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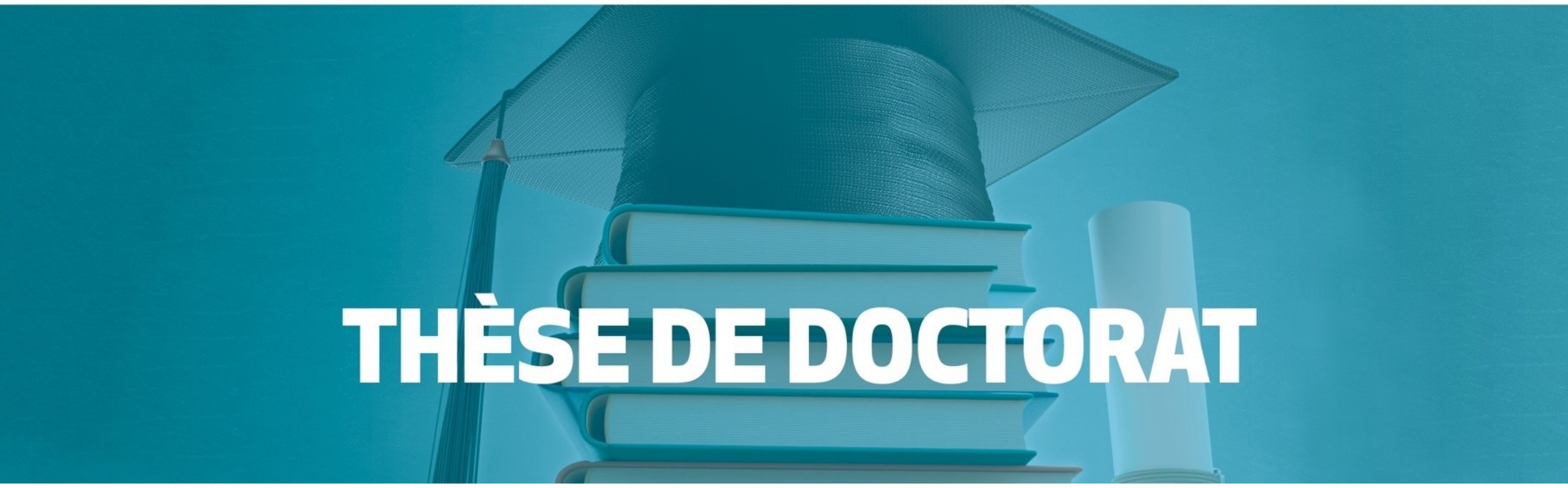

Les défis du développement du leadership en sûreté dans les industries à haut risque : une approche organisationnelle.

Le cas du secteur nucléaire.

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Challenges of Developing Leadership for Safety in High-Risk Industries: An Organizational Approach.

The case of the nuclear sector.

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Les défis du développement du leadership en sûreté dans les industries à haut risque : une approche organisationnelle

Résumé : Malgré les efforts déployés pour accroître la fiabilité organisationnelle, les industries dites à haut risque, telles que la production d'énergie nucléaire, ont connu récemment des catastrophes majeures. Ces accidents conduisent à accorder une attention croissante aux facteurs humains et organisationnels et soulignent l'importance du leadership en sûreté. Ainsi, un nouveau type de sûreté émerge – la sûreté gérée – qui devra s'articuler avec la sûreté réglée. La sûreté réglée s'appuie sur des barrières techniques et procédurales pour faire face aux événements prévisibles ou anticipables ; elle vise ainsi la réduction de l'incertitude. La sûreté gérée vise, quant à elle, à développer des capacités organisationnelles afin de faire face de manière proactive aux événements imprévisibles ; elle a pour objectif la gestion de l'incertitude. Les travaux portant sur les organisations à haute fiabilité et sur la résilience montrent que seul le renforcement mutuel de ces deux types de sûreté peut garantir la fiabilité et la résilience. Toutefois, le développement intensif d'un type de sûreté peut compromettre le développement de l'autre. Ainsi, le développement conjoint de la sûreté réglée et de la sûreté gérée reste un défi majeur à relever, mais encore peu étudié.

La littérature académique souligne le rôle crucial du leadership pour la sûreté, et plus particulièrement pour la sûreté gérée. Toutefois les travaux sur le leadership en sûreté sont encore peu développés et le rôle spécifique du leadership dans le développement conjoint de la sûreté réglée et gérée reste à explorer. La recherche existante sur le leadership en sûreté repose principalement sur des approches centrées sur le leader et ses caractéristiques, mais ces approches sont limitées dans leur capacité à expliquer la relation causale entre l'action des leaders et les résultats sur la sûreté organisationnelle. Des premières recherches s'orientent alors sur l'étude des mécanismes du leadership en sûreté ; elles ouvrent une piste intéressante qui mérite d'être approfondie, notamment par la prise en compte du nécessaire développement conjoint de la sûreté réglée et gérée. Notre recherche vise ainsi à répondre à la question suivante : **Comment les mécanismes de leadership permettent-ils le développement conjoint de la sûreté gérée et réglée ?** Pour ce faire, elle s'appuie sur une étude de cas réaliste critique, menée dans une centrale nucléaire européenne. Ancrer notre recherche dans la perspective du réaliste critique permet de saisir la complexité du leadership en sûreté en découvrant ses mécanismes, en les dissociant des pratiques de leadership observables et en explorant les interactions entre les mécanismes, la structure organisationnelle et les conditions contextuelles. Cette approche a guidé tant notre analyse de la littérature que notre étude empirique. Nos résultats proposent d'abord un modèle émergent décrivant le processus de développement conjoint de la sûreté réglée et gérée et ses mécanismes. Nous en déduisons alors les limites organisationnelles de l'action managériale. Enfin, nous élaborons un modèle du processus du leadership en sûreté qui permet d'explorer les mécanismes du leadership, leurs interactions et leurs modes d'activation pour le développement conjoint de la sûreté réglée et gérée. Grâce à ce modèle, nous analysons tout particulièrement les interactions entre un des mécanismes du leadership (le sensegiving) et un des mécanismes du développement conjoint de la sûreté réglée et gérée (la mindfulness), en prenant en compte le rôle médiateur de la structure organisationnelle.

Ces résultats permettent de contribuer à la littérature sur le management de la sûreté, notamment en révélant les leviers et les limites de l'action managériale et en identifiant les mécanismes du développement conjoint de la sûreté réglée et gérée. Ils contribuent également à la littérature sur le leadership en sûreté en identifiant ses mécanismes et leurs modes d'activation.

Mots-clés : leadership, management de la sûreté, leadership en sûreté, résilience, organisations à haute fiabilité, limites organisationnelles

Challenges of developing leadership for safety in high-risk industries: an organizational approach

Abstract: Despite their efforts to increase organizational reliability, high-risk industries, such as nuclear power production, have experienced major disasters in recent years. These accidents led to greater attention paid to human and organizational factors and underlined the importance of leadership for safety. As a consequence, a new form of safety emerged - managed safety, which must be developed alongside regulated safety. While regulated safety relies on technical and procedural barriers to cope with predictable or foreseeable events and is aimed at reducing uncertainty, managed safety aims to develop organizational capabilities to proactively deal with unpredictable events, and thus deal with uncertainty. Research on high reliability organizations and resilience shows that only a mutual reinforcement of these two forms of safety can ensure reliability and resilience. However, research also shows that the intensive development of one of these forms of safety can jeopardize the development of the other form. Thus, a joint development of regulated and managed safety remains a major challenge, which has not yet been fully studied.

The academic literature emphasizes the crucial role of leadership for safety and, more particularly for managed safety. Notwithstanding some important developments, leadership for safety is still underdeveloped and the role of leadership for safety in the joint development of regulated and managed safety needs to be further explored. The existing leadership for safety research relies mainly on leader-centric approaches, focused on leaders' characteristics, but these approaches are limited in their ability to explain the causal relationship between leaders' actions and organizational safety outcomes. The pioneering research is therefore focusing on the investigation of leadership for safety mechanisms; this opens up an interesting avenue that deserves to be explored further, particularly by taking into account the necessary joint development of regulated and managed safety. In this context, this doctoral research addresses the following question: **How do leadership mechanisms enable the joint development of managed and regulated safety?** This research is based on a critical realist case study of a European nuclear power plant. This critical realist approach allows to capture the complexity of leadership for safety, by uncovering its mechanisms, disentangling them from observable leadership practices, and exploring the interactions among mechanisms, organizational structure and contextual conditions. The critical realist approach guided both the literature review and the field study. We first develop an emergent model describing the process of the joint development of regulated and managed safety and its mechanisms. From this, we then deduce the organizational limits of managerial action. Finally, we also elaborate a model of the leadership for safety process, which allows to explore the mechanisms of leadership, their interplay and their modes of activation for the joint development of regulated and managed safety. Based on this model, we analyse, in particular, the interactions between a leadership mechanism (sensegiving) and a mechanism of the joint development of regulated and managed safety (mindfulness), while also taking account of the mediating role of the organizational structure.

