corbin’s (1990) approach. In fact, all phases (open, axial, and selective) will be performed using the software.
- Through NVivo, this researcher will fracture the data and read line-by-line following the grounded theory coding approach until all adaptive capacity assessment criteria have been explored.
- This software has many features that allow the researcher to visualize the coded items and categories which will help in identifying the relationships among the categories (Axial coding).
- This software supports various data formats and sources including, text (portable document format and standard text documents) audio, images, spreadsheets and online web contents (QSR International, 2019).

PHASE I. IDENTIFYING ADAPTIVE CAPACITY CRITERIA IN COMPLEX SYSTEMS USING GROUNDED THEORY CODING

The primary objective of this phase is to identify a set of criteria that are necessary to enable the adaptive capacity in complex systems. To achieve this objective, this phase is divided into the following steps:

1- **Establishing the adaptive capacity data pool** that will be used as an input and grounded theory coding process. This level includes surveying and screening all adaptive capacity related data before including them in the pool. The data sources pool includes but is not limited to academic literature from various disciplines (i.e., environmental science, ecological systems, disaster management, safety and risk management, engineering, organizational behavior, and management), investigation reports related to accidents or disasters, and government/public policy reports and publications.

2- **Open coding** from the data available in the adaptive capacity data pool sources. Open coding is an analytic process of coding all concepts related to adaptive capacity without any preconceived idea of the coding outcome.

3- **Axial coding** is a process that builds upon the outcomes of open coding, where all concepts associated with adaptive capacity criteria are identified. This process involves building relationships and connections among the identified categories in step 2.

4- **Selective coding** is the final step in the coding process, where a new theory will emerge. It is a process of integrating all coded categories under specific adaptive capacity core criteria.

First Grounded Theory Coding Process: Open Coding

When Glaser and Strauss (1990) wrote their book, *The Discovery of Grounded Theory*, they sought, "to further the systematization of the collection, coding, and analysis of qualitative data for the generation of theory"(p.18). Afterward, each one of them had his grounded theory coding version. However, they both agreed on the first coding procedure which is the open coding.

Open coding is a process of coding the data under review without any preconceived idea about the outcome of the analysis (Walker & Myrick, 2006). The process starts with breaking down the data with codes in an analytical manner. Codes will then be applied to specific pieces of data, and – as the process develops – the researcher can label similar patterns under one category.

These codes and categories arise throughout the process, not prior to the coding process beginning (Corbin & Strauss, 1990). The researcher will investigate the data (gathered in the data pool), read it, and analyze it line-by-line to find any piece that indicates a criterion to assess adaptive capacity. A numerical value is counted each time a code is applied. For example, a researcher notes a piece of data that indicates *communication* as a criterion to assess adaptive capacity in an oil refinery. Then he applies a code of *communication* to that specific data. Every time the researcher applies the same code to a different piece of data, a number in which that *communication* code is applied will be counted. Then, the frequency of codes will be obtained to conduct numerical analysis of the high-frequency codes that resulted from the open coding process.

When performing the open coding process, there are a few elements that the researcher should take into consideration (Jaradat, 2014):

1) The purpose of the coding process, in general, is to answer the following question, *what are the criteria needed to assess adaptive capacity in complex systems*. Therefore, the researcher at the stage of open coding should identify any line in the data that may indicate assessing adaptive capacity in an industry or environment that is considered complex, per complex systems attributes discussed in the literature review section.
2) The researcher shall conduct detailed and extensive searching and read the dataset line-by-line and sentence-by-sentence to unearth any potential criteria to assess adaptive capacity.
3) The previous two steps should be performed without any preconceived idea about the outcome of this process and what might emerge as adaptive capacity criteria. Thus, the researcher shall be open to any result.
4) The coding words should be clear, not ambiguous, and directly related to the coded line.

Throughout the open coding process, it is essential that the researcher maintain theoretical sensitivity. Walker and Myrick (2006) stated that with theoretical sensitivity, “the researchers can theoretically and conceptually think about the data from a distance, while simultaneously maintaining a close-in level of sensitivity and understanding about the process and their involvement in that process". While both Glaser (1978) and Strauss and Corbin (1990) highlighted the importance of theoretical sensitivity, the latter provided analytical techniques to maintain the theoretical sensitivity. These techniques include the flip-flop technique, making close-in and far-out comparisons, questioning, and the red flag technique.

- **Questioning**: questioning the data leads the researcher to see that data from a holistic view and then give the right code. Examples of the questions are who, when, where, what, how, why, etc.
- **Flip-flop technique**: if the data indicated one direction, the researcher should look into the opposite and compare the extremes. In other words, turning the concept upside down in order to look into the word or the phrase from a different angle.
- **Waving the red flag technique**: it suggests that the researcher should stop and further investigate the data whenever he notices certain words or phrases, particularly absolutes such as, never, always, none, etc. The purpose of this technique is to allow the researcher to see beyond the plain data and challenge the common assumption.

Second Grounded Theory Coding Process: Axial Coding

After all data sets are inspected and coded (open coding process), the second step is applying axial coding. Axial coding builds on the codes identified on the previous step through discovering relationships and correlations among codes (i.e., categories and sub-categories).

According to Corbin and Strauss (1990) “in axial coding, categories are related to their sub-categories, and the relationships [are] tested against data". The process of relating a specific sub-category to its category or one category to another category requires looking into the "coding paradigm" of context, conditions, consequences, and strategies which comprise the logic link. The purpose of axial coding is putting the data together and building relationships after it was fractured in the open coding (Corbin & Strauss, 2008).

The coding paradigm focuses on three elements of the phenomenon (Walker & Myrick, 2006):

- The **conditions** that contribute to the occurrence of the phenomenon.
- The **actions** or interactions of the phenomenon.
- The **consequences** of the action.

The phenomenon should reflect the core idea, which is in this research the adaptive capacity criteria.

Some analytical techniques in NVivo software will be used such as model coding analysis and text search query. The feature of model coding analysis can be used to further explore the relationships between the categories and their sub-categories. The text search query is another instrument that enables the researcher to investigate all related concepts and definitions in connection to one category.

Third Grounded Theory Coding Process: Selective Coding

Selective coding is the final grounded theory coding process (Strauss & Corbin, 1990). This step aims to unify related categories under one core category. The purpose of selective coding is to integrate identified categories into a central theme to generate the theory. Strauss and Corbin (1998) stated that selective coding is the "process of integrating and refining the theory" (as cited by Walker and Myrick, 2006, p. 143). Therefore, the researcher is required to integrate the data to form a theoretical model (an emerging central theme of the phenomenon). In this research, this step involves identifying the key criteria to assess adaptive capacity in complex systems. Thus, the derived coding processes: open coding, axial coding, and selective coding.

PHASE II. CONCEPTUALIZATION OF THE IDENTIFIED CRITERIA

Following the identification of the adaptive capacity criteria, detailed definitions and explanations will be provided for each criterion. Additionally, the identified criteria will be particularly applied to the complex system domain.

PHASE III. DEVELOPMENT OF THE ADAPTIVE CAPACITY ASSESSMENT INSTRUMENT

This phase involves designing an adaptive capacity assessment instrument that can be applied to a specific complex system to measure its adaptive capacity level. There are four main objectives that can be achieved from the development of such an instrument:

1) The instrument will define the structure of the information identified in the previous two phases.
2) The instrument will provide the ability to communicate the identified criteria in a clearer manner.
3) The instrument will facilitate the use of the assessment criteria for application purposes in a more practical way.
4) The instrument will help researchers and decision-makers to understand, assess, and improve the adaptive capacity of their organizations.

This phase is crucial as it builds on the previous two phases. The adaptive capacity assessment instrument will rely on the results of Phase I and Phase II. The instrument will be designed to capture the organizational factors that enable or restrict the adaptive capacity in complex systems. Besides, the assessment instrument will be able to show the areas/points of strength or weakness in the complex system under investigation.

The structure of the adaptive capacity assessment instrument will be drawn from two similar models: Adaptive Capacity Wheel (Gupta et al., 2010) and the Vulnerability Scoping Diagram (Polsky et al., 2007). The structure of the assessment instrument will include a center of the instrument surrounded by two rings:

- The center of the instrument represents adaptive capacity in complex systems
- The first ring around the center represents criteria identified in the axial coding process (sub-categories).
- The third ring involves the dimensions/core criteria identified in the selective coding process (main categories).

In addition to the structure, it is vital for the assessment instrument to encompass a scoring scale system that shows adaptive capacity's areas of strengths and weaknesses of the complex system under investigation. In this research, the scoring system of Gupta et al. (2010) (Table 8) will be adopted. The scoring system range varies between high (green: numerical value +2) to low (red: numerical value -2).

Table 8. Adaptive Capacity Wheel Scoring System.

Effect of a criterion on adaptive capacity	**Score**
Positive effect	2
Slightly positive effect	1

Neural or no effect	0
Slightly negative effect	-1
Negative effect	02

PHASE IV. VALIDATION OF THE DEVELOPED ASSESSMENT INSTRUMENT

Qualitative Research Validation

Some scholars questioned the term validation in relation to qualitative research and suggest other terms, such as verification, trustworthiness, and confirmability (Creswell, 2009; Leedy & Ormrod, 2010). There is no specific recognized method to confirm the validity of qualitative research findings. Leedy and Ormrod (2010) in their discussion of validity in qualitative research stated that "researchers use a wide variety of approaches to support the validity of their findings. Different approaches are appropriate in different situations, depending on the nature of the data and the specific methodologies used." This flexibility has kept the door open for researchers to find the appropriate method that can confirm their findings.

Methods of Experts Elicitations

Expert elicitation as an approach is used to verify the research findings or when there is insufficient knowledge about a subject matter (Knol et al., 2010). It began in the second half of the 20th century with the Delphi Method (Hasson & Keeney, 2011). Since then, the literature has witnessed many systematic expert elicitation protocols and methods (Ayyub, 2001; Doria et al., 2009; Engel & Dalton, 2012; Hemming et al., 2018; Knol et al., 2010; Martin et al., 2012).

There is no universal protocol for the application of expert elicitation, however, there are some common protocols and approaches that typically require some modification based on the researcher's needs (Knol et al., 2010). In this section, some of common protocols will be discussed. According to Martin et al. (2012), the general approach of conducting an expert elicitation consists of five steps:

- **How the information derived from experts will be used**: The purpose of this step is to decide how the information and judgments received from experts will be used and where it fits in the research structure (e.g. will the expert elicitation be incorporated into a model). The exact role of elicitation in the research should be clear and decided before initially approaching experts.
- **Clearly identifying areas of elicitation**: This includes determining the variables that have uncertainty or knowledge deficiency, therefore, the elicitation can be helpful.
- **Designing the expert elicitation**: The expert elicitation process should be carefully designed based on the research needs. This step includes experts' identification based on their relevant background, the format of the elicitation (e.g. survey, interviews, group meeting, etc.), identification and evaluation of the questions to be asked, and methods of data analysis.
- **Performing the elicitation**: This can be accomplished directly, indirectly, individually or through a panel that involve group of experts.
- **Encoding the information received from experts**: This entails transferring the responses received from experts into a quantitative format to be analyzed. The format, technique, number of experts, and analysis methods depend on the purpose of research, its nature and available resources.

In a similar vein, Knol et al. (2010), suggested a seven-step formal procedure for conducting expert elicitation:

- **Characterization of uncertainties**: This step focuses on determining the appropriateness of the elicitation to the uncertainties in a particular context.
- **Scope and format of the elicitation**: The second step is concerned with answering questions such as how many experts will be needed and whether to conduct interviews, group meetings or surveys.
- **Selection of experts**: This step focuses on selecting appropriate experts. There are three types of experts: 1) generalists who are knowledgeable in a relevant discipline, 2) the subject matter experts who are prime experts in their fields and whose opinion generally matters, and 3) the normative which includes people who are usually practitioners and have a good operational knowledge in their profession.
- **Design of the elicitation**: This step revolves around the questions that will be asked to the experts and their related techniques.
- **Preparation of the elicitation sessions**: This is concerned with all related preparation issues, such as the session program plan.
- **Elicitation of expert judgements**: This involves performing the elicitation and executing the session program plan.
- **Aggregation and reporting**: These involve gathering the expert responses and reporting the results.

In the area of Conservation and Natural Resource Management, Hemming et al. (2018) highlighted the importance of having a structural protocol to avoid issues related to biased solicitation, bad selection of experts or poorly-specified question. Therefore, they proposed the IDEA structured protocol (“Investigate,” “Discuss,” “Estimate” and “Aggregate”). The application of the IDEA four-step protocol shall be preceded by the preparation phase. The preparation phase includes project planning (team roles, budget, elicitation format, etc.), project material development (project description, practice questions, elicitation questions), and participant recruitment. When the preparation process is completed then the IDEA structured elicitation can start:

- **Investigate**: At this stage, questions and instructions are sent individually to experts to get their responses (this can be done remotely).
- **Discuss**: Experts are shown anonymous responses of each participant, then the team shall facilitate and encourage a discussion.
- **Estimate**: This is the second round of the investigation. Questions are sent again to give experts a chance to revise and adjust their answers in response to the previous discussion session.
- **Aggregate:** This is the post-elicitation step, it includes collecting final responses, converting the final data into graphs, tables and comments, and sending it for final review.

For the purpose of this research, the developed assessment instrument will be reviewed by subject matter experts. The purpose of this step is validating and testing the design of the assessment instrument before it can be deployed and applied to a specific complex system. The subject matter experts are anticipated to review and validate the instrument in terms of the following:

- Value of the identified criteria in enabling adaptive capacity in complex systems.
- Completeness of the criteria.
- Duplication, redundancy, and inadequacy.

Scholars who have tackled the issue of expert elicitation have highlighted the importance of knowledge and experience of the selected members (Ayyub, 2001; Engel & Dalton, 2012). In this research, an expert is defined as a person with knowledge and experience in a field that is related to adaptive capacity and complex systems/organizations.

Ayyub (2001), discussed a few criteria to select SMEs; these criteria include:

- Relevant expertise in the subject matter through education or professional training.
- The familiarity of the subject matter from various aspects.
- Willingness to be part of a group of experts to evaluate the issues of interest
- Availability to commit the required time and effort.
- Excellent communication skills.

The key criteria for selecting experts in this research will be based on the following elements:

- Academic degree/education.
- Direct experience in the issue of interest.
- Broad knowledge in the subject matter.
- Willingness to participate and availability to devote time and effort.

CHAPTER SUMMARY

This chapter has provided an outline of the research design approach and discussed specific methods, techniques, and strategies used during this research. A qualitative method using the grounded theory approach is the primary method to execute the first phase of this research. The research design approach consists of four phases. The first phase aims to identify the adaptive capacity organizational factors through analyzing data from the following sources: related journal articles, government publications, technical reports, and the disaster's investigation report. The second phase focuses on the conceptualization of the derived organizational factors in the first phase. The third phase is the development of the adaptive capacity instrument that is built on the outcomes of the first and the second phases. The final step of this study is the validation phase, the main validation technique is through eliciting the opinions of subject matter experts in validating the findings of this research (i.e. the adaptive capacity assessment instrument).

CHAPTER IV

RESEARCH ANALYSIS AND FINDINGS

This part of the research provides a discussion of the results, methodological details and findings in theoretical and analytical approaches. To do this, this chapter is divided into five sections. The first section reviews the research questions and the grounded theory approach as the main methodological approach used in this study and discusses the data sources. The second section discusses open, and axial coding processes as well as theoretical sensitivity and the three techniques used to address it in this study, namely questioning, comparing using flip-flop technique, and waving the red flag. This section concludes with a discussion of the selective coding process as the last step in phase one of the data collection process.

The third section examines the second phase of building an adaptive capacity instrument which is the conceptualization of the identified organizational factors. This phase is dedicated to conceptualizing each factor to establish the adaptive capacity instrument in the context of complex systems. The fourth section discusses the adaptive capacity instrument based on the findings derived from the data collection and analysis process. This chapter ends with section five of the analysis process which discusses the final phase of building an adaptive capacity instrument, the validation phase.

The last chapter reviews the key implications and findings and provides a discussion of the study's limitations and this researcher's thoughts and recommendations for future research.

RESULTS

This section starts with a review of the research questions of this study. Next, a discussion of the grounded theory approach and data sources are presented. This section is followed by a discussion of the four phases developed in this research to arrive at establishing the adaptive capacity instrument in this study.

Review of the Research Questions

There are two research questions that guide this study. These questions are:

Question No. 1. *What organizational factors are needed to assess adaptive capacity in complex systems?*

Question No. 2. *How can an instrument to assess adaptive capacity in complex systems be developed?*

Grounded Theory Approach

As discussed in the previous chapter, research methodology experts on grounded theory have different approaches for data analysis (Charmaz, 2006; Corbin & Strauss, 1990, 2008; Glaser & Strauss, 1967). This study follows the most common approach suggested by (Corbin & Strauss, 1990, 2008). The discussion of differences between approaches and the rationale of choosing this particular approach is discussed in chapter three. The following section discusses the analytical approach of selecting the data sources, and then provides analysis of the outcome of the first phase of the study, the grounded theory coding procedures.

Data Sources

For this research, establishing a data pool to select data sources includes surveying and reviewing all adaptive capacity and its assessment-related material. The data sources stem from the following:

- Peer-reviewed journal articles in various disciplines (crisis management, environmental science, ecological systems, disaster management, safety and risk management, engineering, organizational behavior, and management). Most of the gathered articles investigate particular real-world cases of disturbances.

- Investigation reports of landmark accidents and disasters from different industries
- Government publications
- Technical reports
- White papers

The analytical approach of establishing the data sources consists of five steps as shown in figure 7. These steps are explained as follows:

1. Gathering adaptive capacity related material from various sources. This process resulted in gathering more than 180 documents.
2. Scanning and reviewing the gathered documents based on their suitability to the study: all the gathered documents were subject to review to ensure their suitability to the research at hand. Out of the 183 documents, 102 documents were selected for the coding analysis.
3. Establishing the data sources pool that is ready for the analysis
4. Starting the coding process
5. Saturation Level: This refers to the point where no more new codes emerge. The saturation level has been achieved in the first round as there were two or more planned rounds. The second round is conditional on the results of the first round. In other words, if the saturation level has not been reached during the first round, which includes 102 documents, the second round will be established with the same process as the first one.