By revealing the levers and limits of managerial action and by identifying the mechanisms of the joint development of regulated and managed safety, our results contribute to the literature on safety management. They also contribute to the literature on safety leadership by identifying its mechanisms and their modes of activation.

Key-words: leadership, safety management, leadership for safety, safety leadership, resilience, high reliability organizations, organizational limits

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Table of Contents

Introduction

Despite efforts to avoid negative consequences of high-risk activities, some sectors and industries (such as nuclear power production, aviation, aerospace, chemical manufacturing, etc.) have experienced major disasters, including the Three Mile Island nuclear accident (1979), the Challenger shuttle (1986), the Chernobyl nuclear reactor (1986), the Columbia shuttle (2003), Air France Flight 447 (2009), the Fukushima nuclear plant (2011) and the Boeing 737 max crashes (2018, 2019). The accidents have become the objects of organizational research in seeking to improve our knowledge about safety (e.g., Oliver et al., 2017; Perrow, 1984; Shrivastava, 1987; Starbuck & Farjoun, 2005; Vaughan, 2007; Weick, 1993). These analyses and the lessons learnt from previous past events help to improve safety and highlight the need for greater consideration of **human and organizational factors as well as their interactions in complex and dynamic environments** (Hamer et al., 2021; IAEA, 2016; INSAG International Atomic Energy Agency, 1991; WANO, 2013). Recent research highlights the need for improving understanding of extreme contexts, in particular by developing managerial and organizational knowledge (Hällgren et al., 2017; Rouleau et al., 2021). In fact, a better understanding of how organizations operate in high-risk environments and daily mitigate the risks of adverse events would benefit society as a whole (Hällgren et al., 2017; Rouleau et al., 2021; van der Vegt et al., 2015).

In line with these concerns about human and organizational factors, the nuclear sector improves the knowledge about safety, especially following the analysis of major accidents. The Chernobyl accident (1986) initiated the discussion in the international community about the broadening of technical safety standards to human and organizational aspects of safety and the importance of a “safety culture”. These discussions resulted in the publication of the International Atomic Energy Agency (IAEA) International Nuclear Safety Advisory Group the INSAG-4 report (INSAG International Atomic Energy Agency, 1991), which describes the concept of a 'safety culture' in relation to both the organizations and individuals engaged in nuclear power activities. Analysis of the Fukushima Daichi accident (2011) contributed to complete this work by pointing to the need to deal with unexpected events. This refocused attention on the inherent environmental uncertainty in nuclear activities and underlined the importance of considering hypothetical, but credible extreme events. Lessons learned from this event contributed to the agreement to establish international rules highlighting the importance of **leadership for safety**. This in turn resulted in the construction of a set of standards related to management and leadership for safety, mostly published in 2016 by IAEA (IAEA, 2016). General Safety Requirement No. GSR Part 2 "Leadership and management for safety" specifies the requirements for managers at all levels to demonstrate leadership for safety, including establishing and integrating goals and priorities, acknowledging interactions among human, technological and organizational issues and fostering safety behaviours and attitudes. Consequently, training programmes on leadership for safety are designed to accompany the implementation of these requirements, including trainings provided by international safety institutions (IAEA, 2022; WANO, 2018). However, training for leadership is difficult to implement and often fails to achieve their objectives (Beer et al., 2016). In particular, managers find it effortful to apply the acquired knowledge due to managerial and organizational barriers and tend to fall back on usual practice. This is because leadership training fails to acknowledge that an organization is not a simple aggregation of individuals, but rather a complex system of interacting elements with different organizational dynamics (interactions of roles, responsibilities, cultures, processes, practices, policies, etc.), all of which need to be considered.

This evolution in the approach to safety, increasingly emphasizing human and organizational factors, underlines a deeper trend towards an inclusion of safety improvement based on the **development of capabilities to manage uncertainty**. While the technical and procedural barriers to dealing with predictable events have been studied in some depth, scholars have suggested to pay closer attention to the adaptation capabilities required to deal with unpredictable events. The complexity of the environment of emergent dynamics underlines the lack of solely regulated safety (technical and procedural systems) to maintain safety and suggests the need to complement this approach with managed safety. Managed safety refers to operational teams' competencies and real-time ability to adapt to unexpected situations. This trend on growing focus on managed safety is being adopted by both practitioner institutions (Besnard et al., 2017; Daniellou et al., 2010) and academics (Morel et al., 2008; Nascimento et al., 2014; Oliver et al., 2017; Vidal-Gomel, 2017; Zhang & Wu, 2014).

Development of managed safety is in line with studies on High-Reliability Organizations (HROs) (e.g., La Porte & Consolini, 1991; Leveson et al., 2009; Roberts, 1990; Schulman, 1993; Vogus & Welbourne, 2003; Weick, 1987; Weick et al., 1999; Zohar & Luria, 2003). This literature stream discusses the importance of a collective cognitive process of mindfulness and suggests five processes that contribute to high organizational reliability: preoccupation with failure; reluctance to simplify interpretations; sensitivity to operations; commitment to resilience; and deference to expertise (Weick et al., 1999; Weick & Sutcliffe, 2007). Scholars oppose resilience (handling uncertainty) to anticipation (diminishing uncertainty through prediction and prevention) (Sutcliffe & Vogus, 2003; Vogus & Sutcliffe, 2007; Wildavsky, 1988). Weick and colleagues (1999) stress, in particular, that although natural attention of the HROs is focused on anticipating possible failures, they should not over-rely on it, but also develop capabilities for resilience. Corresponding resilience research stream (Barton & Sutcliffe, 2009; Grote, 2019; Vogus & Sutcliffe, 2007; Williams et al., 2017) considers resilience as the organizational ability to absorb strain and preserve functioning despite the presence of internal and external adversity (Sutcliffe & Vogus, 2003). In other words, resilience is defined as the organizational capacity to cope with the unexpected in the present moment (Grote, 2019; Weick et al., 1999; Williams et al., 2017), echoing development of managed safety.

Both organizational theories related to HROs and resilience (Atkins, 2008; Fiol & O'Connor, 2003; Grote, 2019; Katz-Navon et al., 2020; Klein et al., 2006; Ray et al., 2011; Vogus et al., 2010) point to the **paramount role of leadership for safety**. Specifically, the literature highlights three impacts of leadership on enabling safety. First, leaders contribute to developing and disseminating safety values (safety culture) (Flin & Yule, 2004; Guy, 1990; Turner et al., 1989; Weick et al., 1999) and their translating into corresponding behaviours and attitudes (Flin & Yule, 2004). Second, leaders contribute to developing cognitive capability to construct meaning (sensemaking) in complex and sometimes ambiguous environments (Atkins, 2008; Barton et al., 2015; Fiol & O'Connor, 2003; Hannah et al., 2009; Roberts & Bea, 2001; Uhl-Bien et al., 2007; Vogus et al., 2010; Williams et al., 2017). Third, leadership facilitates coordination to face adversity (Geoffroy et al., 2016; Grote, 2019; Hale & Borys, 2013b; Zohar, 2002b), especially, unexpected adversity. This empathizes the role of leadership in enhancing the development of managed safety.

Leadership for safety involves a relatively small research community, mainly represented by safety science scholars (e.g., Barling et al., 2002; Clarke, 2013; Conchie et al., 2013; M. A. Griffin & Talati, 2014; Hofmann & Morgeson, 2004; Inness Michelle et al., 2010; Lekka & Healey, 2012; J. E. Mullen & Kelloway, 2009; T. Wu, 2008; Zohar, 2002b). The extreme nature of the high-risk contexts in which leadership for safety develops, provides an opportunity for developing valuable insights into leadership in general (Bamberger & Pratt, 2010). Work on leadership for safety builds on trends of leadership research more generally. In particular, leader-centric theories of leadership, focused on leader styles and behaviours, have received considerable empirical support (Lekka & Healey, 2012; Pilbeam, Doherty, et al., 2016). However, the limitations of these leader-centric approaches to leadership, specifically, their weaknesses to explain the causal links between individual leaders' characteristics/behaviours and organizational outcomes, have led to calls for a more processual view of leadership (Denyer & Turnbull, 2016; Dinh & Lord, 2012; Fischer et al., 2017; Uhl-Bien et al., 2007). Some recent studies focus on the mechanisms of leadership for safety (M. B. Nielsen et al., 2016; Pilbeam et al., 2019; Tucker et al., 2016), but this work deserves to be further developed. Further research should focus on extending the existing academic knowledge to achieve a better understanding of the role of leadership mechanisms for improving safety (e.g., Clarke, 2013; Epitropaki & Turner, 2020; Hannah et al., 2009; Katz-Navon et al., 2020; Zohar, 2010), as well as improving practitioner knowledge to enable high-risk actors to effectively implement leadership for safety and to create appropriate training in leadership for safety (K. Nielsen et al., 2010; Schwatka et al., 2020; Tafvelin et al., 2019).

Growing recognition of the managed side of safety

Following several tragic accidents, safety management has integrated the notion of uncertainty and focused on the roles played by human and organizational factors. Safety is therefore considered an emergent property of a complex system (Hamer et al., 2021; Wahlström, 2018). However, complex environments are inherently uncertain and involve multiple and potentially contradictory (paradoxical) paths and absence of deterministic links among elements (Marion & Uhl-Bien, 2001; Osborn, 2008; Uhl-Bien & Arena, 2018).

Recent research in the field of organizational studies (e.g., Roberts, 1990; Roberts & Bea, 2001; Weick et al., 1999; Weick & Roberts, 1993) and resilience in particular (e.g., Hillmann & Guenther, 2020; Linnenluecke, 2017; Sutcliffe & Vogus, 2003), deals with the organizational ability to handle unforeseen events. However, growing number of studies at the intersection of safety and organizational studies, in particular, focus on organizational rules and routines in high-risk contexts and highlights the need for dealing with both, foreseen and unforeseen, events (Grote et al., 2009; Morel et al., 2008; Nascimento et al., 2014; Perin, 2007). Organizations respond to uncertainty by trying to diminish it (reducing freedom and standardizing) or by attempting to deal with it (maximizing freedom and enhancing competencies to deal with complex tasks) (Grote et al., 2009). This echoes earlier studies of HROs, which suggest that effective HROs develop capabilities to face both types of events (Roberts & Bea, 2001; Sutcliffe & Vogus, 2003; Vogus & Sutcliffe, 2007; Weick et al., 1999). The tension among approaches for dealing with foreseen and unforeseen events crystallizes in two forms of organizational safety: regulated and managed safety (Amalberti, 2021; Besnard et al., 2017; Morel et al., 2008; Oliver et al., 2017). Organizations have to deal with both predictable events, through anticipation (through technical systems and procedures) and unexpected situations, through resilience (through proactivity and adaptability) (Morel et al., 2008; Weick & Sutcliffe, 2007; Wildavsky, 1988; Williams et al., 2017). Safety is enabled by a **joint development of regulated and managed safety**, which ultimately allows both to diminish uncertainty (through anticipation) and to deal with uncertainty (through resilience) (Weick & Sutcliffe, 2007; Wildavsky, 1988).

However, while only the simultaneous development of both forms of safety can ensure safety outcomes, some recent studies show that the design of high reliability systems (regulated safety) can limit the cognitive abilities of actors (managed safety) to face ambiguous or unexpected situations (Oliver et al., 2017, 2019). In other words, the development of regulated safety can jeopardize the development of managed safety (Bourrier & Bieder, 2013), what refers to organizational limits for safety development (Farjoun & Starbuck, 2007; Oliver et al., 2017). Studies in the vein of HROs point, in particular, to the role of mindfulness as a key element for managed safety development (Fiol & O'Connor, 2003; Fraher et al., 2017; Sutcliffe & Vogus, 2003; Weick & Sutcliffe, 2006), but also for enabling the mutual reinforcement of regulated and managed safety (Levinthal & Rerup, 2006, 2021; Schulman, 1993). Therefore, understanding the deep nature of the tension between regulated and managed safety is essential (Amalberti, 2021; Cowley et al., 2021; Hannah et al., 2009). A question then arises – how can regulated and managed safety coexist optimally and be developed jointly? This debate suggests that organizations need to achieve the right balance between elements of standardization and flexibility (Busby & Iszatt-White, 2016; Denyer, Tranfield, & van Aken, 2008; Grote et al., 2009; Hale & Borys, 2013a, 2013b; Sutcliffe et al., 2016). This challenge echoes the meta-tension between stability and change, that actually may be mutually reinforcing (Farjoun, 2010). Thus, the joint development of regulated and managed safety involves their interactions by combination, rather than by solely 'adaptative switches' between them (Grote, 2019). **However, the underlying mechanisms of the joint development of these two types of safety have not been systematically studied by organizational researchers.** There continues to be a need for a better understanding of the mechanisms through which reliability (based on both, regulated and managed safety) is achieved and the ways in which organizations design control mechanisms to respond to unexpected disturbances (Barton & Sutcliffe, 2009; Boin & Schulman, 2008; Fraher et al., 2017; Linnenluecke, 2017; Vogus & Rerup, 2018, 2018; Wears & Roberts, 2019, 2019).

The academic literature on safety management increasingly points to the **role of leadership**. Specifically, the role of leaders in the development of managed safety is emphasized (Barton et al., 2015; Sutcliffe & Vogus, 2003; Williams et al., 2017). However, the need for joint development of both managed and regulated safety is implicitly recognized pointing to the need of further research on the part played by leadership in resolving the stability-adaptation tension (Grote, 2019). In other words, there is a call to explore **the role of leadership in the joint development of the capabilities required to deal with predictable and unpredictable events** (Christianson et al., 2009; Clarke, 2013; Inness Michelle et al., 2010; Katz-Navon et al., 2020), which is the focus of this doctoral research. Extant studies suggest the links between leadership abilities and mindfulness (Atkins, 2008; Fiol & O'Connor, 2003; Ray et al., 2011), leadership abilities and efficiency of sensemaking and learning (Roberts & Bea, 2001; Tucker et al., 2016; Zohar & Luria, 2003). However, further investigation is necessary to explore these suggested links.

The role of leadership in the joint development of regulated and managed safety

In academia, debate is ongoing on leadership for safety as a research area in development. Scholars commonly focus on leader-centric approaches to leadership for safety (Lekka & Healey, 2012; Pilbeam, Doherty, et al., 2016; Pilbeam et al., 2019) and seem to suggest that, for example, a transformational leadership style is better adapted to achieving safety (e.g., Barling et al., 2002; M. A. Griffin & Talati, 2014; Inness Michelle et al., 2010; Katz-Navon et al., 2020; J. E. Mullen & Kelloway, 2009; T. D. Smith et al., 2020). However, similar to discussion about leadership in general, leader-centric approaches need be complemented by research explaining the causal link between leaders' actions and organizational outcomes, such as safety (Dinh & Lord, 2012; Fischer et al., 2017; Langley & Tsoukas, 2017; Meyer et al., 2005). There have been several calls for a deeper investigation of leadership for safety mechanisms (e.g., Clarke, 2013; Epitropaki & Turner, 2020; Hannah et al., 2009; Katz-Navon et al., 2020; Zohar, 2010)

A processual approach has been proposed as a relevant perspective on leadership for safety, since it acknowledges the complex, contingent and dynamic nature of safety and examines causal explanations of leadership outcomes, beyond observable effects (i.e., the "why") (see e.g., Fischer et al., 2017; Kempster, 2006; Uhl-Bien et al., 2007). Some recent studies provide an advancement by investigating the generative mechanisms and explaining how safety is achieved through appropriate leadership (Pilbeam et al., 2019; Tucker et al., 2016). For example, Pilbeam and colleagues (2019) propose a more processual approach and theorize the interactions among context, interventions, mechanisms and outcomes (Denyer, Tranfield, & van Aken, 2008). This strand of work is a first step towards a better understanding of the leadership for safety mechanisms but needs to be completed and enriched. First, capturing and understanding these underlying mechanisms remain challenging because **the little agreement exists about the very nature of mechanism.** In both the general leadership literature and research focused on leadership for safety, these mechanisms are poorly defined and, often, are indistinguishable from practices (Fischer et al., 2017; Gutermann et al., 2017; Hernandez et al., 2011; Humphreys et al., 2012; Pilbeam, Doherty, et al., 2016; Pilbeam et al., 2019; T. Wu et al., 2011; Young et al., 2020). In addition, mechanisms referring to leadership are not conceptualized separately from the mechanisms referring to organization goal of safety. Second, **particular challenge of the joint development of regulated and managed safety is overlooked and need to be further investigated**. Existing work focuses on safety in general but does not examine the role of leadership for safety in the development of the specific capabilities needed to jointly deal with expected and unexpected events. Thus, **it may be possible to uncover stronger mechanisms of leadership for safety. However, relatively little is known about the interplay between the mechanisms of leadership influence and the mechanisms of safety management for a joint development of regulated and managed safety.**

Research question

Contemporary high-risk organizations have to find ways not only to respond to a regulated context, but also to develop managed safety capacities to deal with unpredictable events. By bridging the different conversations (safety management, leadership and leadership for safety), the present research builds on recent work (Pilbeam et al., 2019) to try to understand how leadership contributes to the development of managed safety in the context of regulated safety.