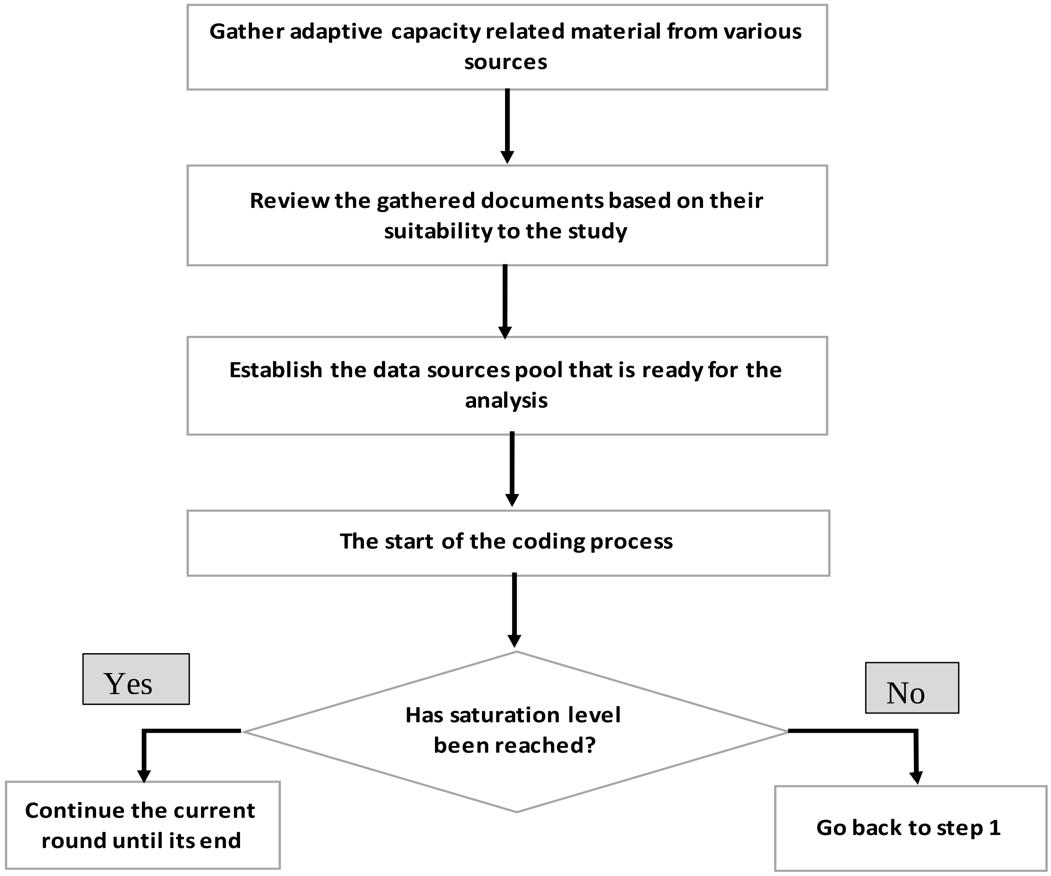

Figure 7. Analytical Approach of Establishing the Data Selection Process

PHASE I RESULTS: OPEN CODING ANALYSIS, AXIAL CODING ANALYSIS, AND SELECTIVE CODING PROCESS

Grounded Theory Approach: Open Coding Analysis

Open coding is a process of breaking down the data into smaller segments that reflect themes which describe an emerging theory or phenomenon (Leedy & Ormrod, 2010). For example, the researcher might note that there are pieces of data that have similar themes. Therefore, these elements of data with similar themes are grouped together in the same category (node). For example, a researcher reviews an investigation report and notices several indications that suggest flaws in the communication process and the researcher labels these as “poor communication”. The purpose of this process is to give the researcher new insights through exploring the data in a technique that is different from traditional ways of thinking or assumptions in interpreting a phenomenon under investigation (Strauss & Corbin, 1990).

Researcher’s Role in the Open Coding Process

As its name suggests, open coding requires that the researcher should be open to all possible outcomes. The key task of the researcher in this phase is to explore and observe all possible patterns and themes in the data. Openness in exploring the data is vital to avoid the inherent biases that may exist. In other words, “grounded theory requires the researcher to enter the research field with no preconceived problem statement, interview protocols, or extensive review of literature. Instead, the researcher remains open to exploring a substantive area and allowing the concerns of those actively engaged therein to guide the emergence of a core issue” (Holton, 2007, p. 169).

In this study, after establishing the data sources pool, the researcher carefully analyzed the dataset through reading the data line-by- line and sentence-by-sentence. Codes or categories were applied on segments of data that reflect a theme (i.e. adaptive capacity organizational factors). Therefore, when reading a line, sentence, or paragraph that suggests an adaptive capacity assessment factor, a code that describes the factor will be applied. For example, a sentence that highlights the importance of transferring information quickly to executive management during a crisis, the researcher coded that sentence with “rapid information sharing”. Figure 8 provides an example from the open coding process of a sentence that suggests an adaptive capacity factor. It is coded with “information sharing” category as the sentence tenor suggests.

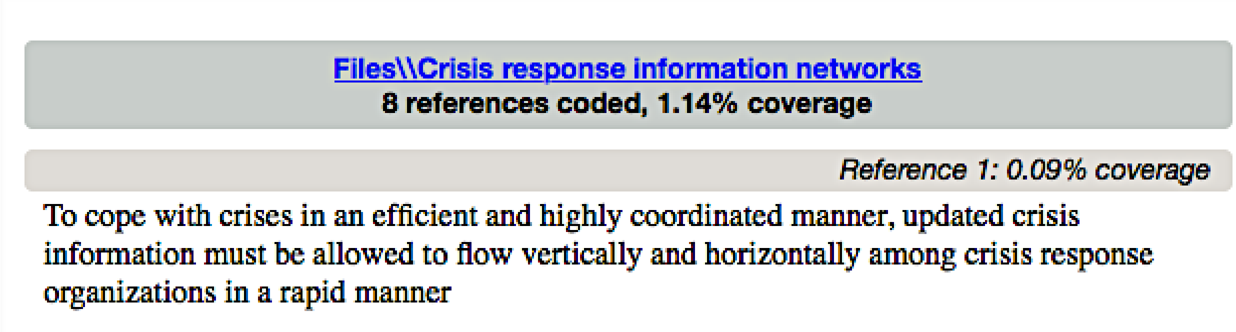

Figure 8. Snapshot of a Data Segment Coded with “Information Sharing”

It is important to highlight that the researcher has no preconceived idea of the coding outcomes, throughout the open coding process. Hence, the researcher focused on a central question: what are the adaptive capacity assessment factors that might emerge from the dataset? The answer will not be found explicitly in the dataset. Instead, the researcher’s understanding of the dataset and its tenor helped him infer answers for the above question. Appendix A demonstrates a sample of open coding results of a white paper, government report, accident investigation report, and a journal article, respectively.

Open Coding Analysis in This Study: Main Results

Once a code is created, it can be applied to any similar theme in the dataset. For example, the code *effective communication* is the most applied code in the open coding process, occurring 228 times. Table 9 shows the top six codes and their output number. This indicates the central importance of these factors in shaping adaptive capacity in complex systems. It is important to note that this is not the final outcome of the coding process, since the upcoming axial coding will study the relationships among codes and that might change the final outcome of the coding process.

When the saturation level was reached, the process of open coding ceased. The saturation point can be reached when no more codes are emerging. Charmaz (2006) stressed that “categories are saturated when gathering fresh data no longer sparks new theoretical insights, nor reveals new properties of these core theoretical categories."

In this study, the researcher discerned that there were no new codes created in the last 21 documents in the first round of the data pool. Hence, the saturation level was reached in document number 81 of the data sources pool. The open coding process resulted in 62 codes, with the highest code output of 228 and lowest output of 3. Appendix A shows a snapshot of part of the open coding results in NVivo software. Table 10 lists all codes that resulted in the process of open coding.

Table 9. Top Six Codes in the Open Coding Process

Code Name	Code Output
Effective Communication	228
Stakeholders Engagement	165
Resources Management	109
Learning	108
Coordination	107
Information and Data	100

Table 10. List of Codes Resulted from Open Coding Process

Accurate Data	Consistency	Holism	Policy
Adaptive Strategy	Context	Human Dimension	Redundancy
Adaptive Learning	Continuous Learning	Information & Data	Safety Culture
Agile Leadership	Control	Information Sharing	Self-organization
Autonomy	Coordination	Innovation	Silo-mentality
Awareness	Decentralization	Knowledge	Situational Awareness
Centralization	Decision Making	Leadership	Socio-technical System
Challenge Assumption	Detection	Learning	Speedy Decision Making and Rapid Response
Change Management	Dynamic Learning	Management-Prioritization	Stakeholders Engagement
Clarity	Effective communication	Network	Stakeholders Involvement
Cognition-psychological	Evolvement	Novelty	Training
Coherence	Expert Acquisition	Organizational Culture	Transformability
Collaboration	Feedback	Organizational Structure	Transparency
Collaborative Learning	Flexibility	Planning	Trust
Use of Technology	Restructuring		
Accountability	Collaborative Leadership	Governance	Resources Management

Theoretical Sensitivity

Theoretical sensitivity means that the researcher should be engaged with the data at the theoretical level as well as in the sensitivity level. According to Walker and Myrick (2006) “researchers can theoretically and conceptually think about the data from a distance, while simultaneously maintaining an in-close level of sensitivity and understanding about the process and their involvement in that process” (p. 552). Theoretical sensitivity techniques are designed to achieve the three main purposes (Hull, 2013):

- **Avoiding classic ways of thinking**: This helps the researcher to dig deeper in exploring and analyzing the data line-by-line, and sentence-by-sentence. Fracturing the data with theoretical sensitivity helps in investigating new perspectives of the data instead of the relying on a general understanding of the context of the data. Also, it helps in
- **Challenging assumptions**: The use of these techniques can clarify or debunk any existing preconceived assumptions held by the researcher. According to Hull (2013), theoretical sensitivity can “steer the researcher out of the confines of technical literature and personal experience” (p. 13).

There are several techniques that are used in this research to enhance theoretical sensitivity (Strauss & Corbin, 1990). These techniques include questioning and comparing through using the flip-flop technique and waving the red flag. These techniques are explained in the following section.

First: **Questioning**

The purpose of the *questioning* technique is to further explore and open up the data for new perspectives and themes (Strauss & Corbin, 1990). Questioning was practiced once the researcher noticed a condition, consequence, process, and pattern associated with adaptive capacity (Hull, 2013). Questioning can start with the basic questions such as who, what, how, and when, until inclusive analysis of the data is achieved. Table 11 shows an example from the NVivo open coding analysis and the use of questioning technique in exploring the data and identifying relevant codes.

Table 11. Example of Questioning Technique, Theoretical Sensitivity

Text	"Toyota struggled to come to terms openly and publicly with the problem. The combination of Toyota's strategy of holding back information to its customers and a very slow communications strategy (Schoenberger, 2010) not only caused anxiety and worries about personal safety among Prius car owners but impacted negatively on the public trust in the company."
Questions	*Why did the company struggle with its customers?*
	What is missing in Toyota's relationship with their customers during this crisis?
	Can effective communication and information sharing aid in building trust and better adapt to the problem?
Codes	Effective Communication, Information sharing
Source	Files\\Contrasting cases of corporate crisis management systems- a research report 2 references coded, 1.57% coverage

Second: Comparisons (Flip-Flop Technique)

The flip-flop technique ensures that the researcher finds out the opposite of a particulate category (code) and makes a comparison of both ends of a dimension (Strauss & Corbin, 1990). The purpose of this technique is to enhance the sensitivity to relevant adaptive capacity dimensions and explore new possible codes. Hull (2013) asserted that "this technique forces the researcher to think analytically, rather than descriptively, about the data and helps to generate provisional categories and find their properties and dimensions" (p.14). To further explain how the flip-flop technique was used in this research, Table 12 illustrates an example from the NVivo open coding process that captures the use of the flip-flop technique.

Table 12. Example of Flip-flop Technique, Theoretical Sensitivity

Text	"I think we need to review that kind of interaction and the kind of specific roles, responsibilities, to ensure that authority and responsibility is commensurate in terms of the role definitions for the various levels of management in NASA."
Flip-flop technique	**Code**: Clarity of roles & responsibilities
	Opposite code: ambiguous roles and responsibilities
	How do both ends impact the adaptive capacity? Do ambiguous roles and responsibilities undermine adaptive capacity? Are there any events in the report that suggest ambiguity?
Codes	**Clarity of roles & responsibilities**
Source	Files\\INVESTIGATION OF THE CHALLENGER ACCIDENT 7 references coded, 0.11% coverage

Third: Waving the Red Flag

There are particular words and phrases that wave a red flag to the researcher, such as the use of absolute qualifiers. Therefore, whenever the researcher notices words or phrases, such as never, rarely, must and always, he inspects the whole segment and asks the relevant questions that go beyond the basic interpretation of the data. In the example illustrated in Table 13, the word "must" in the sentence raises a red flag. Therefore, the word "must" in this case suggests that information sharing is mandatory and not recommended in the context of coping with crises.

Hence, it can be concluded that information sharing is an essential condition in achieving adaptive capacity during crises.

Table 13. Example of Waving the Red Flag Technique, Theoretical Sensitivity

Text	To cope with crises in an efficient and highly coordinated manner, updated crisis information must be allowed to flow vertically and horizontally among crisis response organizations in a rapid manner
Waving Red Flag	*What is meant by the word "must"?* *What are the consequences if information sharing is missing?* *Under what conditions does "information sharing" is mandatory?*
Code	Information Sharing
Source	Files\\Crisis response information networks **8 references coded, 1.14% coverage**

The open coding process is the most critical coding phase which sets the stage for the axial and selective coding. It is imperative to note that this researcher started this phase with no preconceived idea of its outcomes, and it concluded with 62 codes. Table 14 summarizes the open coding process. The identified codes, and connections will be subject to further investigation on the axial coding process in the next section of this chapter.

Table 14. Summary of Open Coding Analysis Process

Definition	Open coding is a process of breaking down data into smaller segments that reflect themes that describe an emerging theory or phenomenon
Purpose	To give the researcher new insights through exploring the data in an analytical approach that is different from traditional ways of thinking or assumptions in interpreting a phenomenon under investigation
Number of Data Sources	102 data sources
Approach	Analyzing the data line-by-line, and sentence-by-sentence with no preconceived idea of the analysis outcomes until the saturation point is reached
Techniques	Questioning Comparison using the flip-flop technique Waving the red flag
Results	62 categories/codes were identified

Axial Coding Analysis

Axial coding analysis is the second coding analysis that focusses on the relationships by exploring the connections among the identified categories in the open coding (Walker & Myrick, 2006). Axial coding is more complex than open coding as it involves systematic and analytical techniques (Hull, 2013). The primary purpose of axial coding is to bring the fractured data back into coherence after it was fragmented in the open coding process (Holton, 2007). Building relationships between categories and sub-categories should be made through analyzing the conditions, context, and consequences that bring them together (Strauss & Corbin, 1990).

In this study, the rationale for performing the axial coding analysis is based on the following steps:

- **Inspecting** each category through reviewing all associated coded segments (lines, sentences, and paragraph) to come up with a short delineation that describes the theme. The delineation stems from coded segments.
- **Analyzing** the connection and correlation among categories within the groups using *the paradigm model*.
- **Clustering** all similar categories/codes together. Based on the previous two steps, codes that carry similar features were put in one cluster/group as shown in Figure 9.
- As a result of the analysis and clustering stages, codes were organized as **main categories** (parent node) and sub-categories (child nodes) based on the similarities among them.

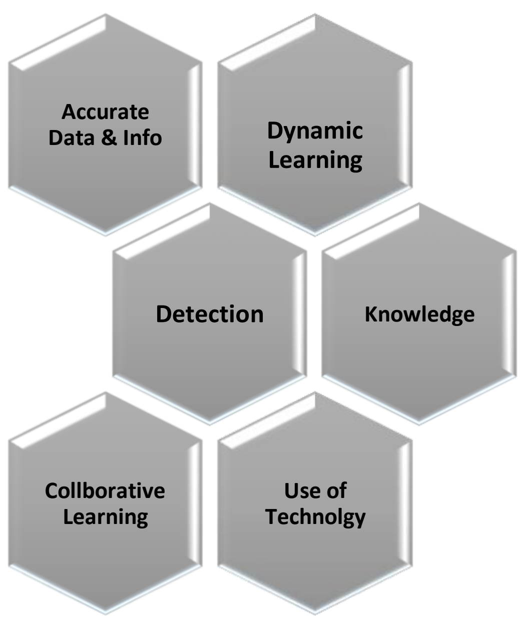

Figure 9. Example of Clustering Codes with Similar Features

Testing the connection and correlations among categories was performed using the paradigm model that is suggested by Strauss and Corbin (1990). The paradigm model provides a systematic approach that enables the researcher to relate the fractured data back to a coherent structure. The paradigm model that was used in this study consists of the following components:

First. Causal Conditions which include all the conditions and events that contribute to the emergence of a theory or phenomenon. The central question of this component was how the identified categories of the organizational factors contribute to enhancing or hindering the adaptive capacity in complex systems. For example, how does "stakeholder engagement" impact adaptive capacity?

Second. Phenomenon it is the central theme of the study at hand, to which all categories are related. All categories in this research are organizational factors/criteria that are related to the central subject of this study which is adaptive capacity assessment. Investigating the connection between the organizational factors (categories) and the adaptive capacity assessment criteria (phenomenon) is essential in the axial coding analysis.