More specifically, we address the following research question:

How do leadership mechanisms enable a joint development of managed and regulated safety?

In the light of the insights from the literature, we address this question by adopting a processual view of leadership. In this doctoral research, we define **leadership for safety as a process of influence of individual and collective cognition and behaviours to meet the expectations of safety management.** The implications of this are as follows:

- It is therefore necessary to consider both – the influence process and the safety management process;
- Influence process is enabled by leadership practices (observable) and underlying mechanisms (unobservable);
- It is therefore essential to understand safety management expectations for enabling effective leadership for safety. Insights from practitioners and scholars, highlight the challenge of joint development of regulated and managed safety;
- This joint development is relying on daily actions, including managerial actions (rules, compliance control, tools, etc.) and on activation of underlying mechanisms;
- However, safety management needs to take account of organizational limits and the dangers of them being exceeded;
- Finally, leadership for safety relies on the interplay between leadership mechanisms and safety management mechanisms.

Therefore, our research question can be re-specified as following:

How are leadership mechanisms activated and combined with safety management mechanisms in daily activities, to respond to the challenge of a joint development of managed and regulated safety that does not exceed organizational limits?

Context and research methodology

The nature of the research question relative to the interactions and activation of leadership for safety mechanisms suggested a qualitative research method. To answer our research question, we chose to conduct a **qualitative explanatory case study**, carried out within a **critical-realist paradigm** (Avenier & Thomas, 2015; Bhaskar, 1978; Kempster & Parry, 2011; Tsoukas, 1989). We have chosen to do this research in the critical realist paradigm mainly because of its capacity to take into account the complexity of the social world. Critical realism recognizes the emergent properties of the social realm and pays particular attention to non-deterministic causality – explained by the underlying mechanisms (Bhaskar, 1978; Mingers & Standing, 2017). A critical realist approach places the mechanisms at the heart of the understanding of the social world, in particular, by highlighting their role in the stratified reality (Bhaskar, 1978). Critical realism provides a stratified view of the world, spanning three domains: the real (generative mechanisms and structures with causal powers); the actual (generated events); and the empirical (experienced events) (Bhaskar, 1978; Brannan et al., 2017; Mingers, 2004; Mingers et al., 2013; Mingers & Standing, 2017). In this conceptualization of the world, more or less obvious causal powers of mechanisms and structures exist independently of the observed events but are capable of producing patterns of observed events (Avenier & Thomas, 2015). Mechanisms have the irreducible property of always acting in a specific way, although the consequences might vary, depending on the countervailing forces of other intervening mechanisms and structures (Archer, 1998b; Mingers, 2004; Tsoukas, 1989). Critical realism suggests that the emergent causal power of mechanisms and structures should be explored, but considered in non-deterministic way, since the manifestation of this power depends on the contextual conditions (Tsoukas, 1989). Therefore, the focus on the underlying mechanisms in a multi-level reality, allows to capture the complexity of the leadership for safety process (Kempster & Parry, 2011) by uncovering mechanisms, disentangling them from observable leadership practices and exploring the interactions among mechanisms, structures and the contextual conditions.

Our choice of critical realism guided us all along our research project, from the development of the literature review to the case study investigation. We performed the literature review across diverse literature streams representing different epistemological paradigms, by seeking to distinguish between practices and underlying mechanisms, context and elements of organizational structure. We adopted an approach that allowed us to disassemble elements from different literature domains, organize them into discrete units (practices, mechanisms, structure, context), and combine and re-assemble these dispersed contributions into a coherent theoretical framework (Ackroyd & Fleetwood, 2004; Archer, 1998b; McAvoy & Butler, 2018). This involved interpretation of the existing literature and identification of relationships among observable (context and practices), partly observable (social structures) and unobservable (mechanism) elements (Gordon & Yukl, 2004; Kempster & Parry, 2011; Parry, 1998). The literature review focused on the generative mechanisms providing causal, but non-deterministic relations that explain observable practices (Tsoukas, 1989).

Critical realism also guided the conduct of our case study. The focus in this doctoral research was on distinguishing observable practices, context, organizational structure and non-observable generative mechanisms. Our objective was not to identify new generative mechanisms or to be exhaustive, but rather to understand how leadership practices, mediated through structure (Archer, 1998a, 1998b) and context, activate generative mechanisms allowing the joint development of managed and regulated safety. This understanding of underlying mechanisms and of their effects at work was gained through the literature review and from the field. Our methodology, which combines induction and abduction, aimed to generate knowledge about generative mechanisms and their activation modes. More particularly, we were interested in exploring how mechanisms are activated or blocked in different concrete contexts and to reveal the interplay between non-observable mechanisms and observable practices and contexts.

The case study of the present thesis is conducted in the context of the nuclear sector, within a nuclear energy operating company, which, for reasons of confidentiality, we call ATOM. We chose the nuclear sector as the context for our empirical study since it is one of the most salient examples of the high-risk industries, characterized by a complex and dynamic environment. Nuclear sector is illustrative of high-risk industry, but leadership for safety remains a preoccupation of other complex, technologically interdependent systems that face high levels of risk in day-to-day practices, such as air traffic control, aerospace, chemical manufacturing, etc.

The high impact of potential accidents makes the nuclear industry strongly regulated and controlled and requires of organizations operating in this context to proactively face high level of uncertainty (Hällgren et al., 2017). The nuclear industry recognizes the importance of leadership for safety, which is formalized in standards published in 2016 (IAEA, 2016; WANO, 2019). However, nuclear sector companies and international safety institutions estimate that understanding of leadership for safety remains incomplete. There is real demand from the nuclear power plant operators and international organizations for more research on the development of leadership for safety. This interest in the development of leadership for safety has led to the launch of the European Leadership for Safety (ELSE) project, funded by the European Union through its Instrument for Nuclear Safety Cooperation (INSC) in cooperation with IAEA. The ELSE project's aim is to develop an innovative research-based approach to advanced education in the domain of leadership for safety, bringing together the most up-to-date academic knowledge and professional expertise (ELSE Project, 2021). This doctoral research is conducted in the framework of the ELSE project, which facilitated access to nuclear sector safety actors and, specifically, to ATOM.

The case study focuses on a Nuclear Power Plant (NPP) of a European nuclear energy operating company, ATOM, which is one of the leading European nuclear operating companies, applying the latest nuclear sector standards and regulations and integrating world best safety practices. However, despite considerable advances, ATOM acknowledges that there is room for improvement in terms of safety. For our in-depth study, we selected a NPP within ATOM, which experienced some problems related to improving safety. The need for an in-depth understanding of the complex context, required an implementation of a two-stage process of data collection: 1) immersion (2017-2018); and 2) in-depth case study within the NPP (2019-2021). Data for the in-depth case study were collected in two phases - in June 2018 and in June 2019 – and included document analysis, non-participant observations (8) and semi-structured face-to-face interviews (14 individual and 4 collective interviews). Data analysis followed the conventional coding process (open coding followed by a process of abstraction) (Charmaz, 2014; Gioia et al., 2012). The abstraction process was aimed at exploring generative mechanisms and their activation modes (Avenier & Thomas, 2015).

Results & Contributions

The significant efforts made by international safety institutions and operating companies (such as ATOM) have resulted in considerable enhancements to safety and reliability in this sector. However, there is always room for improvement and the objective of this doctoral research is to contribute to further improvement of safety. The findings of this research should not be interpreted as evidence that the NPP studied is not sufficiently safe or that leaders ignore safety, but rather how safety can be further improved.

First, our results highlight the **mechanisms of the joint development of regulated and managed safety,** by contributing to a better understanding of these two forms of safety and their possible jeopardizing effects and, more specifically, by highlighting the existence of organizational limits and the negative impacts of their exceeding. This allows to make a contribution to safety management and organizational limits theory. Our study provides new insights for the safety management literature by examining the role of managerial control in more depth (Amalberti, 2001; Dekker, 2003; Grote et al., 2009; Hale & Borys, 2013b; Schulman, 1993). The existing literature suggests that attention should be paid to rule formalization (number and type of rules) (e.g., Amalberti, 2001; Bourrier & Bieder, 2013; Grote et al., 2009; Hale & Borys, 2013b) and rule elaboration (top-down or bottom-up approach) (Eydieux et al., 2018; Hale & Borys, 2013b; Kudesia et al., 2020; Schulman, 1993), but our results suggest the need to focus on rule implementation and types of indicators used to monitor rule implementation and compliance. Moreover, we make an additional contribution to organizational limits theory (Farjoun & Starbuck, 2007; Oliver et al., 2017) by providing a more in-depth understanding of the limits relative to managerial control.

Second, our research highlights the **mechanisms of leadership influence.** By identifying and reordering fragmented theoretical contributions from leadership studies (Acton et al., 2019; Anderson & Sun, 2017; Behrendt et al., 2017), we developed an integrative, multilevel **framework to capture leadership as a process** (Day, 2000, p. 200; Fischer et al., 2017;

Gordon & Yukl, 2004; Kan & Parry, 2004; Kempster & Parry, 2011; Osborn et al., 2002; Parry, 1998; Uhl-Bien et al., 2007; Yukl, 2013). More specifically, our results advance the current discussion on the leadership influence process and its mechanisms, already existing in the current state of art, by outlining the modes of their activation, not yet identified within the context of safety.

Third, our results extend the leadership as process framework, by applying it to the context of safety management and its requirement of joint development of regulated and managed safety. The novelty of our findings consists in providing a more refined conceptualization of the leadership for safety process (Pilbeam et al., 2019). We contribute to leadership for safety theory by proposing an **integrative framework of the leadership for safety process with a particular focus on its mechanisms** (Clarke, 2013; Epitropaki & Turner, 2020; Fischer et al., 2017; Hannah et al., 2009; Katz-Navon et al., 2020; Pilbeam et al., 2019; Zohar, 2010). Our research also provides emergent models capturing the process of the joint development of regulated and managed safety and the role of leadership in this process. In sum, our results extend the current knowledge on the **interplay between the mechanisms of leadership influence and the mechanisms of safety management for the joint development of regulated and managed safety**.

Fourth, based on a critical-realist informed model of leadership for safety, our case study explores in detail the pivotal role of one of the main leadership mechanisms and its activation modes. We add to the theoretical knowledge by providing a better understanding of how practices-mechanisms cascade through different organizational levels, within a hierarchical chain. We also show the effects of organizational barriers on the activation of this mechanism.

Finally, our results make significant managerial contributions aiming to improve managerial control and leadership for safety practices and provide recommendations for an effective training programme in leadership for safety.

Structure of the thesis

The purpose of this research is to explore how leadership mechanisms enable a joint development of managed and regulated safety. To address the research question, the thesis is organized in five chapters. The first two (Chapters 1 and 2) position our research in the current state of the art, identify the major limits to the current knowledge that need to be further explored, and develop the conceptual framework mobilised in this research. Chapter 3 describes the epistemological framework within which this research is anchored, as well as the choice of the research method employed. Chapter 4 presents the empirical findings. Finally, Chapter 5 discusses the findings and their contributions.

Figure 0.1 depicts the structure of this the thesis.

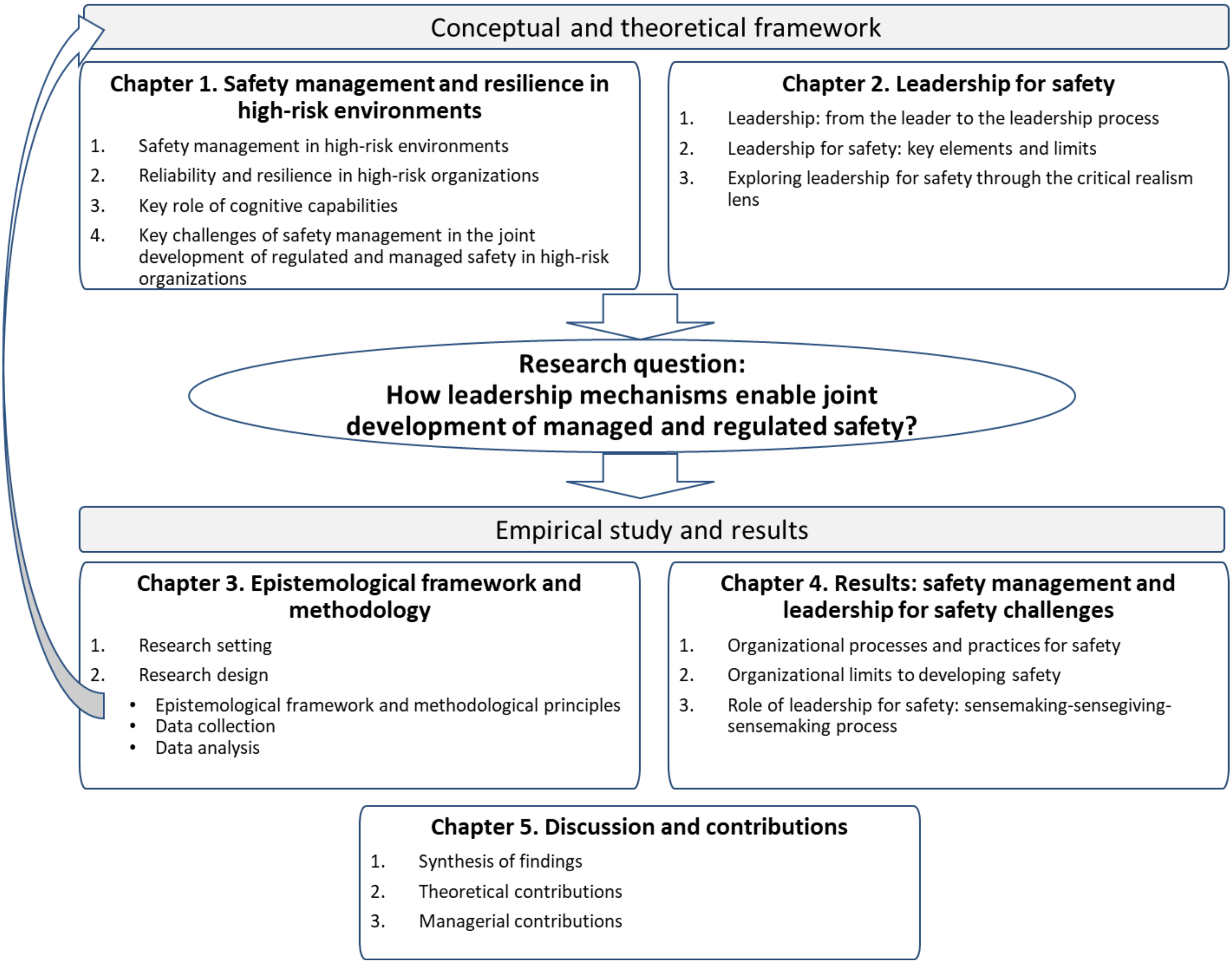

Figure 0.1. Structure of the thesis

Chapter 1 offers a review of key literature on safety management and resilience. It discusses the research on safety management and the advances made by the literature on high-reliability organizations and resilience. Then, the key role of cognitive capabilities for improving safety is underlined. It concludes by discussing the state of the art on challenges of a joint development of regulated and managed safety, involving cognitive and structural dimensions.

Chapter 2 reviews the leadership and leadership for safety literatures. First, it describes the evolution of leadership in general towards a more processual approach and proposes a critical-realist informed framework of leadership as process. It is followed by the review of key literature on leadership for safety. Then, this chapter proposes an integrative framework of the leadership process for safety, build through a critical realist lens.