Third. Intervening Conditions which includes all contextual elements that impact the emergence of the adaptive capacity assessment criteria.

Fourth. Consequences which involves closely inspecting all causal conditions that lead to the development of the theory; therefore, it involves inspecting all categories and distinguishing between causal conditions and intervening conditions. It also helps in exploring the strength of the relationship between the categories (organizational factors) and the central phenomenon.

Additionally, throughout the course of the axial coding process, some NVivo analysis instruments were used to assist in exploring the data. For example, the text query analysis shown in Appendix A was used to explore the occurrence of particular terms and their relationships with other terms. Also, the coding query helps in exploring the connection between the content of selected coded nodes. Besides, the word frequency query was used to gain more insights about the dataset content and explore the most frequently occurring words/concepts in the dataset. Words such as crisis (6688 counts), management (5624 counts), response (3927counts), system (3438 counts), and information (3428 counts) were at the top of the list.

As part of the axial coding analysis process, 62 codes were analyzed in the approach explained above. When closely inspecting the 62 codes, the researcher noticed some similarities that make some codes interchangeable. Therefore, these very similar codes that carry the *same* meaning were merged using the “merge” feature in the NVivo software. Table 15 shows some examples of the merged codes.

Table 15. Sample of Merged Codes in Axial Coding Analysis

Continuous Learning		Dynamic Learning
Adaptive Learning		Dynamic Learning
Collaborative Learning		Dynamic Learning
Collaborative Leadership	Merged With ➔	Leadership
Agile Leadership		Leadership
Safety Culture		Organizational Culture
Novelty		Innovation
Stakeholder Involvement		Stakeholders Engagement

As a result of the axial coding analysis, 38 codes were grouped in 9 main categories. The number of codes decreased from 62 in open coding to 38 in axial coding due to merging similar codes as illustrated in Table 15. Codes that were placed in one group shared similar features. For example, dynamic learning, detection, accurate information and data, and knowledge are all share the essence of learning process associated with disturbances in complex systems. Another example is governance, flexibility, and accountability, where the latter two codes are related to governance of rules and regulations. In a similar vein, all other groups share a common thread that bring them together.

The nine groups are headed by the following main categories: effective communication, dynamic learning, leadership, organizational culture, cognition, governance, organizational structure, human resources preparedness, and planning. The selection of the nine main categories was based on 1) comprehensive analysis using the paradigm model, and 2) the clustering analysis. Each main category represents a parent node and relates to its subcategories through chide-node links (Appendix A). Table 16 illustrates all main categories with their associated sub-categories as a result of the axial coding analysis.

The axial coding process concluded with total of thirty-eight organizational factors grouped in nine main categories. These organizational factors are interrelated and overlap on many occasions. The impact on adaptive capacity emerges from combination of most of these factors.

Table 16. Main Categories and Their Associated Sub-Categories

Main Categories	Effective communication	Dynamic Learning	Leadership	Planning	Organizational Culture	Cognition	Organizational Structure	Governance	Human Resources preparedness
Sub-categories	Collaboration	Detection	Prioritization	Coherence	Trust	Challenge Assumption	Decentralization	Accountability	Training
	Information Sharing	Accurate data & Information	Resources Management	Consistency	Innovation	Situational Awareness	Clarity of Roles	Flexibility	Expert &Talent Acquisition
	Stakeholders Engagement	Knowledge	Speedy decision making and rapid response	Context	Autonomy	Silo Mentality	Restructuring & Transformability		
	Transparency	Use of Technology	Adaptability Strategy	Holism					

Further discussion will be provided in selective coding and phase III of this research. Table 17, below, summarizes the axial coding process.

Table 17. Summary of the Axial Coding Analysis

Definition	The axial coding analysis is the process of exploring and analyzing the connections among the identified categories in the open coding
Purpose	Its purpose is to bring the fractured data back into new coherence after it was fragmented in the open coding process.
Analysis Approach	- Inspecting all categories and creating associated delineation. - Analyzing categories using a paradigm model and other techniques - Clustering categories with similar themes - Developing parent and child nodes
Analysis techniques	- Causal conditions - Phenomenon analysis - Intervening conditions - Consequences **Other techniques:** - Text query analysis - Coding query analysis - Frequency query analysis
Results	38 codes grouped in 9 main categories

Selective Coding Analysis

Following the analysis in the course of open coding and axial coding, categories and sub-categories need to be unified around central theory (Hull, 2013). Selective coding is a process of unifying all categories around one core concept/category (Corbin & Strauss, 1990; Walker &

Myrick, 2006). The core category refers to the central phenomenon by which all categories are related to. For example, main categories, such as dynamic learning, effective communication, leadership and organizational culture are all related to a central theory that represent the connection among them.

The three coding phases, open coding, axial coding, and selective coding aim to develop a theory that can answer the first research question. The first research question revolves around identifying criteria that captures the organizational factors to assess adaptive capacity in complex systems. Thus, because of the selective coding process, nine main categories and their associated sub-categories are selected to directly from the central theory of the study. During the selective coding process, a new theory has emerged. The central component of the theory is the assessment of adaptive capacity in complex systems using the nine categories. These categories are effective communication, dynamic learning, leadership, organizational culture, cognition, planning, governance, organizational structure, and human resources preparedness. The nine categories and their sub-categories represent organizational criteria to assess adaptive capacity in complex systems.

In this regard, it is necessary to highlight two important points:

1. Having nine categories does not mean that these factors (categories and subcategories) impact the complex system in an isolated manner. In fact, most factors have some degree of overlap among them. For instance, stakeholder engagement and collaboration overlap on some occasions. However, they are not interchangeable factors and do not refer to the same exact concept in terms of their meaning and essence. Collaboration cannot replace stakeholder engagement as the latter has more specific connotations and application processes.

2. The influence of a particular factor may go beyond its group attributes. For example, the "use of technology" code is placed in the dynamic learning group because it shares many features with other codes in the same group. Yet, the use of technology is not limited to the learning domain; rather it extends to other domains such as communication and planning.

To visualize the nine categories and their associated subcategories, Appendix A shows a tree map (hierarchy chart) that is obtained from the NVivo software. The size of the rectangle represents the number of codes a category has received.

PHASE II: CONCEPTUALIZATION OF THE IDENTIFIED CRITERIA

In the previous phase, important outcomes have yielded as a result of grounded theory, open coding, axial coding, and the selective coding processes. The outcome of Phase I is a theory of adaptive capacity assessment criteria that consists of 38 elements. This phase is dedicated to conceptualizing these criteria in the context of complex systems. This phase will provide a description of each criterion based on:

- All criteria descriptions are provided in the context of complex systems.
- The description emerged from exhaustive reading the coded segments associated with each criterion. For instance, *stakeholder engagement* has 165 coded segments in the NVivo, the researcher reviewed all coded segments and come up with a description that better explain the essence of *stakeholder engagement* reflected in these segments.
- To enhance the understanding of the context of each criterion, the researcher has used some techniques such text query analysis, coding query analysis and causal conditions.

The following section provides a discussion of the thirty-eight organizational factors that reflect the essence of each term considering the grounded theory processes.

Dynamic Learning

It is a continuous learning process, before, during, and after a disturbance. Adverse events in complex systems accelerate quickly in an unpredicted fashion, and this behavior should be accompanied with a dynamic learning process that detects, gathers information and data, and creates knowledge to set the stage for a quick response.

Detection

Complex systems should be equipped with active capabilities to discover early warnings of any emerging threat. Detection is the first step in the dynamic learning process. Once a threat is detected, it should be disseminated through the internal communication system.

Accurate Data and Information

One of the most important factors to achieve adaptive capacity is the ability to quickly gather accurate information and data to be used when needed. One of the challenges associated with complex systems' adverse events is ambiguity and incompleteness of data. Incomplete and inaccurate data may do more harm than good. Therefore, it is essential to ensure the accuracy of information gathered as any response will be built on these data.

Knowledge

Developing knowledge is an essential part of the organizational learning process in the context of achieving effective adaptive capacity. The accumulated information and data are the foundation for developing shared knowledge. The shared knowledge will improve the quality of decisions and responses during crises and enhance situational awareness among various system actors.

Use of Technology

The use of technology is recommended whenever deemed necessary in any adaptive capacity related features. However, the use of technology in the detection and data gathering process is critical as it conserves time and effort.

Organizational Structure

The hierarchy and the line of authority largely impact the process and the speed of the system's response to disturbances. The organizational structure defines the roles, responsibilities, and authorities through which it influences the dynamics of adaptive capacity.

Decentralization

Systems are considered decentralized when authority is not concentrated at the top level but shared through the hierarchy. These systems are more dynamic and able to quickly adjust and adapt due to their short decision cycles. Centralized systems should be prepared to move to a more decentralized structure during crises.

Clarity of Roles and Responsibilities

When a complex system experiences a disturbance that destabilizes the system, the roles and responsibilities become ambiguous which hinders its ability to respond. Therefore, clarity of roles and responsibility in a time of disturbance is essential to avoid the situation of having "too many cooks in the kitchen."

Restructuring and Transformability

When a complex system is hit by an adverse event, the existing system structure may not be able to effectively respond to the newly emerging conditions. Therefore, restructuring becomes inevitable. The restructuring may include modifications in lines of authority, relationships, operations, management systems, and governance. In some cases, limited restructuring cannot accommodate the level of needed change and there is a necessity for a fundamental reform that transforms the system to a new state when the original state became undesirable.

Leadership

The role of leadership is pivotal in creating and maintaining high adaptive capacity through good management, and strategy. Leaders are needed to lead the effort of advancing the ability of the system to adapt and adjust to disturbances. The leadership is instrumental in making necessary decisions, building trust, initiating partnerships, easing conflicts, managing resources, and engaging stakeholders. The needed leadership traits are not limited to executives but extend to anyone who has authority. Leaders with emotional intelligence seem to have positive impact in creating a healthy atmosphere that helps in adaptation.

Speedy Decision Making and Rapid Response

In complex systems' disturbances, we compete with time as things usually accelerate quickly in a dynamic manner, and "time is money" — and sometimes lives. Therefore, timely response and deliberate decisions, which are based on accurate facts, are essential to promote adaptive capacity.

Resources Management

Resources are always scarce and will never be infinite. During crises, managing resources in the most efficient way is critical in strengthening the ability of the complex system to adapt to the new conditions. Resource management should be in line with the prioritization process.

Prioritization

It is an ongoing process of evaluating management tasks and ranking them based on their urgency and importance. The prioritization process aids in enabling speedy decision making and good resource management.

Adaptability Strategy

High-level strategy is embraced by the leadership that defines the system response to disturbances. The strategy represents a road map to navigate the system crises through adaptive capacity.

Effective Communication

Effective communication is the most coded criteria in this study. The role of effective communication is central and without it, no adaptive capacity can be achieved. The effective communication system is necessary at all times, but in a time of crisis, it becomes a cornerstone in making quick decisions, effective responses, and comprehensive plans as well as reaching out to stakeholders. It represents the veins of the complex system.

Collaboration

Collaboration includes cooperation and coordination efforts to build partnerships within the system's various actors or external entities. Collaboration usually targets specific tasks or addresses certain needs.

Information Sharing

Obtaining information and data is crucial, yet no effective response is possible without access to the necessary information. Timely information sharing and having accessible channels for all stakeholders can significantly accelerate necessary decisions and responses.

Stakeholder Engagement

Stakeholders include all individuals, groups, and entities that can impact or be impacted by the complex system. The process of stakeholder engagement can be established by identifying stakeholders, classifying them into primary and secondary, analyzing their roles and influence, and assessing the level of engagement needed based on their importance. Stakeholders often have different agendas. Therefore, it is important to avoid conflict of interests among them.

Transparency

Credibility, honesty, and truthfulness are crucial for all stakeholders to act fast and in an effective manner. Moreover, transparency is key to building trust among stakeholders.

Planning

Planning is the ability to develop, and regularly evaluate plans that respond to either existing vulnerabilities or expected adverse events. This can involve detailed, flexible, or high-level planning depending on the situation in hand. Planning is an ongoing effort, not only before the occurrence of a crisis but also in the middle of it.

Coherence

Coherence refers to the integration of diverse entities and capabilities into achieving a common objective. The unity of efforts of all primary stakeholders is essential for a successful preparedness and effective response.

Consistency

This refers to the consistency of all governing rules, policies, regulations, and standards within the system and outside of its boundaries. Consistency also involves avoiding conflicting messages in dealing with stakeholders to ensure a shared vision.

Context

It is crucial to appreciate and understand the system's surrounding conditions, patterns, and circumstances that influence the system and may facilitate or limit its ability to adapt and survive a disturbance. It is important to note that the context is dynamic and constantly evolving.

Holism

Due to the high interdependence among complex systems' entities, it is vital to understand how all diverse systems' elements interact with each other. Therefore, avoid conducting incoherent and isolated preparedness apart from the whole system's holistic view.

Governance

Governance refers to all internal policies, rules, and mechanisms that should promote adaptive capacity and its dimensions. Accountability, rapid decision making, and flexibility are all core areas to establish governance and achieve adaptive capacity.

Accountability

Effective accountability is necessary for all governance practices, such as accountability for the proper use of resources. Clarity of responsibilities should go hand-in-hand with clarity of accountability measures.

Flexibility

Care must be taken that good governance should accommodate some degree of flexibility in its policies, rules, and regulations. This does not mean loose governance, however, effective governance that considers the need for flexibility whenever deemed necessary, especially during times of unanticipated adverse events.

Cognition

All mental processes that are related to perceiving risks and sensemaking their severity and scale.

Situational Awareness

The process of forming a good understanding of what is going on around us. It is centered around the comprehension of information inflow and the ability to frame it in the right context. In other words, the ability to see through the crises irrespective of its ambiguous nature and incomplete information.

Challenge Assumptions

Assumptions are not facts. According to the Cambridge dictionary, an assumption is "something that you accept as true without question or proof." During an adverse event, decision-makers should not let their unchecked assumptions influence their decisions, which should, instead be built on facts and accurate information.

Silo Mentality

The imaginary barriers that people create that hamper their ability to cooperate and effectively communicate with other people and entities.

Organizational Culture

The set of shared values, beliefs, norms, attitudes, and practices that shape the culture within the complex system. The shared culture can have a significant impact on advancing adaptive capacity in many aspects, such as innovation, flexibility, dynamic learning, trust, and transparency. Besides, the organizational culture in safety-related applications can prevent significant threats and save the system firsthand.

Innovation

Complex systems are usually challenged with unanticipated risks which highlight the importance of creativity and innovation. New and unique risks usually require novel and unique methods to address them. The room for innovation should be always available in the practices of all complex system functions, and not just in a time of crises. Innovation should be involved in the processes of detection, analysis, planning, and response.

Autonomy

Some degree of autonomy is necessary to foster adaptive capacity dynamics, such as a quick decision-making process. Going through the line of hierarchy for every emerging problem in rapidly changing conditions will undoubtedly slow the response and hinder the adaptive capacity. Autonomy is also necessary for creating innovative solutions to emerging novel threats.

Trust

Building a culture of trust among stakeholders (e.g. executives, personnel, clients, contractors, suppliers, media, community, etc.) is fundamental in unifying their effort towards a common objective. The atmosphere of trust will advance the adaptation effort to the emerging circumstances in the event of crises, whereas, lack of trust will disjoint these efforts.

Human Resources Preparedness

The human dimension is the most valuable asset in any complex system. Human resources preparedness directly impacts the way an adverse event is handled. Preparedness includes, but is not limited to education, training, performance management systems, and required skills.

Training

The quality and the amount of training that personnel receive impact their preparedness in dealing with any emerging conditions. Proper training should be provided to all personnel in different risk-related matters to enhance their knowledge and skills as well as creating a wide risk awareness among them.

Experts and Talent Acquisition

The ability to recruit, train and retain the most talented people can have a significant impact on all adaptive capacity aspects, such as innovation, planning, knowledge creation, training, organizational culture, and cognition and awareness.

The following section describes the third phase of the analysis process which results in establishing an adaptive capacity instrument. This section is followed by a discussion of the final phase which is the validation process.

PHASE III. ADAPTIVE CAPACITY INSTRUMENT

The literature has few assessment methods designed to evaluate adaptation in the environmental and ecology contexts. As discussed in chapters one and two, there is no adaptive capacity assessment methodology that targets complex systems. Adaptive capacity is a new concept in the areas of engineering management, systems engineering, and systems theory. Therefore, it was imperative to closely study this emerging notion in those disciplines. This study is devoted to cultivating an understanding of adaptive capacity in the context of engineering management and systems engineering.

Grounded theory was used in this research since it is one of the most powerful research tools to explore new phenomena or theories. The previous two phases aid in identifying and conceptualizing criteria necessary to assess adaptive capacity in complex systems. Thus, these organizational criteria need to be situated in an adaptive capacity instrument to serve its purpose. The instrument has criteria, structure, and scale. The criteria have been identified in Phases I and

II of this study, and the structure and the scale were drawn from Gupta et al. (2010) and Polsky et al. (2007).

There are four practical reasons behind building this instrument:

1. After the first two phases of this study, it was necessary to set the derived criteria into a structured instrument to achieve its ultimate purpose.
2. The adaptive capacity instrument will assist researchers, practitioners, decision makers and other stakeholders in making informed decisions to assess and enhance their adaptive capacity as well as dealing with disturbances.
3. Ease of use and communication: the instrument encompasses all the criteria in one structure through which the communication with regards to showing its elements and results becomes much easier.
4. Through the application of the adaptive capacity instrument, stakeholders can visualize the areas of weaknesses and strengths. Therefore, they can invest and allocate their resources in an appropriate manner.

The resulted adaptive capacity instrument shown in Figure 10 consists of the following:

1. Thirty-eight adaptive capacity criteria grouped into nine main categories. The main categories are dynamic learning, effective communication, leadership, organizational culture, planning, human resources preparedness, cognition, organizational structure, and governance. Under each category there are sub-categories. They all form criteria to assess adaptive capacity.

2. The center of the instrument indicates its purpose that is confirmed by the selective coding, which is adaptive capacity criteria. Every element connected to the center is considered an organizational criterion.
3. The second ring in the middle represents the nine main categories of assessing adaptive capacity.
4. The third ring consists of sub-categories that are related to their parent categories in the second ring.

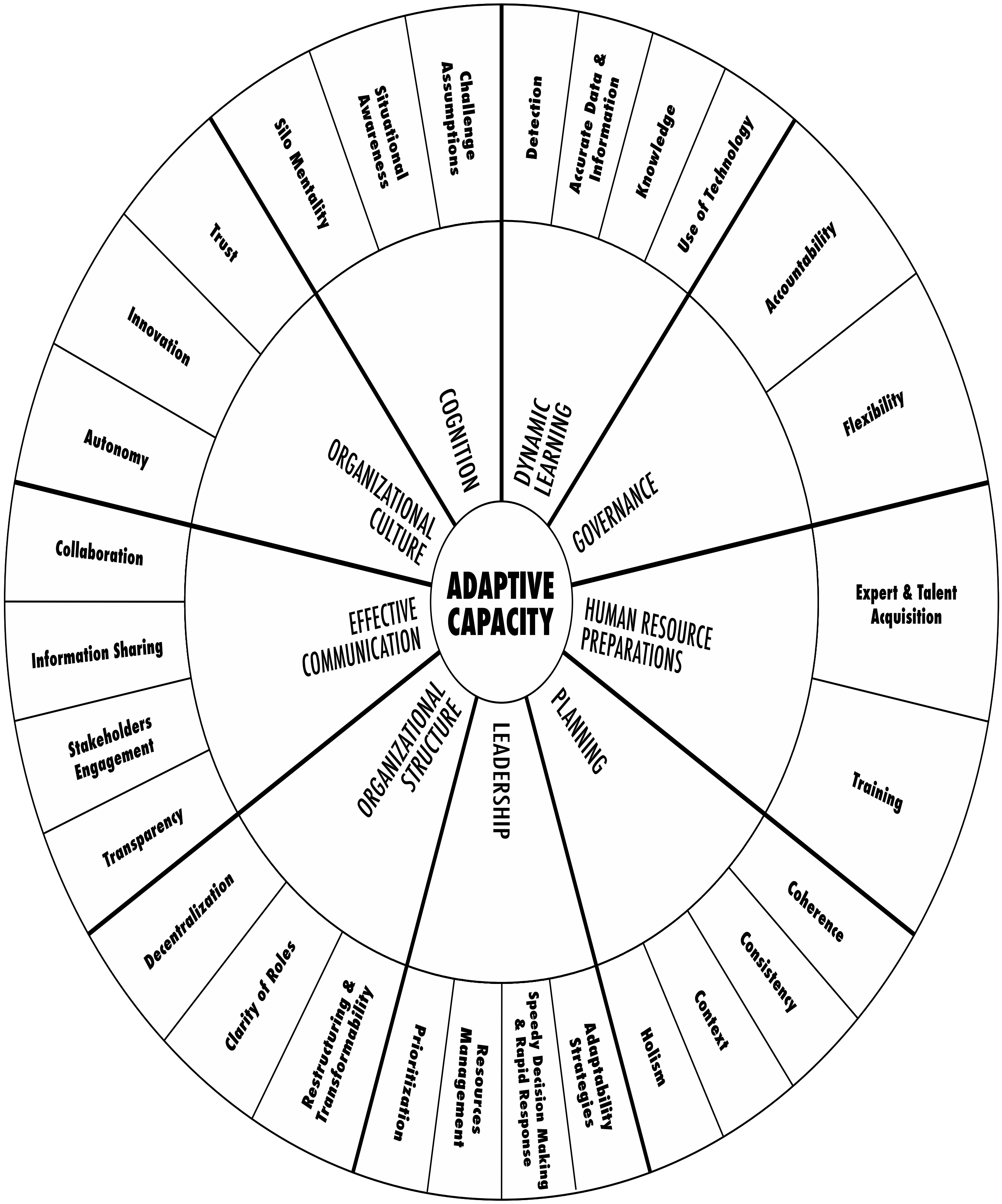

Figure 10. The Adaptive Capacity Assessment Instrument

For future application of the assessment instrument, it is important that it be accompanied with a scoring scale. The scoring scale assists in gaging adaptive capacity in a particular complex system and shows areas of weaknesses and strengths. The scoring scale (Table 18) is adopted from Gupta et al. (2010) as they developed a similar model but in a different context. The adopted scoring system ranges between (+2) which is the highest positive effect and given a green color code. The lowest negative effect in the scoring system is (-2) which is given a red color code. The numerical assessment can range between these two numbers.

Table 18. Adaptive Capacity Scoring Scale

Effect of a Criterion on Adaptive Capacity	**Score**
Positive Effect	2
Slightly Positive Effect	1
Neutral or No Effect	0
Slightly Negative Effect	-1
Negative Effect	02

When dealing with the adaptive capacity instrument it is imperative to point out that:

- The criteria are not working in a parallel and isolated manner. Instead, almost all criteria are interrelated with each other. For example, resources management is necessary to develop most of the organizational criteria such as human preparation, dynamic learning, and others. Also, some organizational criteria are dependent on each other. For instance, dynamic learning cannot be achieved without effective communication components. The overlap, interrelationships, and dependency are mostly common the organizational criteria in the instrument.

- However, there is a possible tension among some criteria. For example, there is a possible tension between resources management and other criteria that require resources investment. Also, it is possible to have tension among governance, innovation, and autonomy.
- The adaptive capacity assessment instrument captures the necessary organizational factors to promote adaptive capacity in a complex system. It is not an alternative for business continuity plans, disaster management plans, risk response plans, crises management plan, etc. However, the instrument includes essential organizational qualities in the system that are necessary for the success of any risk/crises/disaster plan. Adaptive capacity augments all other risk management/analysis efforts in complex systems.

Context of the Adaptive Capacity Assessment Instrument

The instrument is developed to be suitable to the complex system problem domain in complex organizations and high-hazard industries such as mining and oil and gas industries. However, one of the most important aspects that determine the successful application of the instrument is appreciating the context within which the system is embedded including the political and institutional context. The system's context can be defined as the set of circumstances, factors, conditions, values, and patterns that influence the system and may constraint or enable its development, execution, and evolution (Keating & Katina, 2015). Therefore, prior to the application of the instrument, a detailed contextual analysis should be performed as part of a structured protocol that should be tailored and designed for the complex system under investigation. The contextual analysis consists of four elements (Adams & Meyers, 2011):

- Identification: this step involves identifying all relevant contextual aspects that can influence the system.
- Assessment: this step focus on studying the impact of the identified contextual aspects such as the degree and scale of influence.
- Response: the strategies and activities that should be taken in response to the assessment step.
- Monitoring: given the dynamic nature of complex systems, continuous monitoring of the changes in the context is vital. Therefore, this step focuses on identifying the changes and restarting the loop again.

PHASE IV. VALIDATION

The validity in qualitative research is different as compared to quantitative research. Internal, external, validity, and reliability are not relevant concepts to the qualitative research (Creswell, 2009; Leedy & Ormrod, 2010). The validity in qualitative research indicates that the researcher should apply strategies and techniques to ensure the accuracy of the research findings. Leedy and Ormrod (2010), in their discussion of validity in qualitative research, stated that "researchers use a wide variety of approaches to support the validity of their findings. Different approaches are appropriate in different situations, depending on the nature of the data and the specific methodologies used" (p.101). This flexibility has kept the door open for the researcher to find the appropriate method that can confirm their findings.

Terms such as trustworthiness, credibility, authenticity, and verification are used in the qualitative research literature to indicate validity (Creswell, 2009; Leedy & Ormrod, 2010). Creswell (2009) recommends employing one or more strategies to ensure validity, such as using triangulation, thick description, and external validity.

In this research, several strategies and techniques were used to enhance the validity and accuracy of the findings:

- Throughout the **Open Coding Process**, several techniques were used to maintain the theoretical sensitivity and ensure accuracy of the coded segments. These techniques - as discussed previously in Chapter Three - include the flip-flop technique, making close-in and far-out comparisons, questioning, and the red flag technique.
- **Triangulation** is one of the most widely used strategies to enhance validity in qualitative research. It means that the researcher uses more than one source of data to build a coherent justification of the finding (Creswell, 2009; Leedy & Ormrod, 2010). Therefore, to promote qualitative validity, researchers use different sources that contribute into creating a coherent theme.

  In this study, several sources of data were used to support the validity of the research findings. The data sources include academic journal articles (with enormous numbers of case studies), government publications, investigation reports, white papers, and reports published by the private sector. The purpose of diversifying the data sources is to ensure a holistic view of adaptive capacity that takes into consideration the different perspectives from various actors in the complex systems realm. When tackling an emerging concept, such as adaptive capacity, it is critical to address it from all viewpoints. This is because different actors have different perspectives and these perspectives together can form a more holistic assessment of adaptive capacity in complex systems.
- **Conceptualization**. Creswell (2009) indicated that *thick description* is one of strategies that supports validity. The second phase of this research is conceptualization of the

identified criteria, which aims to provide a clear and sufficient description of more than 40 identified criteria. Conceptualization adds clarity to these criteria, so that the reader can have a good grasp of not only adaptive capacity criteria, but also their exact meaning and context.

- **Subject Matter Experts** (SMEs) are an important step in enhancing validity; subject matter experts were asked to provide their feedback on the findings of this study. For this specific purpose, a structured protocol was developed.

The following section discusses the structured protocol that is designed and applied to elicit the subject matter experts in this research.

Expert Opinion Structured Protocol

Generally, expert elicitation is used when there is uncertainty or incomplete knowledge or data with regards to a certain researched subject. Therefore, eliciting experts can help in bridging this knowledge gap (Engel & Dalton, 2012; Hemming et al., 2018; Knol et al., 2010). The subject matter experts protocol in this study is used as a verification step to further enhance validity of the research findings. To further validate this study, a four-step structured protocol was developed. These steps include:

- Characterization the need for SMEs' validation
- Preparation
- Eliciting SMEs Opinions
- Response Analysis

Step 1: Characterization the need for subject matter experts (SMEs) validation

As explained above, eliciting the subject matter experts aims to enhance the validity of the study at hand. Adding to the validity is expected through verifying the following:

- **The importance of adaptive capacity in the context of enhancing resilience in complex systems**. The importance of an adaptive capacity emerges from its ability to improve the system's capacity to adjust and cope with all circumstances that may develop following a disturbance in complex systems. However, the notion of adaptive capacity is not commonly used as a clear concept in outside ecology and environmental research. Therefore, one of objectives of this study to expand the discussion of adaptive capacity to include the engineering management, systems analysis, and risk management landscape.
- **Assessing adaptive capacity is key**. Introducing adaptive capacity into new disciplines not only defines the concept; but extends to setting clear standards that precisely identify and describe the characteristics of this concept. Thus, it is vital to understand how complex systems can improve their adaptive capacity, and what the factors are that can contribute to and impact this capacity. This research undertakes the mission of developing an adaptive capacity assessment instrument through rigorous research design.
- One of the main objectives of this step is **eliciting the subject matter experts** on the adequacy of the identified criteria to assess adaptive capacity in complex systems from organizational perspective.
- **Comprehensiveness of identified criteria**. This study yields thirty-eight organizational criteria to assess adaptive capacity. As a validity step, experts were asked to review the identified criteria and provide their feedback, for example, in adding, merging, or removing certain criteria in the case of duplication, redundancy, and inadequacy.
- **The expected effectiveness of the suggested assessment instrument in informing the decision-makers**. One of the important factors that reflect the expected effectiveness of the instrument is its anticipated ability to predict the capacity of the systems to cope with

disturbances and consequently inform decision makers of the weakness and the strengths of their complex systems in term of adaptive capacity.

Step 2: Preparation

The preparation step should be preceded by identifying and defining the need for the elicitation (step 1). The preparation step involves preparing the scope and format of this study, selecting experts, developing supported material regarding the description of the study, and designing the elicitation questions. These steps are discussed in the following section in more detail.

- **Scope and Format**. The elicitation focuses on validating the outcomes of the study.

The elicitation was sent via email to all the SMEs. Each SME responded individually to the elicitation.

- **Selection of Experts**. The number of experts is selected based on a similar elicitation in the literature that has been conducted in the past, such as Plumb (2011). Four subject matter experts were invited to participate in the elicitation.

  There are four criteria for selecting the subject matter experts:

  - **Education**. Educational background of the expert should be in a related field to the study at hand, such as engineering, management, and environmental science.
  - **Direct Experience**. The expert should have no less than 10 years of experience in a field related to the study.
  - **Broad Knowledge in the Subject Matter**. All selected subject matter experts are expected to have a broad knowledge in their field and that, for example, can be exhibited through their current positions and/or effective participation in activities such, publications, conferences, workshops, technical and academic writings, etc.

- **Willingness to Participate**. Subject matter experts will not be elicited unless they accept the invitation and are willing to participate in the study.

- **Study Description**. A brief description of the study was sent to the potential SMEs via email to solicit their acceptance to participate. Once they were identified as willing to participate, they received a summary of the study which included an introduction, a brief description of the methodology, and outcomes of the study (refer to Appendix B).
- **Elicitation Questions**: The SMEs were invited to answer questions related to the findings of the research (i.e. the adaptive capacity assessment instrument and its criteria). The developed questions are meant to be clear, and free from ambiguity. Also, they should be written in a language that aligns with common knowledge in the field (Hemming et al., 2018). Based on these rules, eight questions that directly responded to the needs discussed in step 1 were developed (refer to Appendix C).

Step 3: Eliciting SMEs' Opinions

After performing all necessary preparations discussed in step 2, the elicitation was sent via email to each subject matter expert individually. The responses were received within 7 days.

Step 4: Response Analysis

An electronic questionnaire has been used as the mode of collection for all questions. Web-based questionnaires are fast, easy to use, and practical options for collecting data. The time frame of collecting the responses was envisioned to be around one week depending on the rate of successful responses. Follow-up emails were sent to noncompliant participants 3 days after the initial email request.

Once the responses were received, they were analyzed based on four dimensions:

- The role of adaptive capacity assessment in enhancing overall resilience;

- The expected effectiveness of the suggested instrument;
- The importance of the assessment instrument for decision-makers; and
- The comprehensiveness of identified criteria.

The Role of Adaptive Capacity Assessment in Enhancing Resilience

The first question in the questionnaire was designed to seek the experts' opinions on the role of adaptive capacity in enhancing the overall resilience of complex systems as it is a novel subject in complex systems realm. The question is:

- *Assessing adaptive capacity at the organizational level can improve overall resilience in complex systems* (*strongly agree, agree, neutral, disagree, and strongly disagree*).

Resilience in this research is defined as "the capacity to decrease vulnerability, the ability to change and adapt, and the ability to recover quickly from disruption" (Erol, Henry, Sauser, & Mansouri, 2010, p.1). All experts agreed on the importance of adaptive capacity in enhancing the overall resilience in complex systems (Appendix D). The experts' response was imperative as it confirms the position of adaptive capacity as a central component of resilience in complex systems.

The Expected Effectiveness of the Suggested Instrument

SMEs were asked to provide their opinions on the expected effectiveness of the suggested instrument to predict the ability of the complex system to cope with disturbances. Three questions were asked to predict the effectiveness of the instrument. The questions are as follows:

- *The proposed adaptive capacity wheel can assess adaptive capacity in complex systems* (*strongly agree, agree, neutral, disagree, and strongly disagree*)

- *The organizational criteria suggested in the wheel can predict the ability of a complex system to cope with disturbances emerging from its internal dynamics* (*strongly agree, agree, neutral, disagree, and strongly disagree*).
- *The organizational criteria suggested in the wheel can predict the ability of a complex system to cope with disturbances emerging from the external environment* (*strongly agree, agree, neutral, disagree, and strongly disagree*).

The first question was to seek the experts' opinion on the overall ability of the instrument (the wheel) to assess adaptive capacity in complex systems. It is important to highlight that the experts expressed their opinions with regards to the expected effectiveness in the absence of a specific protocol to apply the instrument. The second and third questions were focused on the expected effectiveness of the suggested criteria to predict the ability of complex systems to cope with disturbances internally and externally, respectively. The responses of the SMEs were 75 percent positive for all three questions (Appendix D). It is important to note the effectiveness of the instrument cannot be fully tested without applying the instrument in a real-world complex system problem.

The Importance of the Assessment Instrument for Decision-Makers

One of the key objectives of this research is to provide the decision-makers with an instrument to evaluate their systems' adaptive capacity and consequently make informed investment decisions. SMEs were asked whether the current instrument can help decision-makers to identify areas of weaknesses and strengths associated with adaptive capacity. The question is:

- *How important is the proposed wheel and its criteria for decision-makers to identify areas of weaknesses and strengths associated adaptive capacity? (very important, important, fairly important, slightly important, not important)*

All experts think that the instrument is very important in guiding decision-makers to make informed decisions.

The Comprehensiveness of Identified Criteria

The last area of evaluation is circled around the comprehensiveness of identified adaptive capacity criteria. There are two questions in the questionnaire that are meant to respond to this area. The questions are:

- *Do you think the proposed wheel encompasses all potential organizational factors that can impact adaptive capacity in complex systems? (all factors, almost all factors, some factors, few factors, none)*
- *Do you think there are other organizational factors that can enable adaptive capacity in complex systems and not included in the wheel, please list them below? [open-ended question]*

All experts think that "almost all criteria" represent potential organizational factors that can impact adaptive capacity in complex systems. Some experts suggested elaboration on certain dimensions, here are the suggested factors by the experts:

- Inclusion as part of the organizational culture
- Environmental factors
- Organizational memory as part of dynamic learning or situational awareness.

Table 19 provides a reflection of the experts' responses based on the aforementioned four-dimensions. Experts have shown positive impact of the need, and expected effectiveness of the proposed instrument as well as the adequacy of the thirty-eight organizational criteria. All responses are provided in Appendix D.