Chapter 3 describes the epistemological framework and methodology used for our research. First, it provides the specific context of the nuclear sector and ATOM, the organization within which the data collection is conducted. Then, this chapter presents our epistemological positioning of critical realism, which guided our literature review and theoretical framing, as well as our empirical study. Finally, it discusses the methodological principles applied for the present qualitative case study.

Chapter 4 explores in detail the results of our case study. First, organizational processes and practices for the joint development of regulated and managed safety, introduced by case company, are described. Then, the organizational limits of developing safety are highlighted. Finally, a specific focus on the process of the leaders' sensegiving-sensemaking process is presented.

Chapter 5 first presents the synthesis of the findings and provides emerged models of a joint development of regulated and managed safety, and leadership for safety role in this development. More specifically, our results highlight the interplay between leadership influence mechanisms and safety management mechanisms, while considering the negative effects of exceeding organizational limits. Secondly, the theoretical contributions of these results and models are discussed. Thirdly, managerial contributions are presented.

The **Conclusion** offers a synthesis of the findings, presents the limitations and proposes some directions for future research.

1. Safety management and resilience in high-risk environments

Technical and economic progress involves risk and requires organizational efforts and capabilities to cope with uncertainties (U. Beck, 1992). Safety management is one way to deal with risks. High levels of risk in day-to-day practices are inherent in certain types of organizational activities such as nuclear power production, air traffic control, and the aerospace and chemical manufacturing sectors. These high-risk environments require organizational attention to safety management.

Safety management evolves over the time and, pushed by tragic accidents and world crises and there is a need for more managerial and organizational knowledge on these high-risk and extreme contexts (Hällgren et al., 2017; Rouleau et al., 2021). Research on High Reliability Organizations (HROs) examines how they face high levels of risk in their daily activities, in order to learn about their behaviour, such as anticipation and resilience, in response to expected and unexpected events (Hällgren et al., 2017; Sutcliffe et al., 2016; Sutcliffe & Vogus, 2003; Weick et al., 1999). The more recent HROs research moved toward studies on resilience as a way to deal with uncertainty.

The literature on reliability and resilience highlights the challenges that confront high-risk organizations, often characterized by complex technology and high levels of bureaucracy (Hale & Hovden, 1998), which constitute technical and procedural barriers to dealing with predictable risks. However, high-risk organizations also require adaptation capabilities to deal with unpredictable events. Another characteristic of high-risk contexts is that a trial-and-error learning is infeasible because non-contained errors can have catastrophic consequences (Weick, 1987), highlighting the importance of cognitive capabilities, such as mindfulness, and of learning.. High-risk organizations have to deal with both predictable and unpredictable events. This requires the development of a range of capabilities to both diminish and face the uncertainty (Grote et al., 2009) or, in other words, to jointly develop regulated and managed safety. The joint development of these capabilities is not straightforward and involves cognitive and structural dimensions. The recent literature highlights the role of leadership in this joint development of capabilities to deal with the predictable and the unpredictable events (Christianson et al., 2009; Clarke, 2013; Inness Michelle et al., 2010; Katz-Navon et al., 2020), which is the central focus of this doctoral research.

In Chapter 1, we review the literature on safety management in high-risk environments (Section 1.1) and reliability and resilience in high-risk organizations, and their overlaps (Section 1.2). In Section 1.3 we discuss the importance of cognitive capabilities for successful safety management and highlight challenges related to the joint development of regulated and managed safety. Section 1.4 concludes this part by identifying constraining and enabling factors related to this joint development, including leadership.

1.1.Safety management in high-risk environments

Knowledge and safety management practices are constantly evolving. Approaches to safety have changed from technical to more integrated perspectives that take account of human and organizational factors. Following several tragic accidents, safety management has integrated the notion of uncertainty and focused on the part played by human and organizational factors (1.1.1.). This has highlighted the need for continuous management of paradoxical tensions, stemming from potentially conflicting goals (e.g., safety versus production) or potentially conflicting means of achieving these goals (e.g., compliance versus flexible adaptation) (1.1.2.).

1.1.1. Evolution of approaches to safety in high-risk environments: progressive acknowledgement of uncertainty

1.1.1.1. Eras of safety

Studies on safety in high-risk contexts emerged in the mid-20th century in parallel with the development of industrial safety in practice (Hale & Hovden, 1998; Hollnagel, 2014). The focus on safety shifted from a purely technical, to procedural approach, finally to integrate human and organizational factors. In their literature review, Hale and Hovden (1998) identify three eras of approaches to safety: 1) the technology era (pre-1970s); 2), the human factors era (from the 1970s to around 1986); and 3) the safety management era (starting in 1986). Focusing on the development of the nuclear energy industry, Hamer et al. (2021) suggest that safety management era coincides with three ages: a complex socio-technical systems age, an integration/cultural age and an adaptative age. Over time, the nuclear energy industry has been involved in several catastrophic accidents such as Three Mile Island, the Challenger disaster, Chernobyl and Fukushima. The analysis of these accidents resulted in the evolution of approaches to safety presented in

Figure 1.1.

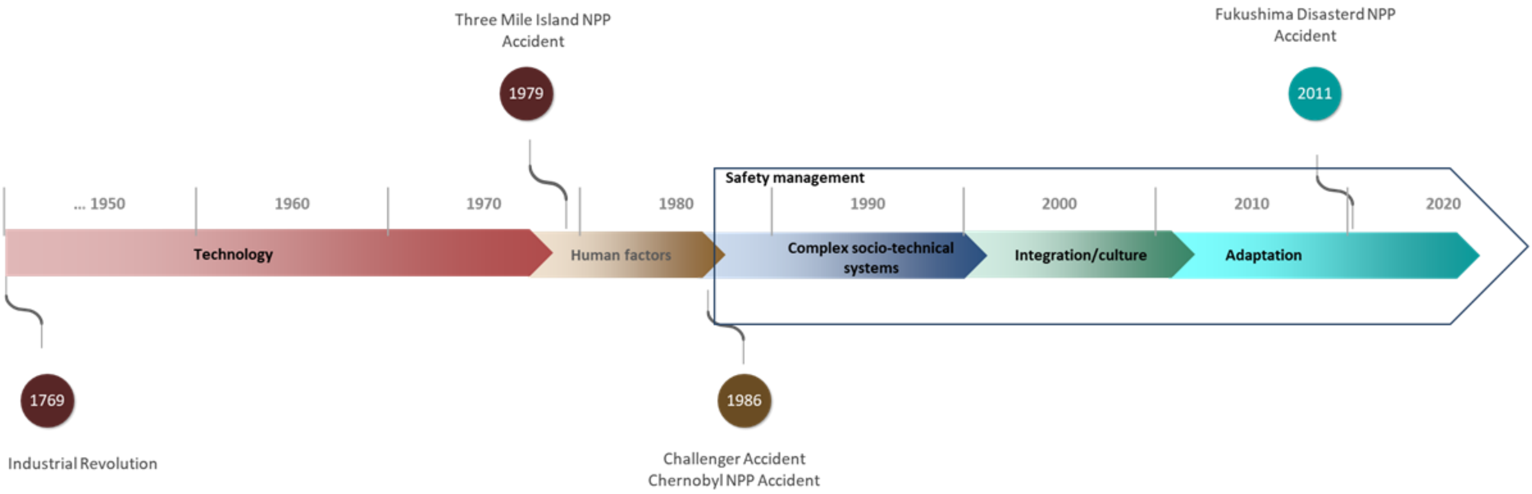

Figure 1.1. Timeline of the evolution of approaches to safety (after Hale and Hovden, 1998; Hamer et al.,2021)

The first safety era (the technology era) emerged with the expansion of industries that introduced entirely new risks. In this era, the main preoccupation was finding technical means to enable safe operations and prevent accidents. In the late 1970s, the approach to safety evolved from being purely technical to one, which included human factors and human error (human factors era). At that time the focus shifted to operational activities. However, the inclusion of human behaviour was mechanistic rather than systemic, and considered human input as an unreliable component in charge of reliable technology (Hale & Hovden, 1998). From the end of the 20th century, safety issues were studied through the lens of human factors and ergonomics (Hamer et al., 2021). There was a growing acknowledgement that technical risk assessments and prevention measures to improve human responses to technical requirements could not solve all of potential problems. During the mid-1980s safety began to be considered in terms of not just technical and human errors but also organizational factors (safety management era). The approach to safety moved to the development and research on management systems. Academic and practitioner attention began to focus on subtler organizational aspects (policies, manuals, practices) to explain behavioural causes of failures

(Hale & Hovden, 1998). The idea of a safety culture was promoted by the organizational culture literature, in particular, in relation, to the Chernobyl accident (INSAG International Atomic Energy Agency, 1991).