Table 19. Expert Response Analysis

Area of validation	Associated Question/s	SMEs Response Discussions		
		Positive	**Neutral**	**Negative**
The importance of adaptive capacity assessment in enhancing overall resilience	Question 1	All experts (100%) have agreed that adaptive capacity is important to improve overall resilience		
The expected effectiveness of the suggested instrument	Questions 2, 3, and 4	75% of experts think that the suggested instrument is effective and can predict adaptive capacity in CS.	25% of experts were neutral	
The importance of the assessment instrument for decision makers	Question 5	All experts (100%) think that the instrument is important to inform decision makers		
Comprehensiveness of identified criteria	Questions 6 and 7	All experts think that “almost all factors” in the instrument impact adaptive capacity in CS.		

CHAPTER SUMMARY

This chapter has presented the analysis, results, and interpretations of this research. It started with establishing an analytical approach for the data source. The analytical process resulted in selecting one hundred and two datasets from various sources. The datasets have gone through a detailing grounded theory coding analysis. The open coding analysis resulted in deriving sixty-two codes that represent the preliminary organizational factors. Open coding was followed by axial coding analysis, where all the relationships, correlations among the derived codes are analyzed. There were several analysis techniques that were used in this phase, such as causal conditions, phenomenon analysis, and intervening conditions. The researcher applied some techniques to maintain high theoretical sensitivity techniques, namely: questioning, comparison through using the flip-flop technique and waving the red flag. The axial coding has yielded thirty-eight organizational factors grouped into nine categories. The selective coding process has concluded that all thirty-eight factors represent criteria to assess adaptive capacity in a complex system. The last phase of this chapter has focused primarily on validating the findings of the study by subject matter experts. The experts have provided positive feedback about the applicability and the expected effectiveness of assessment instrument.

CHAPTER V

CONCLUSION

This chapter presents a summary of the study, and discusses the research implications from theoretical, methodological, and practical dimensions. It also illustrates the research limitations and concludes with recommendations for future research.

RESEARCH SUMMARY

The primary purpose of this research is to develop an assessment instrument that captures the organizational factors that enable adaptive capacity in complex systems. The first chapter of this research provided a thorough background about the importance of adaptive capacity as a key component of resilience in complex systems. Besides, the chapter explained the purpose of the study, research questions, and research significance. The chapter concluded by providing definitions of the key terms that will be used in the research.

The second chapter focused on the related literature to the study at hand. It began with discussing the adaptive capacity literature, its related terms, and themes as well as its assessment methods. Then the chapter elaborated on the characteristics of complex systems. The third chapter illustrated the research design approach. It is a four-phase methodology. The first phase is concerned with using the grounded theory coding process, the second phase is the conceptualization of the organizational factors derived from the grounded theory process. The third phase is the development of the assessment instrument. Validating the study using subject matter experts in the final phase of the study.

The fourth chapter of this study has shown the detailed analysis results of the execution of the research methodology. The adaptive capacity assessment instrument was developed. The instrument consists of thirty-eight criteria grouped into nine categories. The study’s findings were then validated by subject matter experts. The experts reflected positive feedback about the applicability of the developed assessment instrument.

RECOMMENDATIONS FOR FUTURE RESEARCH

- The scope of this research starts with building the theory for adaptive capacity in complex systems and concludes with developing its assessment instrument. Yet, it does not include applying the instrument into a real-world complex system. Therefore, the next step is to take the instrument into the application and use the assessment instrument to measure the adaptive capacity in a particular complex organization/system. This research has laid the foundation for more researches that are concerned with resilience and adaptive capacity applications.
- This research has focused on the organizational factors that are responsible for enabling adaptive capacity in complex systems. However, the assessment does not cover technical and sociotechnical elements as some of these dimensions are unique to a certain industry. Therefore, adaptive capacity can be extended to these areas in specific industries. For instance, adaptive capacity in the oil and gas industry can be studied thoroughly from organizational, technical, and sociotechnical aspects.
- One of the potential areas of research that can be built on this dissertation is to develop application techniques and structured protocols on particular applications of the assessment instrument. This can be achieved through finding out what is the best approach to apply the criteria (e.g., surveys, structured interviews, semi-structured interviews, reviewing policies, records, and document, etc.) and how it can be applied (i.e., external or internal team). The suggested protocol can be tailored to a particular industry/system/organization

to account for aspects that should be followed in accordance with the industry/system context.

- To come up with an assessment instrument, this research used academic journal articles, investigation reports, technical papers, and governmental publications to derive criteria to assess adaptive capacity through rigorous qualitative research. The research design approach that was used in this study can be used with similar topics or issues.
- The organizational criteria associated with adaptive capacity are not static but may evolve or change over time based on the dynamic nature of complex systems. This study does not claim that the derived criteria are final. In fact, all researchers who are concerned with resilience and adaptive capacity are encouraged to build on this study by suggesting modifications or providing critiques to improve its effectiveness.

RESEARCH IMPLICATIONS

The implications of this research from theoretical, methodological, and application perspectives are addressed in this section.

Theoretical Perspective

This research contributes to the engineering management and systems engineering (EMSE) body of knowledge by introducing the notion of adaptive capacity into the field. The ability of complex systems to adapt to and cope with the internal emerging conditions resulting from disturbances is critical for their survival. However, the literature lacks any instrument, method, or model that is purposefully designed to assess their preparedness for such crises. This research fills this gap in the literature and introduces the concept of adaptive capacity with its assessment instrument that consists of thirty-eight factors. Therefore, one of the theoretical implications that can be drawn from this research is its ability to use a new concept of adaptive capacity and tailor it to the needs of the complex systems' domain.

Methodological Perspective

Due to the novelty of adaptive capacity in the area of EMSE, the researcher has adopted the grounded theory methodology to explore the organizational factors through which adaptive capacity can be assessed. Grounded theory is a methodology used to explore a new theory that is grounded in the data through systematic analysis and coding (Strauss & Corbin, 1994). It is imperative to use the appropriate research design approach that can achieve the purposes of this study. The grounded theory approach was followed by conceptualizing all organizational factors that resulted from the coding process. The importance of the conceptualization phase stems from the need to provide a clear and concise meaning of all the derived factors to be used in the analysis instrument. The validation process was necessary to verify the findings of the study by subject matter experts. Therefore, these methodological processes represented a road map to achieve the primary purpose of the study. Further, as noted, the four-phase research design approach that was used in this study can be applied to similar research purposes/needs in the field of engineering management and systems engineering.

Applications Perspective

From a practice perspective, this research provides application opportunities in various forms of complex systems. All modern organizations represent complex systems and are prone to constant unanticipated threats as they operate in a dynamic environment. Therefore, enhancing their adaptive capacity should be part of building their resilient systems. All the organizational criteria involved in the assessment instrument are applicable to all modern organizations. Organizations or industries that wish to apply the proposed adaptive capacity instrument can develop their suitable application protocol. The adaptive capacity instrument can be applied to any complex systems including government institutions, private sector organizations, and non-profit organizations.

This research has important outcomes. The following section sheds some light on some of the key research outcomes.

REVIEW OF RESEARCH OUTCOMES

Identification of the key criteria that enable adaptive capacity in complex systems. Thirty-eight organizational criteria were identified through a rigorous qualitative method. They encompass all elements to promote and evaluate adaptive capacity in complex systems. The QSR-NVivo software was in the qualitative coding analysis process. QSR-NVivo is a powerful tool that was used to systematically analyze the huge amount of data using the grounded theory research approach (Hutchison et al., 2010).

Characterization of adaptive capacity criteria. Following the identification of adaptive capacity organizational factors/criteria using grounded theory analysis, a description of each factor was provided. This step is important as it clarifies any misconceptions, and ambiguity related to the criteria and put all criteria into a clear perspective.

Development of an adaptive capacity assessment instrument. One of the purposes of developing the assessment instrument is to unify the identified criteria and put them into a more practical perspective. The instrument is accompanied by a scoring scale that facilitates its application in the real world.

From theory to application. The contribution of this research is not limited to theory development but extends into the real-world. The developed instrument that is built on the derived criteria serves as an instrument to measure the level of preparedness of complex organizations in the face of adverse events and tests their ability to adapt to any disturbances. Thus, decision-makers will be able to uncover their organizational strengths and weaknesses and take necessary actions. For instance, decision-makers can efficiently allocate their resources in accordance with the assessment instrument outcomes.

STUDY LIMITATIONS

This section is concerned with the limitations associated with this research and discusses techniques and strategies that the researcher used to mitigate these limitations. The main limitations can be summarized as the following:

- The novelty of adaptive capacity: The notion of adaptive capacity is a new concept in the field of engineering management and systems engineering and under-researched in areas such as risk management, organizational resilience, organizational behavior, and organizational theory. Therefore, the literature lacks a rich discussion of adaptive capacity and how it is associated with disturbances. The discussion of adaptive capacity is mostly limited to ecology, environmental research, and other related fields. This posed a challenge to the researcher who needed to transition and cultivate the notion of adaptive capacity into the field of engineering management and systems engineering.

- The proposed adaptive capacity instrument in this research has no similar models, techniques that are concerned with assessing adaptive capacity, and that are designed for complex systems. Therefore, there were existing instruments that can be a reference for comparison purposes. The similar instruments and models in the literature are concerned with measuring general resilience and vulnerability (Erol et al., 2010; Justice et al., 2016; Lee et al., 2013; Luers et al., 2003; Mcmanus et al., 2007; Tierney & Bruneau, 2007). Adaptive capacity in these models is either missing or treated as a whole in one factor with no operationalization of the concept. There are a limited number of studies that are concerned with assessing adaptive capacity and are mostly concentrated in the ecology or environmental research fields (Brooks & Eakin, 2004; Engle, 2011; Ford & King, 2015; Yohe & Tol, 2002).
- One of the limitations is associated with the grounded theory that is used in this research. Olesen (2007) highlighted the embeddedness of the researcher may impact data construction and interpretation. Also, the large amount of data associated with the grounded theory should be analyzed through the three stages of the coding analysis processes.

The researcher has implemented some techniques and strategies to mitigate the above limitations through the following:

- Due to the novelty of the notion of adaptive capacity in the engineering management and systems engineering fields, the grounded theory was the most appropriate research design to be used. The grounded theory is designed particularly to develop an understanding of topics that are not theoretically developed (Charmaz, 2007; Glaser, 1992, 1998; Hull, 2013; Strauss & Corbin, 1990). Therefore, the researcher should not have assumptions and predeterminations of the study findings. Therefore, this limitation is mitigated by using grounded theory as a research design approach to identify organizational factors associated with adaptive capacity.

- Two strategies were used to mitigate the lack of similar instruments in the field of engineering management and systems engineering. First, in order to take advantage of the existing adaptive capacity instruments in other fields, the researcher has drawn the structure and the scale of his instrument from Gupta et al., (2010) and Polsky et al. (2007). Building on previous research that tackled similar problems is important, especially in the case of developing new concepts in the landscape of our engineering fields. The second strategy that was adopted to mitigate the lack of similar instruments in the engineering field is through the implantation of the validation phase. Subject matter experts with diverse backgrounds were invited to participate in validating the findings of the study. For this purpose, a structured protocol was designed to conduct the validation of the developed adaptive capacity assessment instrument. The process was carried out as per the protocol and resulted in overall positive responses.
- When performing the open coding process, the researcher has maintained a high level of theoretical sensitivity. It is important that the researcher approaches the data with no predetermined assumptions or preconceived ideas and maintains sensitivity to the data by being able to capture any adaptive capacity theme without any effect of preconceived assumptions. In this regard, the researcher has employed three techniques to maintain theoretical sensitivity: flip-flop techniques, questioning, and waving the red flag technique.

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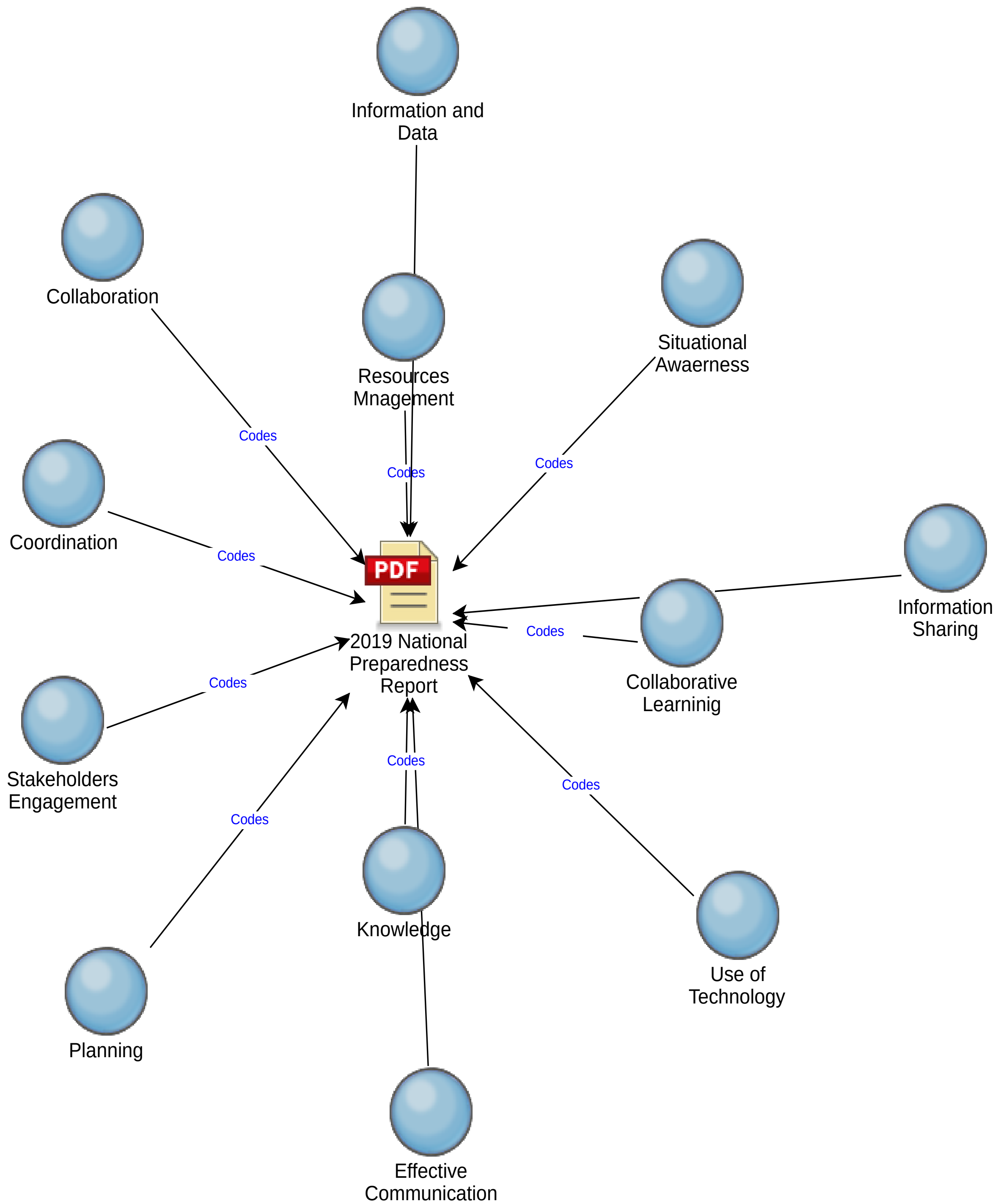
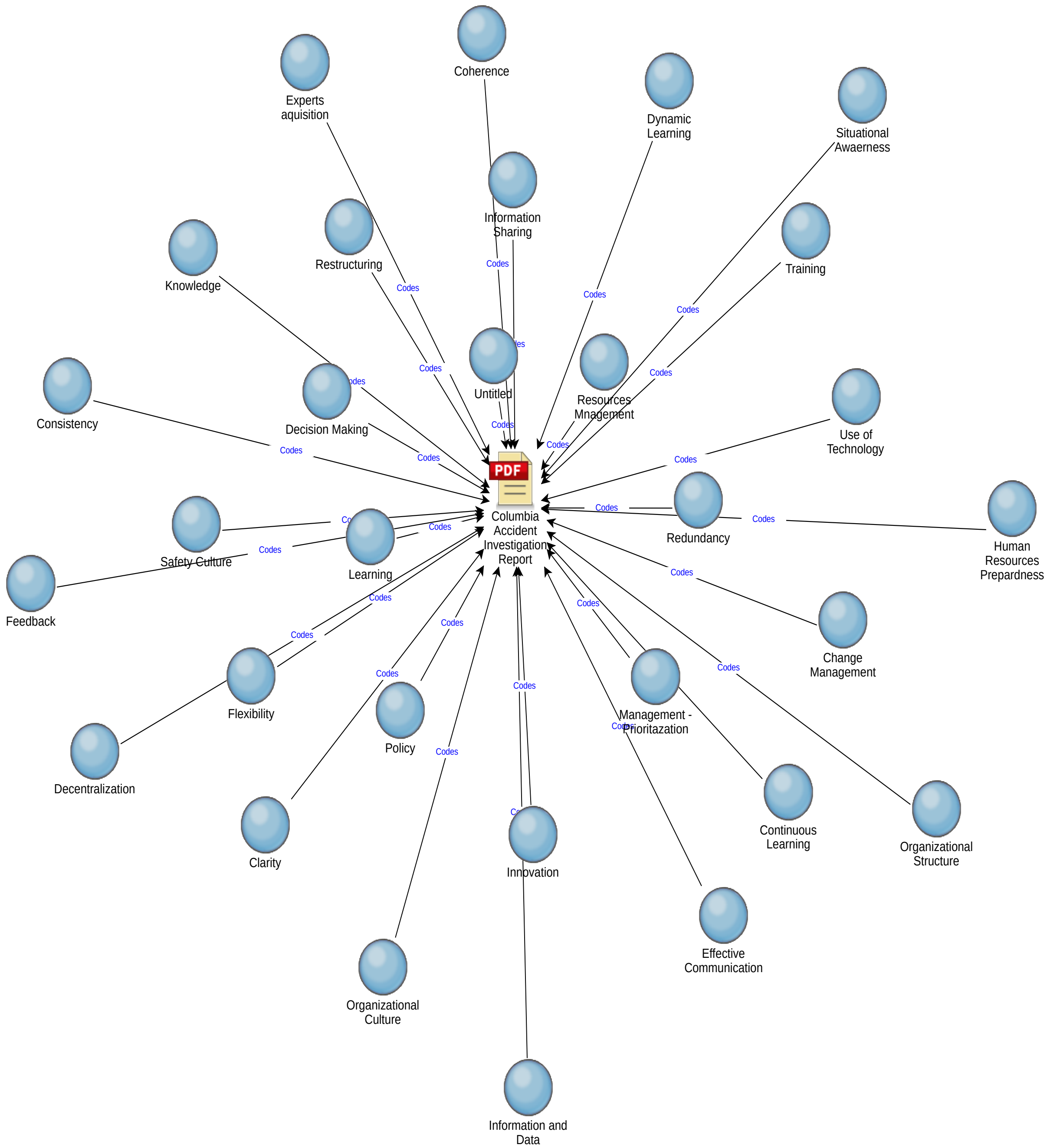
APPENDIX A: GROUNDED THEORY ANALYSIS - NVIVO RESULTS

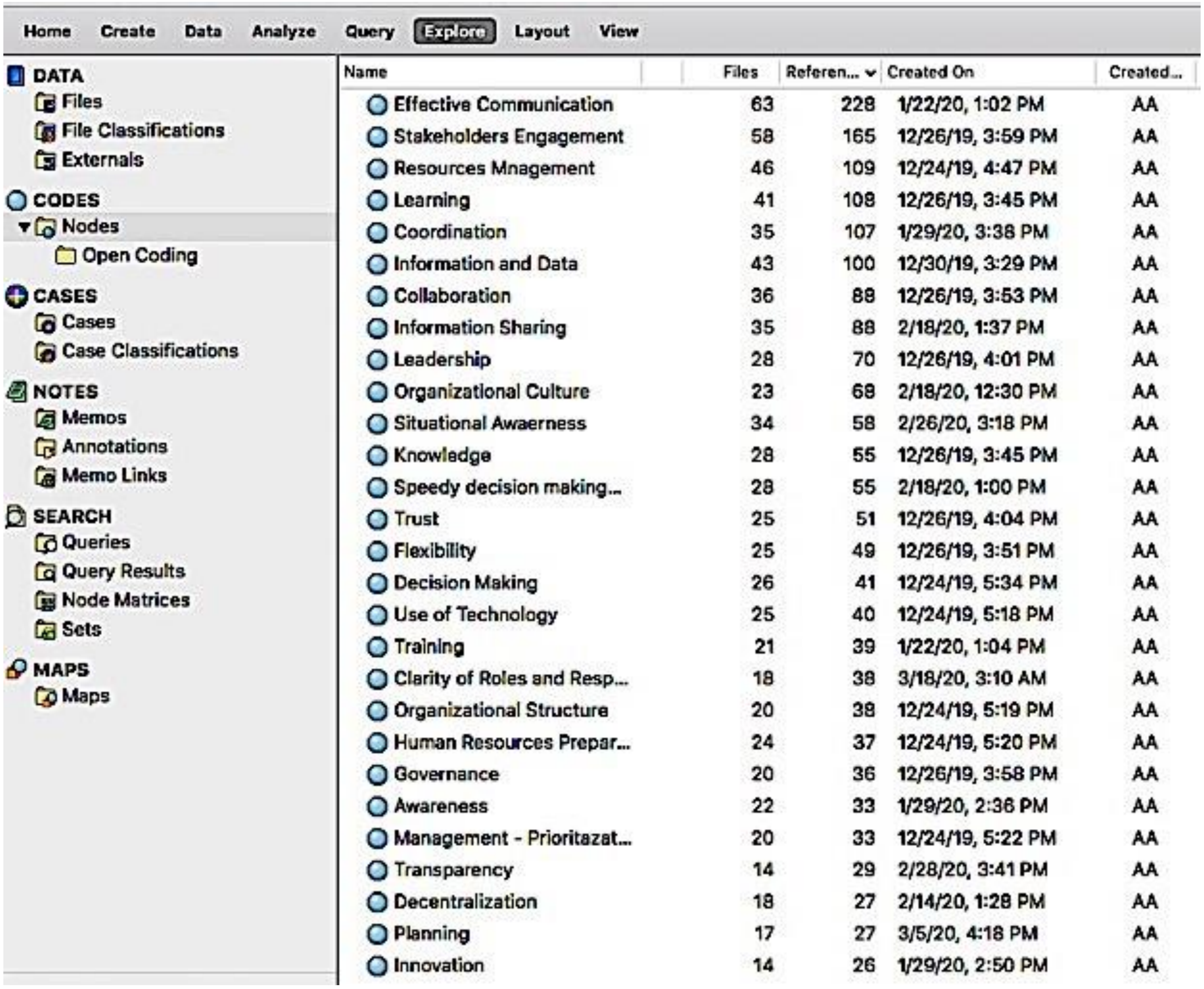
Codes of a White Paper



Codes of a Government Report (Department of Homeland Security)

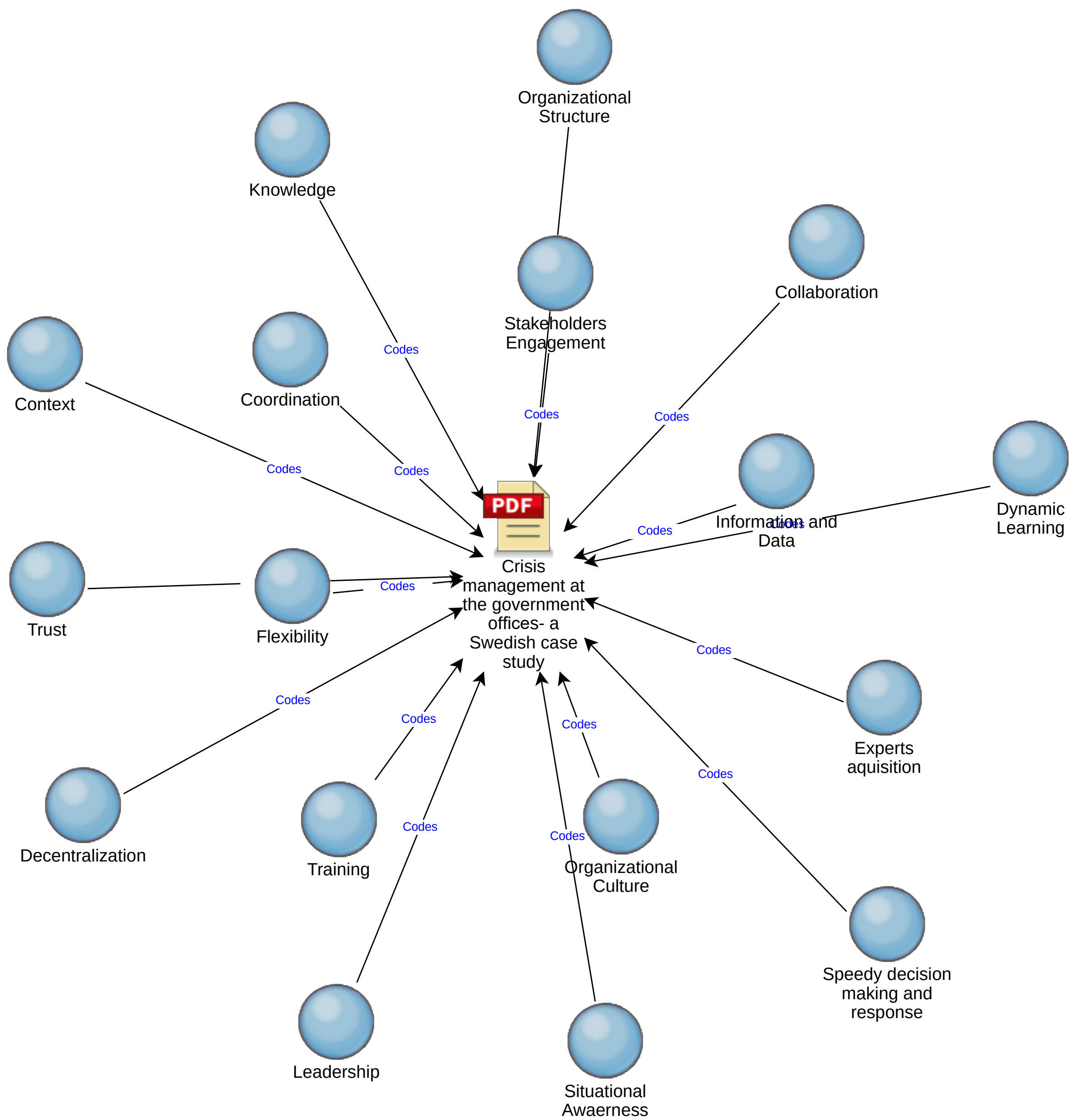


Codes of an Investigation Report (Columbia Accident Investigation Report)

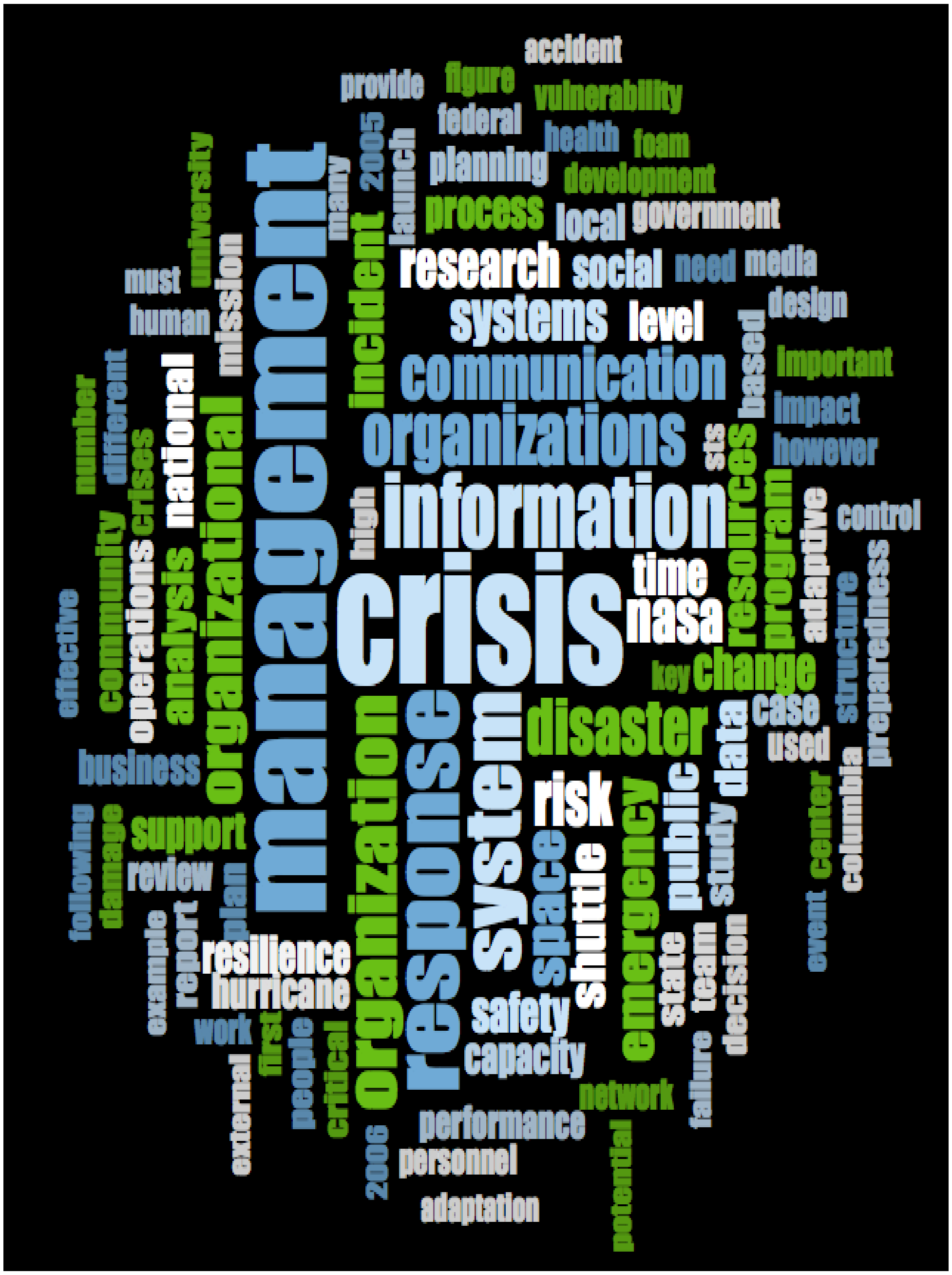


Name	Files	Referen...	Created On	Created...
Effective Communication	63	228	1/22/20, 1:02 PM	AA
Stakeholders Engagement	58	165	12/26/19, 3:59 PM	AA
Resources Mnagement	46	109	12/24/19, 4:47 PM	AA
Learning	41	108	12/26/19, 3:45 PM	AA
Coordination	35	107	1/29/20, 3:38 PM	AA
Information and Data	43	100	12/30/19, 3:29 PM	AA
Collaboration	36	88	12/26/19, 3:53 PM	AA
Information Sharing	35	88	2/18/20, 1:37 PM	AA
Leadership	28	70	12/26/19, 4:01 PM	AA
Organizational Culture	23	68	2/18/20, 12:30 PM	AA
Situational Awaerness	34	58	2/26/20, 3:18 PM	AA
Knowledge	28	55	12/26/19, 3:45 PM	AA
Speedy decision making...	28	55	2/18/20, 1:00 PM	AA
Trust	25	51	12/26/19, 4:04 PM	AA
Flexibility	25	49	12/26/19, 3:51 PM	AA
Decision Making	26	41	12/24/19, 5:34 PM	AA
Use of Technology	25	40	12/24/19, 5:18 PM	AA
Training	21	39	1/22/20, 1:04 PM	AA
Clarity of Roles and Resp...	18	38	3/18/20, 3:10 AM	AA
Organizational Structure	20	38	12/24/19, 5:19 PM	AA
Human Resources Prepar...	24	37	12/24/19, 5:20 PM	AA
Governance	20	36	12/26/19, 3:58 PM	AA
Awareness	22	33	1/29/20, 2:36 PM	AA
Management - Prioritazat...	20	33	12/24/19, 5:22 PM	AA
Transparency	14	29	2/28/20, 3:41 PM	AA
Decentralization	18	27	2/14/20, 1:28 PM	AA
Planning	17	27	3/5/20, 4:18 PM	AA
Innovation	14	26	1/29/20, 2:50 PM	AA

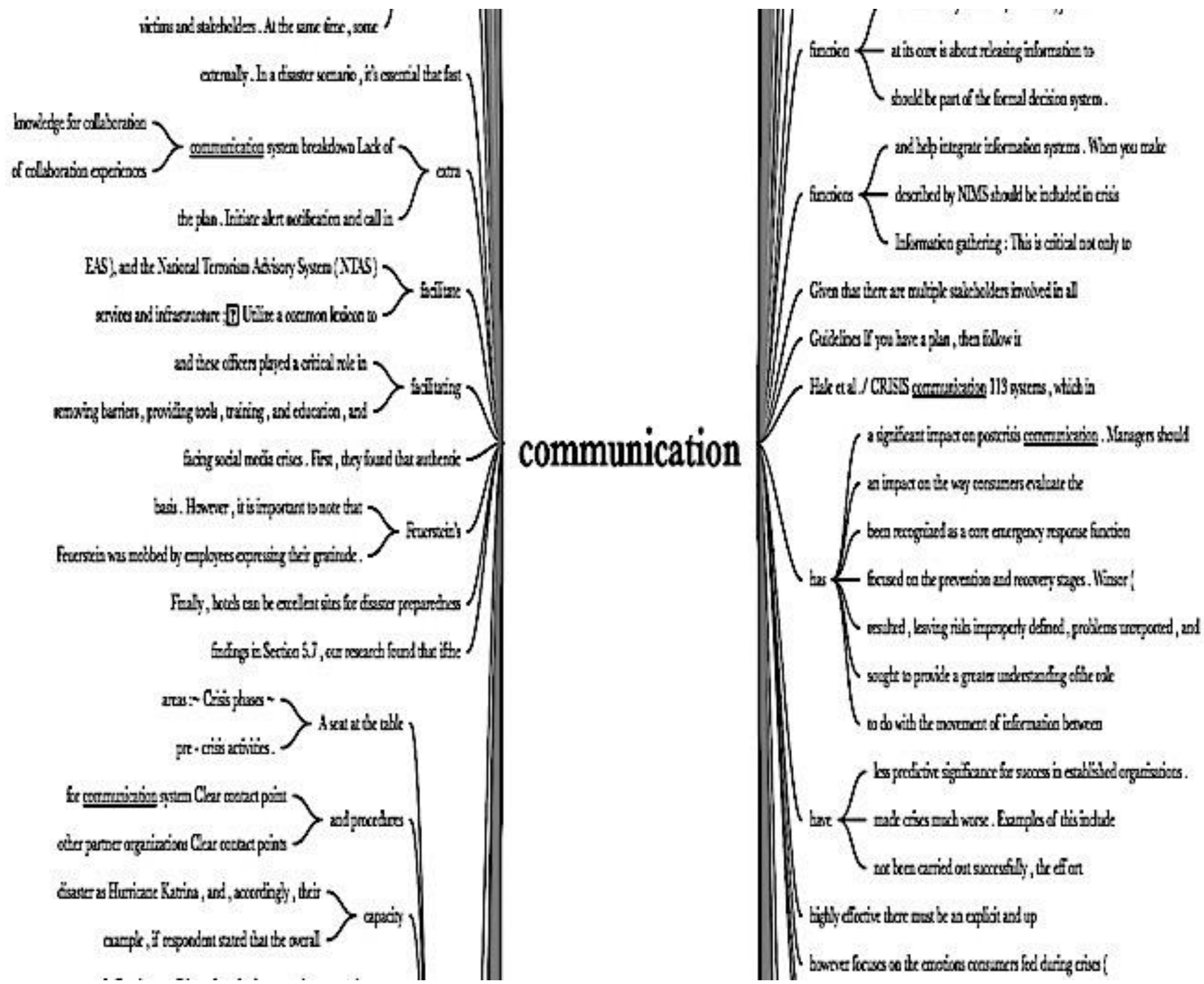
Snapshot of the open coding results from NVivo software