In the 1990s, approaches to safety highlighted the complex, socio-technical nature of industrial systems, such as nuclear power plants. It was suggested that a holistic view of safety management should include technical, human, organizational, and cultural as well as political phenomena (complex socio-technical systems age of safety management era). In this view, **safety is an emergent property of a complex system**, marked by contextual and non-linear interactions among various factors (Hamer et al., 2021). At the adaptive age of the safety management era, the interest is focused on the role of human variability as an asset and new approaches such as, for example, resilience engineering (Hollnagel et al., 2006), appear. The Fukushima plant accident (2011) refocused attention on inherent environmental uncertainty and underlined the importance of considering hypothetical, but credible extreme events. To respond to the integration and adaptation challenge, research on safety began to increasingly focus on the **importance of safety leadership**. For example, the International Atomic Energy Agency (IAEA) included safety leadership in its fundamental safety principles (IAEA, 2016).

This evolution of safety eras highlighted the need to go beyond traditional perspectives, based on technical risk assessment and safety procedures compliance, and to pay more attention to organizational processes, culture and system complexity. It was acknowledged that, traditional risk management was unable to adequately assess risk and that organizational factors, including safety culture, were important.

1.1.1.2. Limits of traditional risk management to assess risk

Traditionally, risk was defined as the probability of the occurrence and consequences of physically harmful events that can be quantified by formal expert evaluation. Therefore, it was considered that risk could be handled through the reinforcement of technical and regulatory barriers (Scheytt et al., 2006). This technical (non-dynamic and expert-based) vision of risk was based on the idea of an accurate and objective risk assessment. It assumed that all risk could be evaluated, predicted and managed, and its occurrence and impact minimized (Fox, 1999). This resulted in the implementation of traditional risk management techniques, promoted by regulatory authorities, such as Probabilistic Risk Assessment (PRA). PRA involves quantified risk assessment and calculation of risk acceptance criteria based on generic failure rates (Hale & Hovden, 1998). As PRA became the standard way to deal with the safety and reliability of technical systems, the technical probabilistic approach was extended to include both technological and human factors (Hollnagel, 2014). The potential for human error was addressed by the inclusion in PRA of Human Reliability Assessment (HRA) methods (Kirwan, 1994).

PRA and HRA methods allowed for the detection of failures and contributed to substantial improvements in safety performance (Renn, 2008). However, research showed that it is difficult to model failure and to predict complex interactions, and that some elements are inherently uncertain (Mitzen & Schweller, 2011). Hollnagel (2014) pointed to the increased recognition that methods developed to deal with technical problems, failed to address human and organizational issues adequately (Hollnagel, 2014). Hollnagel (2014, p. 32) stated that "*at present, the practices of risk assessment and safety management still find themselves in the transition from the second to the third age*". In other words, existing practices were simply extending engineering risk analysis of organizational factors (as a new sub-element of technical or human factors). Hollnagel's critiques contributed to the development of a socially constructed and historically specific conceptualization of risk (Fox, 1999).

The literature (e.g., Miller, 2009) suggested that beyond individual psychology (Slovic, 1990), social forms and culture influence construction of the understanding of risk. In complex, socially constructed systems, risk is subjective and unquantifiable. Scholars progressively acknowledged the dynamic nature of risk perception (Miller, 2009), through interrelated practices, texts and relations that make risk constructed and "known" (Hardy & Maguire, 2016). This view distinguished between hazard, as a natural circumstance, and risk, as a cultural judgment concerning the hazardous event. It referred to the creation of meaning of the experience of harm and hazard by a social and cultural group. The hazardous eventualities of adverse outcomes appear in the discourse and are used to guide and justify risk management work (policies, regulation, communication). Risk perception not only puts a value on an event but can also produce new hazards (Fox, 1999; Renn, 2008). Therefore, the existence of risk depends on the knowledge about risk, which, in turn, might have unintended and unforeseeable negative side effects of collective decisions (Renn, 2008, p. xiv). The reference group's judgment is important since it influences what is and is not considered risky. These beliefs, which are determined by structural forces, enable risk perception (Douglas & Wildavsky, 1982). Over time, actors select and rearrange signals to build risk meaning (Renn, 2008, p. 2) to guide ongoing risk perception construction. Thus, risk perception is socially constructed and results from the interactions among group reasoning, personal experience, social communication and cultural tradition (e.g., Pidgeon, 1991; Renn, 2008).

1.1.1.3. The complexity of organizational factors and uncertainty

The traditional view of risk has been criticized, especially in terms of appropriate risk assessment (Maguire & Hardy, 2013; Pidgeon, 1991). Despite considerable technological and regulatory efforts to control risk, uncertainties persist and must be managed. This is especially important in complex and high-risk environments.

Complex systems are comprised of a large set of interacting and coevolving agents, producing emergent effects (Coveney, 2003). Their emergence is spontaneous and arises from the actions and interactions among lower-level agents (Lichtenstein & Plowman, 2009; Uhl-Bien & Arena, 2018). Hence, a complex environment is inherently uncertain. It offers a multitude of potentially contradictory (paradoxical) paths (Denison et al., 1995; Osborn, 2008), conflicting constraints and amplification effects (Marion & Uhl-Bien, 2001; Uhl-Bien & Arena, 2018). Complex and tightly coupled socio-technical systems (Perrow, 1984) may remain opaque, which constitutes a barrier to direct technical or procedural control and can lead to the accumulation of risk (Rasmussen, 1997; Reason, 1998). For example, investigations into major accidents show that technical means controlled by procedures are no longer sufficient to protect organizations from loss of their production capabilities.

Renn (2008) points to the divergent views on the tolerability of uncertainty. According to Grote et al. (2009), organizations perceive and respond to uncertainty in different ways: 1) by trying to **diminish uncertainty,** by reducing freedom and standardizing the technology; or 2) by attempting to **deal with the uncertainty,** by maximizing freedom and enhancing competencies to deal with complex tasks. Traditional safety management based on administrative control is aimed more at diminishing rather than dealing with uncertainty. In the traditional view, the sources of uncertainty are seen as lack of data, ambiguity and ignorance (Hardy & Maguire, 2016, p. 249). Hence, when organizations have access to more data, they can develop more sophisticated modelling. This view **stresses the idea of anticipation based on knowing what to expect but does not consider management of the unexpected** (Woltjer, 2019). High risk organizations focused on safety "*may tend to be highly administrative in their control*" relying on risk management policies and indicators (Hannah et al., 2009, p. 901). The unexpected cannot be controlled completely, because it is impossible to objectively decompose, measure and analyse the risk. Therefore, organizations face known unknowns (impossible to predict), unknown knowns (impossible to validate), and unknown unknowns (unexpected and unpredictable surprises) (Mitzen & Schweller, 2011; Rumsfeld, 2013). Barton et al. (2015) argue that the context of uncertainty influences the extent to which organizations can rely on systematic formalization and rational, bureaucratic procedures (preparing for the expected), rather than adaptive and proactive behaviours (to support coping with unexpected events) (Woltjer, 2019).

It thus appears that rules and procedures have their limits (Bourrier & Bieder, 2013; D. Smith & Tombs, 1995) and too extensive risk management activities can create additional uncertainties (Scheytt et al., 2006) and disruptions (Leveson et al., 2009). Therefore, dealing with uncertainty should not be based on technological compliance only, but should include an understanding of the interplay among technological, social and organizational factors (Leveson et al., 2009; Osborn & Ashforth, 1990) and practices that guide managerial attention, resources and allocation of responsibilities (Grote, 2007; Scheytt et al., 2006). This interplay may be understood by paying attention, in particular, to safety culture.

1.1.1.4. Contributions and limits of safety culture to deal with the unexpected

The concept of safety culture refers to a common answer to cope with uncertainties (e.g., Grote, 2007; Pidgeon, 1991; Reason, 2000) and encompasses the part played by human and organizational factors in safety (Pidgeon, 1991). Due to the environment specificity, complex and high-risk organizations are considered particularly vulnerable to safety culture deficiencies and investigations. The analysis of major accidents has revealed that major catastrophes are caused by a progressive accumulation of small failures that are due to a deficient safety culture (Boin & Schulman, 2008; *Final Committee Report the Design, Development & Certification of the Boeing 737 MAX*, 2020; INSAG International Atomic Energy Agency, 1991; Starbuck & Farjoun, 2005, 2005).