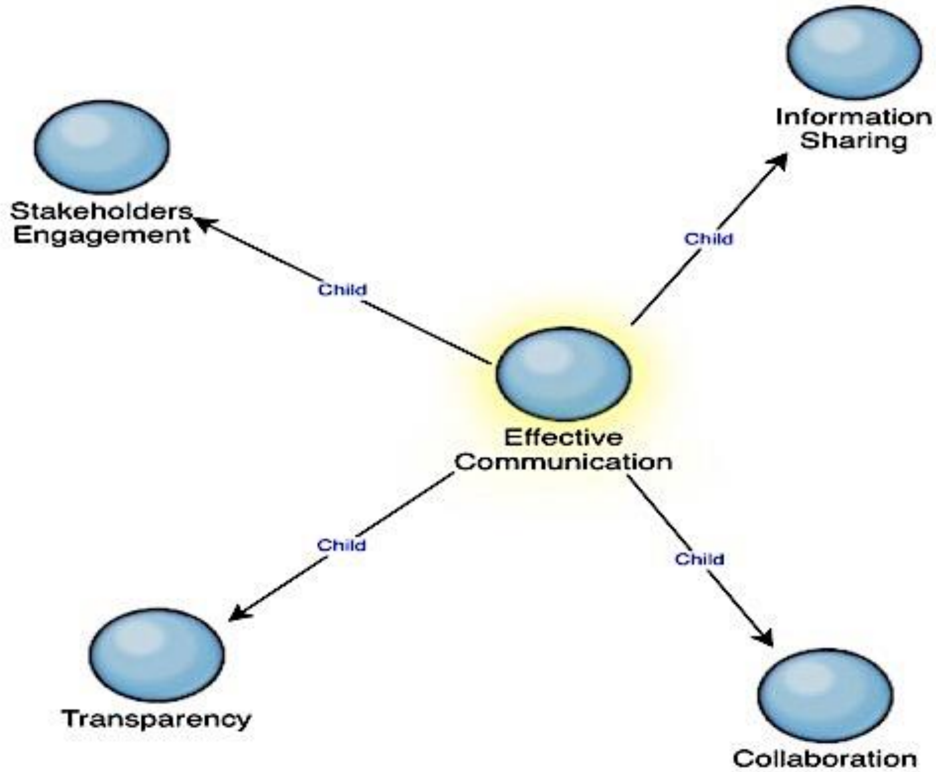
Codes of a Journal Article (Case Study of the Swedish Government)



Dataset word cloud obtained from NVivo



Text Query Analysis



Example of the connection between parent node and child node

Tree Map Analysis- Axial Coding

APPENDIX B: RESEARCH SUMMARY FOR SMES

A FRAMEWORK FOR ADAPTIVE CAPACITY IN COMPLEX SYSTEMS

INTRODUCTION

Complex systems are characterized by their high level of inter-connectivity, ambiguity, and emergence. Therefore, a failure in one element of the system (e.g. cyber layer), due to external or internal disturbance, can lead to a cascade effect that may influence all elements of the system. Consequently, a complex system will not be able to perform its functional performance. Threats originating from complex systems are very dynamic, fast, complex and damage can be severe. Thus, to respond to the nature of complex systems and their associated threats, organizations need to be highly adaptive to survive and thrive in the face of adverse events. Adaptive capacity gives the system the ability to adjust and cope with the new circumstances resulting from an adverse event.

PURPOSE OF THE STUDY

This research aims to develop an assessment instrument that captures key organizational factors necessary for enabling and monitoring adaptive capacity in complex systems. These organizational factors serve as criteria to measure the adaptive capacity and improve resilience as well. The presence of these criteria is critical to any complex system, without which resilience is unlikely to happen.

This study is designed specifically to capture organizational factors that serve as criteria to assess the adaptive capacity in complex systems.

ROLE OF SUBJECT MATTER EXPERTS (SMEs)

Expert validation is the final phase of this study (phase IV-refer to the research approach section below). The SMEs will respond to a questionnaire that aims to validate the findings of the study. The findings are represented in an assessment instrument called *the adaptive capacity wheel* (Figure 1, p. 3). Specifically, the SMEs will be sent a questionnaire about the final assessment instrument, its organizational criteria, and anticipated effectiveness. Description of all adaptive capacity criteria -indicated in the wheel- is provided in pages 4-8. The questionnaire will be sent electronically via email to all the SMEs.

KEY DEFINITIONS

- **Adaptive Capacity**: the ability of a system to quickly adjust to change and cope with the new circumstances that resulted from a disturbance.
- **Complex Systems**: "a complex system is a bounded set of richly interrelated elements for which the characteristic structural and behavioral patterns that produce system performance emerge over time and through interaction between the elements and with the environment" (Keating et al., 2005, p. 200). Modern organizations are considered complex systems.

RESEARCH DESIGN APPROACH

The research design approach consists of four phases. Below is a brief description of these phases.

Phase I: Grounded Theory Coding

This phase focuses on establishing the method of grounded theory to identify a set of criteria that are necessary to enable the adaptive capacity in complex systems. This phase consists of four steps:

5- **Establishing the Adaptive Capacity Data Pool:** First, it is necessary to establish the pool that will be used as input into the grounded theory coding process. Data sources include peer-reviewed journal articles from various disciplines, investigation reports of accidents and disasters, government publications, and technical reports and white papers. The number of data sources that was prepared for analysis was 102 data sources.

6- **Grounded Theory Open Coding:** This draws from the data available in the adaptive capacity data pool. Open coding is an analytic process of coding all concepts related to adaptive capacity without any preconceived idea of the coding outcome.

7- **Grounded Theory Axial Coding**: This process is concerned with building relationships and connections among the identified categories in step 2.

8- **Grounded Theory Selective Coding**: Axial coding is the final step in the coding process where a new theory will emerge. It is a process of integrating all coded categories under specific adaptive capacity core criteria.

Phase II: Conceptualization of Identified Criteria

Following the identification of the adaptive capacity criteria, a description is provided for each criterion. The identified criteria are described in the context of complex systems domain (p. 4-8).

Phase III: Development of the Adaptive Capacity Assessment Instrument

This step is crucial as it builds on the previous two phases. The adaptive capacity assessment instrument relies on the results of phase I and phase II. The instrument is designed to capture the organizational factors that enable or restrict the adaptive capacity in complex systems. When applied, the assessment instrument will be able to show the areas of strength or weakness in a complex system under investigation.

Phase IV: Expert Validation

As a validation step, the developed assessment instrument will be reviewed by subject matter experts. The purpose of this step is to validate the assessment instrument before it can be deployed and applied to a specific complex system.

STUDY FINDINGS

After analyzing 102 data sources through an exhaustive research design approach as described above, this study yielded 38 organizational criteria to assess adaptive capacity in complex systems. The identified criteria are grouped into 9 categories and situated in a structure called the *Adaptive Capacity Wheel* (see the figure below). The adaptive capacity wheel represents the final study outcome. Please find the descriptions of the identified 38 organizational criteria in the context of complex systems on pages 4-8.

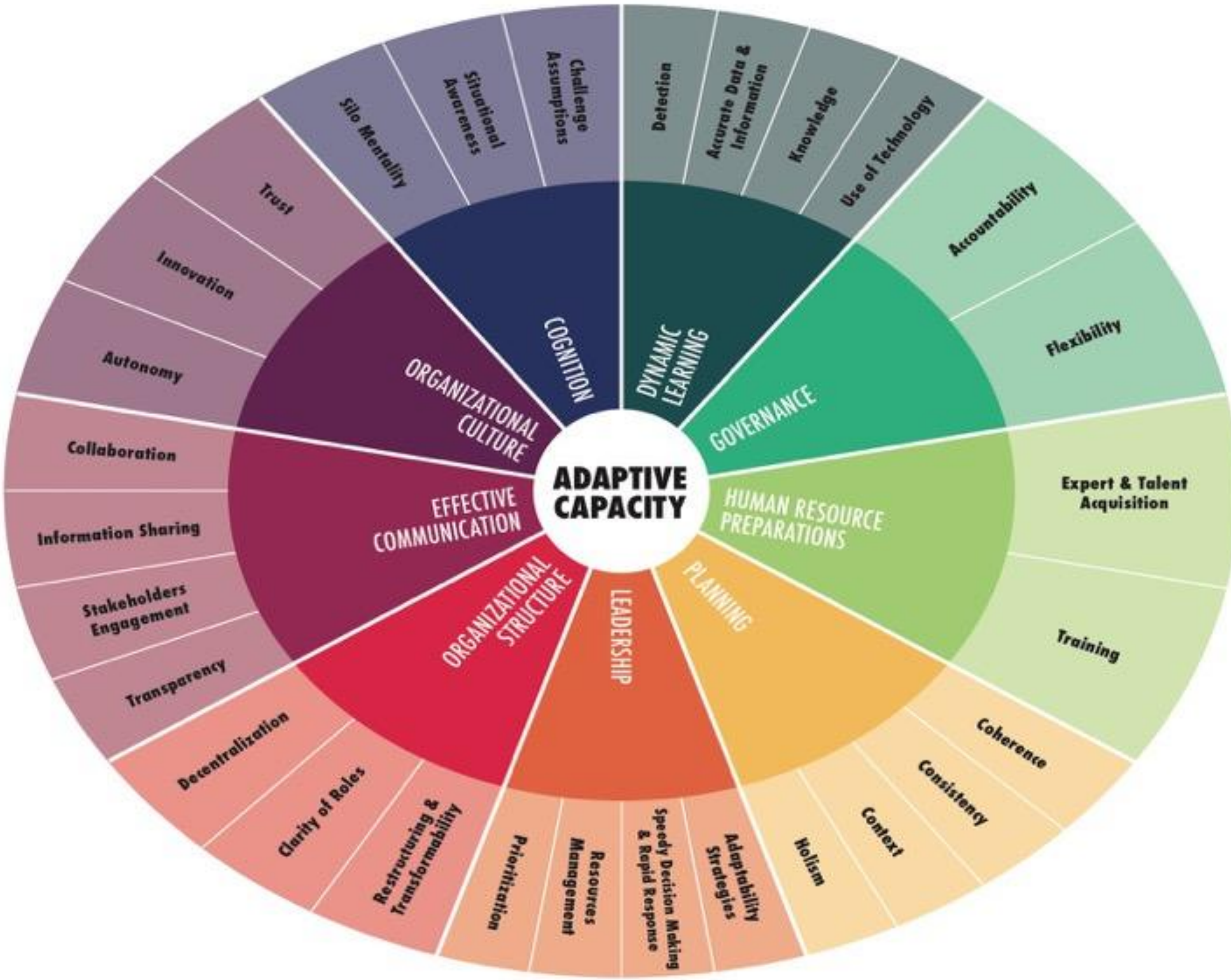


Figure1: Adaptive Capacity Wheel in Complex Systems

DESCRIPTION OF THE ADAPTIVE CAPACITY CRITERIA

DYNAMIC LEARNING
It is a continuous learning process, before, during, and after a disturbance. Adverse events in complex systems accelerate quickly in an unpredicted fashion, and this behavior should be accompanied with a very dynamic learning process that detect, gather information and data, and create knowledge to set the stage for a quick response.
Detection
Complex systems should be equipped with active capabilities to discover early warnings of any emerging threat. Detection is the first step in the dynamic learning process. Once a threat is detected, it should be disseminated through the internal communication system.
Accurate Data and Information
One of the most important factors to achieve adaptive capacity is the ability to quickly gather accurate information and data to be used when needed. One of the challenges associated with complex systems adverse events is ambiguity and incompleteness of data. Incomplete and inaccurate data may do more harm than good. Therefore, it is essential to ensure the accuracy of information gathered as any response will be built on these data.
Knowledge
Developing knowledge is an essential part of the organizational learning process in the context of achieving effective adaptive capacity. The accumulated information and data are the foundation of developing shared knowledge. The shared knowledge will improve the quality of decisions and responses during crises and enhance situational awareness among various system actors.
Use of Technology
The use of technology is necessary whenever deemed necessary in any adaptive capacity related feature. However, the use of technology in the detection and data gathering process is very critical as it saves time and effort.

ORGANIZATIONAL STRUCTURE
The hierarchy and the line of authority largely impacts the process and the speed of the system's response to disturbances. The organizational structure defines the roles, responsibilities, and authorities through which it influences the dynamics of adaptive capacity.
Decentralization
Systems are considered decentralized when large authority is not concentrated at the top level but shared through the hierarchy. These systems are more dynamic and able to quickly adjust and adapt due their short decision cycle. Centralized systems should be prepared to move to a more decentralized structure during crises.
Clarity of Roles and Responsibilities

When a complex system experiences a disturbance that disrupts the system, the roles and responsibilities become ambiguous and that hinders its ability to respond. Therefore, clarity of roles and responsibility in a time of disturbance is essential and to avoid the situation of having "too many cooks in the kitchen".
Restructuring and Transformability
When a complex system is hit by an adverse event, the existing system structure may not be able to effectively respond to the new emerging conditions. Therefore, restructuring becomes inevitable. The restructuring may include modifications in lines of authority, relationships, operations, management systems, and governance. In some cases, limited restructuring cannot accommodate the level of needed change and there is a necessity to undergo a fundamental reform that transforms the system to a new state when the original state became undesirable.

LEADERSHIP
The role of leadership is pivotal in creating and maintaining high adaptive capacity through good management, and strategy. Leaders are needed to lead the effort of advancing the ability of the system to adapt and adjust to disturbances. The leadership is instrumental in making necessary decisions, building trust, initiating partnerships, easing conflicts, managing resources, and engaging stakeholders. The needed leadership traits are not limited to executives but extend to anyone who has authority, large or small. Leaders with emotional intelligence seem to have a positive impact in creating a healthy atmosphere that aids in adaptation.
Speedy decision making and rapid response
In complex systems' disturbances, we compete with time as things usually accelerate quickly in a very dynamic manner, and "time is money"- and sometimes lives. Therefore, timely response and deliberate decisions, that are based on accurate facts, are essential to promote adaptive capacity.
Resources Management
Resources are always scarce and will never be infinite. In the time of crises, managing resources in the most efficient way is critical in strengthening the ability of the complex system to adapt to the new conditions. Resources management should go in line with the prioritization process.
Prioritization
It is an ongoing process of evaluating management tasks and ranking them based on their urgency and importance. Prioritization process helps in enabling speedy decision making and good resources management.
Adaptability Strategy
A high-level strategy embraced by the leadership that defines the system response to disturbances. The strategy represents a road map to navigate the system crises through adaptive capacity.

EFFECTIVE COMMUNICATION
It is the most coded criteria in this study. The role of effective communication is central and without it, no adaptive capacity can be achieved. The effective communication system is

necessary at all times, but in a time of crisis, it becomes a cornerstone of making quick decisions, responses, and plans as well as reaching out to stakeholders. It represents the veins of the complex system.

Collaboration

It includes cooperation and coordination efforts to build partnerships within the system's various actors or external entities. Collaboration usually targets specific tasks or addresses certain needs.

Information Sharing

Obtaining information and data is crucial, yet no effective response is possible without access to the necessary information. Timely information sharing and having accessible channels for all stakeholders can significantly accelerate the necessary decisions and responses.

Stakeholders Engagement

Stakeholders include all individuals, groups, and entities that can impact or be impacted by the complex system. The process of stakeholder engagement can be established by identifying stakeholders, classifying them into primary and secondary, analyzing their roles and influence, and assessing the level of engagement needed based on their importance. Stakeholders often have different agendas; therefore, it is important to avoid conflict of interests among them.

Transparency

Credibility, honesty, and truthfulness are crucial for all stakeholders to act quickly and in an effective manner. Moreover, transparency is key to building trust among stakeholders.

PLANNING

The ability to develop, and regularly evaluate plans that respond to either existing vulnerabilities or expected adverse events. It can be detailed, flexible, or high-level planning depending on the situation in hand. Planning is an ongoing effort, not only before the occurrence of a crisis but also in the middle of it.

Coherence

This refers to the integration of diverse entities and capabilities into achieving a common objective. The unity of efforts of all primary stakeholders is essential for a successful preparedness and effective response.

Consistency

It refers to the consistency of all governing rules, policies, regulations, and standards within the system and outside its boundaries. Also, avoiding conflicting messages in dealing with stakeholders to ensure a shared vision.

Context

It is crucial to appreciate and understand the system’s surrounding conditions, patterns, and circumstances that influence the system and may facilitate or limit its ability to adapt and survive a disturbance. It is important to note that the context is dynamic and constantly evolving.

Holism
Due to the high interdependence among complex systems' entities, it is vital to understand how all diverse systems' elements interact with each other. Therefore, avoid conducting incoherent and isolated preparedness apart from the whole system's holistic view.

GOVERNANCE
Governance refers to all internal policies, rules, and mechanisms that should promote adaptive capacity and its dimensions. Accountability, rapid decision making, and flexibility are all core areas to establish governance and achieve adaptive capacity.
Accountability
Effective accountability is necessary for all governance practices such as accountability for the proper use of resources. Clarity of responsibilities should go hand in hand with clarity of accountability measures.
Flexibility
Care must be taken that good governance should accommodate some degree of flexibility in its policies, rules, and regulations. This does not mean loose governance, however, effective governance that considers the need for flexibility whenever deemed necessary especially during the time of unanticipated adverse events.

COGNITION
All mental processes that are related to perceiving risks and sensemaking their severity and scale.
Situational Awareness
The process of forming a thorough understanding of what is going on around us. It is centered around the comprehension of information inflow and the ability to frame it in the right context. In other words, the ability to see through the crises irrespective of its ambiguous nature and incomplete information.
Challenge Assumptions
Assumptions are not facts. According to the Cambridge dictionary, an assumption is "something that you accept as true without question or proof." In a time of an adverse event, decision-makers should not let their unchecked assumptions influence their decisions that should be built on facts and accurate information.
Minimization of Silo Mentality
An effort to reduce the imaginary barriers that people create, which hamper their ability to cooperate and effectively communicate with other people and entities.

ORGANIZATIONAL CULTURE
The set of shared values, beliefs, norms, attitudes, and practices that shape the culture within the complex system. The shared culture can have a significant impact on advancing adaptive

capacity in many aspects, such as innovation, flexibility, dynamic learning, trust, and transparency. Besides, the organizational culture in safety-related applications can prevent significant threats and save the system firsthand.

Innovation

Complex systems are usually challenged with unanticipated risks which highlight the importance of creativity and innovation. New and unique risks usually require novel and unique methods to address them. The room for innovation should be always available in the practices of all complex system functions, and not just in a time of crisis. Innovation should be involved in the processes of detection, analysis, planning, and response.

Autonomy

Some degree of autonomy is necessary to foster adaptive capacity dynamics such as quick decision-making processes. Going through the line of hierarchy for every emerging problem in rapidly changing conditions will undoubtedly slow the response and hinder the adaptive capacity. Autonomy is also necessary for creating innovative solutions to emerging novel threats.

Trust

Building a culture of trust among stakeholders (e.g. executives, personnel, clients, contractors, suppliers, media, community, etc.) is fundamental in unifying their effort towards a common objective. The atmosphere of trust will advance the adaptation effort to the emerging circumstances during an event of crises, whereas, lack of trust will disjoint these efforts.

HUMAN RESOURCES PREPAREDNESS

The human dimension is the most valuable asset in any complex system. Human resources preparedness directly impacts the way an adverse event is handled. Preparedness includes but is not limited to education, training, performance management system, and required skills.

Training

The quality and the amount of training that personnel receives impact their preparedness in dealing with any emerging conditions. Proper training should be provided to all personnel in different risk-related matters to enhance their knowledge and skills as well as creating a wide risk awareness among them.

Experts and Talent Acquisition

The ability to recruit, train and retain the most talented people can have a significant impact on almost all adaptive capacity aspects such as innovation, planning, knowledge creation, training, organizational culture, and cognition and awareness.

APPENDIX C: VALIDATION QUESTIONNNARE

QUSTIONNAIRE REQUEST LETTER

Dear Participant,

I am writing to request your assistance in participating in a questionnaire as part of my dissertation effort as partial fulfillment of the requirements for the degree of Doctor of Philosophy in Engineering Management at Old Dominion University. The study investigates *'A Framework for Adaptive Capacity in Complex Systems'*.

I would heartily appreciate participating as a subject matter expert and by answering the questionnaire that will be sent to you via email. The questionnaire responses will form an essential source of validity for this study. Please be assured that the information collected will be handled in strict confidence and used only to serve the research purpose.

There is a document attached to this email, it involves a description of the study, key definitions, research methodology, role subject matter experts, and the study findings.

Your cooperation is greatly appreciated.

Best Regards,

Abdulrahman Alfaqiri

Engineering Management and Systems Engineering Department

Old Dominion University 2101 D Engineering Systems Building Norfolk, VA 23529

Email address: aalfa001@odu.edu

Subject Matter Experts Questionnaire

Dear Participant,

This Questionnaire is seeking your opinion based on your experience to validate the findings of this study. This questionnaire is developed to fulfil the dissertation requirements on a study titled: *“A Framework for Adaptive Capacity in Complex Systems”*. A description of the study, methodology, and its findings are provided in a separate document. Based on the research outcomes, the adaptive capacity assessment instrument “the wheel”, and its criteria descriptions, please answer the following questions:

Disclaimer:

* No confidential and personal information needs to be obtained for the purpose of this research.
* Participation in this questionnaire is made voluntary

(1) Assessing adaptive capacity at the organizational level can improve overall resilience in complex systems.

- Strongly agree
- Agree
- neutral
- Disagree
- Strongly disagree

(2) The proposed adaptive capacity wheel can assess adaptive capacity in complex systems

- Strongly agree
- Agree
- neutral
- Disagree
- Strongly disagree

(3) The organizational criteria suggested in the wheel can predict the ability of a complex system to cope with disturbances emerging <u>from its internal dynamics</u>.

- Strongly agree
- Agree
- neutral
- Disagree
- Strongly disagree

(4) The organizational criteria suggested in the wheel can predict the ability of a complex system to cope with disturbances emerging <u>from the external environment</u>.

- Strongly agree
- Agree
- neutral
- Disagree
- Strongly disagree

(5) How important is the proposed wheel and its criteria for decision-makers to identify areas of weaknesses and strengths associated adaptive capacity?

- Very important
- Important
- Fairly important
- Slightly important
- Not important

(6) On a scale of 1 to 5 (1 is low adequacy and 5 is high adequacy), how would you rate the adequacy of the identified criteria to assess adaptive capacity in complex systems

- 1
- 2
- 3
- 4
- 5

(7) Do you think the proposed wheel encompasses all potential organizational factors that can impact adaptive capacity in complex systems?

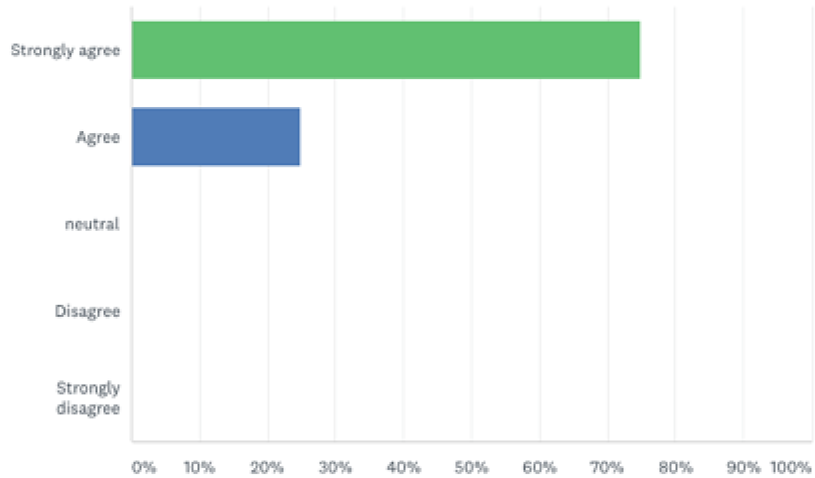
- All factors
- Almost all factors
- Some factors
- Few factors
- None

(8) Do you think there are other organizational factors that can enable adaptive capacity in complex systems and not included in the wheel, please list them below? [open-ended question]

APPENDIX D: QUESTIONNARE RESULTS

Assessing adaptive capacity at the organizational level can improve the overall resilience in complex systems.

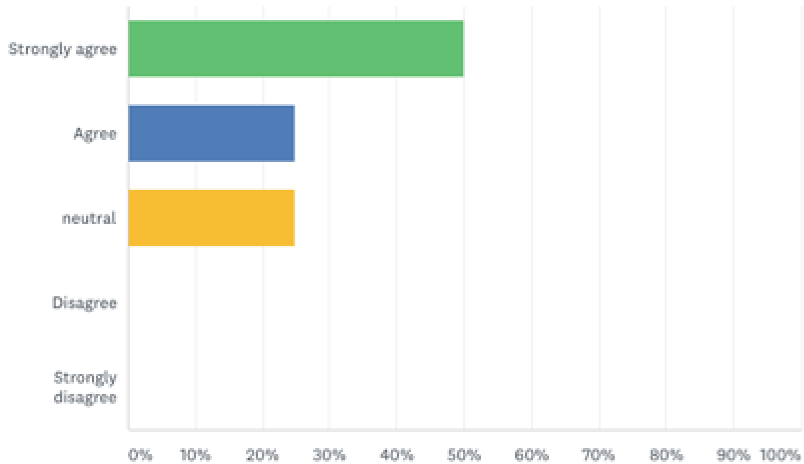
Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
Strongly agree	75.00%	3
Agree	25.00%	1
neutral	0.00%	0
Disagree	0.00%	0
Strongly disagree	0.00%	0

The proposed adaptive capacity wheel can assess adaptive capacity in complex systems

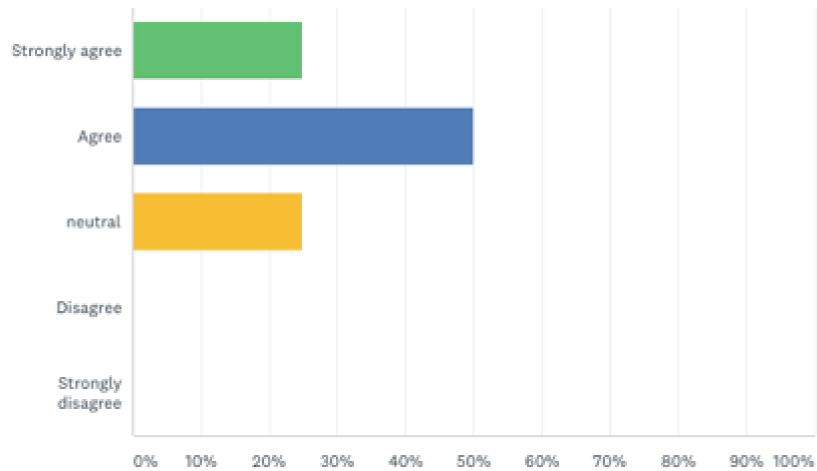
Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
Strongly agree	50.00%	2
Agree	25.00%	1
neutral	25.00%	1
Disagree	0.00%	0
Strongly disagree	0.00%	0

The organizational criteria suggested in the wheel can predict the ability of a complex system to cope with disturbances emerging from its internal dynamics.

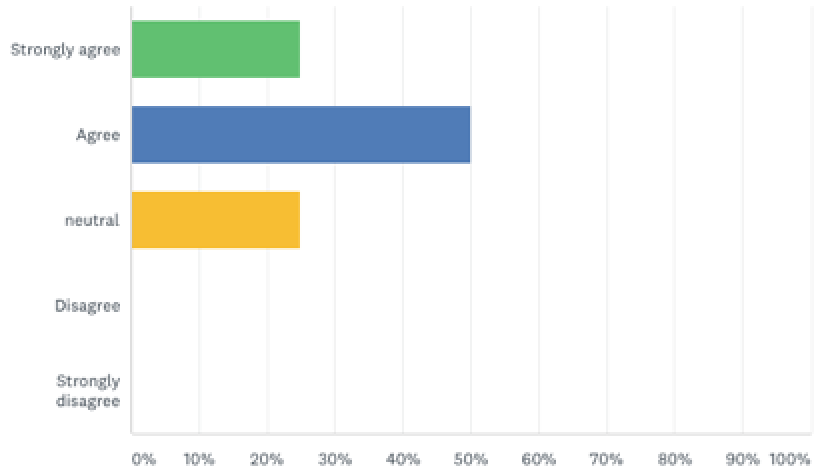
Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
Strongly agree	25.00%	1
Agree	50.00%	2
neutral	25.00%	1
Disagree	0.00%	0
Strongly disagree	0.00%	0

The organizational criteria suggested in the wheel can predict the ability of a complex system to cope with disturbances emerging from its external environment.

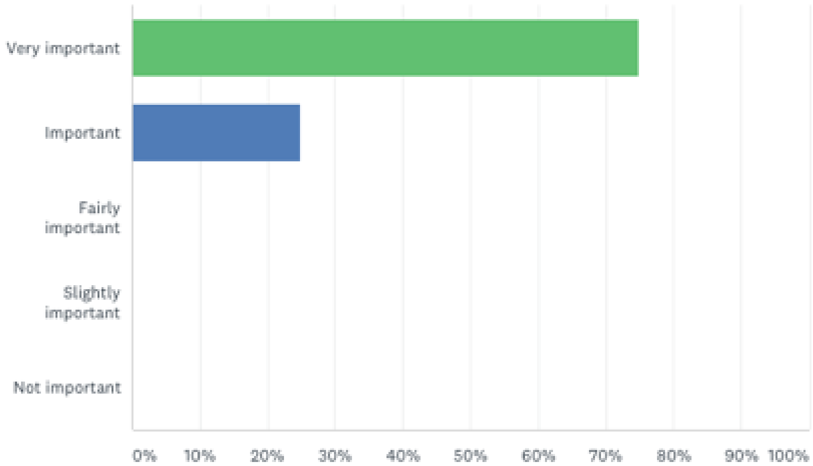
Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
Strongly agree	25.00%	1
Agree	50.00%	2
neutral	25.00%	1
Disagree	0.00%	0
Strongly disagree	0.00%	0

How important are the proposed wheel and its criteria for decision-makers to identify areas of weaknesses and strengths associated with adaptive capacity?

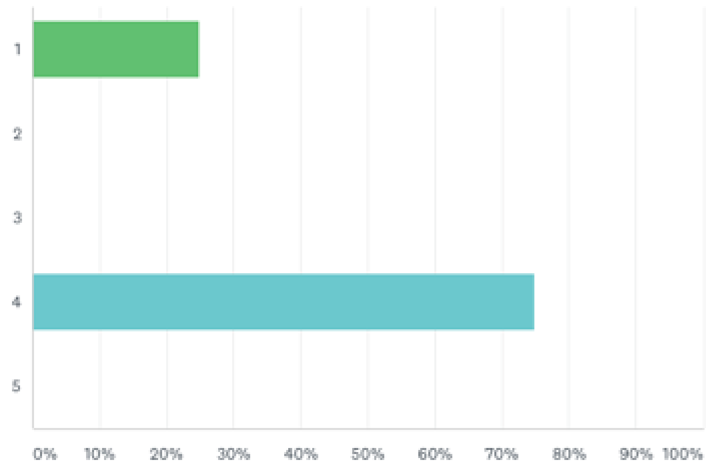
Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
Very important	75.00%	3
Important	25.00%	1
Fairly important	0.00%	0
Slightly important	0.00%	0
Not important	0.00%	0

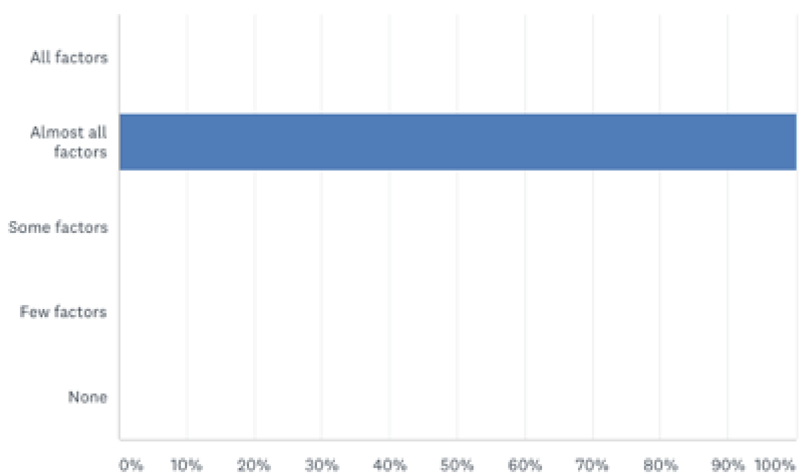
On a scale of 1 to 5 (1 is low adequacy and 5 is high adequacy), how would you rate the adequacy of the identified criteria to assess adaptive capacity in complex systems

Answered: 4 Skipped: 0



Do you think the proposed wheel encompasses all potential organizational factors that can impact adaptive capacity in complex systems?

Answered: 4 Skipped: 0



ANSWER CHOICES	RESPONSES	
All factors	0.00%	0
Almost all factors	100.00%	4
Some factors	0.00%	0
Few factors	0.00%	0
None	0.00%	0

I wonder if some elaboration of the Organizational Culture Dimensions to include an expanded definition of Inclusion as "The experience of inclusion, is "the psychological sense on the part of an individual that he or she is indeed being included" (Ferdman et al., 2009, p. 3), and, more specifically, ""individuals' perception of the extent to which they feel safe, trusted, accepted, respected, supported, valued, fulfilled, engaged, and authentic in their working environment, both as individuals and as members of particular identity groups" (Ferdman et al., 2009, p. 6) might enhance the value of the wheel to predict the ability to identify vital attributes of an "adaptive capacity wheel?"

Organizational memory, which "refers to stored information from an organization's history that can be brought to bear on present decisions", can be an important factor in adaptive capacity. Organizatioal memory can be considered as an output of dynamic learning in the long run or an aspect of situational awareness.

Not specifically, but "all" implies the list is exhaustive. While the wheel is quite comprehensive, there may still be some unknown factors which confound an organization's ability adaptability to adapt.

Environmental factors not incorporated. Who are the stakeholders? What scale? Local ecological knowledge is certainly an important component in preparedness. Innovation is advantageous, but there are plenty of examples whereby risk may be reduced through this traditional knowledge, but it requires trust and listening to these often undervalued members of society.

VITA

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EDUCATION

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January 2010 — **Bachelor of Science- Civil Engineering**, College of Engineering, King Fahd University of Petroleum and Minerals (KFUPM), Dhahran, Saudi Arabia

TEACHING EXPERIENCE

January 2019-May 2020 — **Instructor,** Department of Engineering Management, Old Dominion University, Norfolk, Virginia. ENMA 401 Project Management, ENMA 302 Engineering Economics.

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RESEARCH INTERESTS

Organizational Resilience, Risk Management, Adaptive Capacity, and Systems Analysis