Safety culture definitions. The term safety culture was largely introduced in safety studies by the IAEA report on the Chernobyl accident (Besnard et al., 2017; INSAG International Atomic Energy Agency, 1991). Since then, it has been adopted by several fields and is widely referred to by industry operators.

Since safety culture is part of an organizational culture, most work on safety culture refers to Schein's (1985) seminal article on organizational culture (see Guldenmund, 2000). Schein highlights three levels of culture depending on their observability: artefacts (visible structures, processes, and behaviours); espoused beliefs and values (strategies, ideas, goals, aspirations, and rationalization); and basic underlying assumptions (unconscious, taken-for-granted beliefs, perceptions, feelings) (Schein, 1985, 2004, 2010). He emphasizes that understanding and changing the culture requires action at these three levels and espousal of some basic assumptions (Schein, 1985, 2004, 2010). These assumptions are general and not related specifically to safety. Rather, they guide organizational attitudes and behaviours, including those related to safety.

Many conceptualizations of safety culture are based on Schein's framework (e.g., Pidgeon, 1991; Reason, 1998; Turner et al., 1989). However, there is no consensus on the definition of safety culture (Guldenmund, 2000). More specifically, there is a persisting ambiguity about the inclusion of the observable (visible artefacts) and non-observable (beliefs, values, and assumptions) elements in its definition.

While the international safety institution, the IAEA, defines safety culture as an assembly of organizational or individual characteristics and attitudes, focused on the priority of safety (INSAG International Atomic Energy Agency, 1991) and, primarily, on the observable elements, safety culture scholars' (Grote, 2007; Pidgeon, 1991; Turner et al., 1989) integrate both observable (behaviours, attitudes) and non-observable (values, beliefs, assumptions) elements. Safety science scholars and operators further extend this definition to include a set of overall assumptions, values, beliefs, shared structures, behaviours, and social and technical practices (Besnard et al., 2017, p. 9; Pidgeon, 1991; Reason, 1998, 2000). For example, Pidgeon (1991) defines safety culture as a set of beliefs, norms and rules, but also attitudes and social and technical practices aimed at minimizing exposure to dangerous or injurious conditions. The majority of international safety institutions, such as for example, Insitute of Nuclear Power Operations INPO (2004) and World Association of Nuclear Opertators WANO (2013), favour this more inclusive definition of safety culture. Guldenmund (2000) suggests that the High Scientific Council's Advisory Committee on the Safety of Nuclear Installations (ACSNI) definition is the most complete and describes safety culture as "*the product of individual and group values, attitudes, perceptions, competencies, and patterns of behaviour that determine the commitment to, and the style and proficiency of, an organisation's health and safety management*" (ACSNI Study Group on Human Factors, 1993). However, an overly comprehensive definition of safety culture, includes almost all elements of the organization, can result in a weak conceptualization that makes rigorous investigation of safety culture difficult.

Also, despite the integration of observable elements in the definition, the components of a "good" safety culture are mainly non-observable and cognitive. For example, Pidgeon (1991) recognizes that safety attitudes are linked to individual and collective **beliefs** about safety. He introduces the notion of reflexivity (**cognitive processes**) in safety practices as an ingredient of a "good" safety culture. Here, reflexivity is understood as a learning process that involves search for new meanings in order to develop intelligence about the risk and avoid inflexible application of existing rules (Pidgeon, 1991, 2010).

To facilitate the study of non-observable elements, some authors propose the idea of safety climate (Zohar, 1980). Safety climate reflects employees' perceptions, shared through ongoing social interactions, about the relative importance of safety behaviours, for informing safety priorities (Hofmann et al., 2017; Zohar, 1980, 2010). Guldenmund's (2000) review situates safety climate in relation to attitudes, which, compared to basic underlying assumptions, are more easily captured.

Objectives of safety culture. Despite these different definitions, the literature agrees on the main objectives of safety culture. First, safety culture is aimed at making safety the overriding priority. For example, the IAEA underlines the importance of "all-pervading safety thinking". The priority given to safety is reflected in a questioning attitude, personal and collective commitment to excellence and self-regulation in safety matters (INSAG International Atomic Energy Agency, 1991). Similarly, Rasmussen (1997, p. 192) underlines that a "good" safety culture "acts as a *continuous pressure* compensating the *functional pressure* of the work environment". Despite the existence of sometimes conflicting goals, this commitment to safety is the prime component of safety culture (Flin & Yule, 2004).

Second, safety culture enables the development of capabilities to deal with uncertainty and complexity, which enriches traditional approaches to risk management. Norms and rules are organizational guidelines for actions but might not cover all foreseeable events. Therefore, Pidgeon (1991) warns of the danger of following existing rules too rigidly: "*the inflexible, or ritual, application of existing rules to guard against known hazards might lead to crucial oversights*" (Pidgeon, 1991, p. 136). Also, Weick (1987) sees organizational culture as a source of high reliability and underlines its importance for interpreting and generating meaning. Pidgeon (1991) suggests the search and acceptance of uncertainty promotes alertness and free discussion of risk (in particular "*whistle-blowing*") and development of creativity and "*safety imagination*". Reason (1997) points to safety culture objectives by using the terms: informed culture, reporting culture, just culture, flexible culture and learning culture.

Developing safety culture. Many safety culture scholars highlight practices and attitudes enabling the achievement of a "good" safety culture (Grote, 2007; Pidgeon, 1991; Reason, 1997; Weick, 1987), such as reporting, discussion about risk, etc.. Vogus et al. (2010) provide a theoretical framework of safety culture development, which emphasizes three processes: enabling, enacting and elaborating safety culture (Vogus et al., 2010). Enabling is aimed at creating a favourable context for the development and implementation of safety culture in daily activities. Enacting safety culture refers to effective translation of safety values into organizational practices to increase reliability. Elaborating implies continuous improvement and learning. However, the authors highlight that the interactions among these three processes of safety culture require more investigation (Vogus et al., 2010). Ocasio and Wohlgezogen (2010) suggest that the process of transforming values into operational behaviour (enacting safety culture) is poorly understood while other scholars (Flin & Yule, 2004; Hofmann & Morgeson, 2004) and practitioners (IAEA, 2016) point to a particular role of **leadership** for safety culture development. Leadership is seen as playing a role of disseminating safety values and enabling their translation into corresponding behaviours and attitudes.

In sum, by pointing to the importance of safety culture and the role of leadership for its development, safety management era of safety approach demonstrates progressive acknowledgment of the complexity of organizational factors and uncertainty.

1.1.2. Safety management: managing paradoxes

1.1.2.1. Managing conflicting goals: production versus safety

High-risk organizations, which need to navigate among multiple and perhaps conflicting organizational goals, search for a "*dynamic equilibrium model of organizing*" (W. K. Smith & Lewis, 2011, p. 389). From this perspective, safety management is aimed at dealing with ambiguities about safety issues, created by interconnected, and sometimes conflicting, organizational goals.

A major safety management issue concerns resolving tensions between the objectives of safety (protection, prevention) and performance (profitability, production) (Gaba & Greve, 2019; Goh et al., 2012; Madsen, 2013; Reason, 1997; Woltjer, 2019). HROs research underlines the importance of simultaneous pursuit of multiple goals (e.g., performance and safety) to achieve high reliability (La Porte & Rochlin, 1994). Several authors point to and attempt to disentangle the complex relationship between the management of production and protection (Goh et al., 2012; Madsen, 2013; Reason, 1997). For example, Reason (1997) explores a sequential focus model of a complex relationship between production and protection. He points out that a strong focus on production despite protection efforts can lead to accidents. For example, long periods of accident-free performance reduce perception of the importance of protection, jeopardized by production demands. However, increased production can lead to higher exposure to hazard and will require increased protection. Furthermore, Goh et al. (2012, p. 52) propose a complex causal loop model of a dynamic relationship demonstrating "*how a strong production focus can trigger a vicious cycle of deteriorating risk perception and how increased protection effort can, ironically, lead to deterioration of protection*". On the one hand, a strong focus on production leads to unintentional development of higher risk tolerance, leading to a distorted perception of safety margins, resulting in protection deterioration. On the other, paradoxically, a higher focus on protection leads to overestimation of safety margin resulting in a deterioration of protection and higher risk of organizational accidents (Goh et al., 2012). Madsen (2013) also suggests that profitability goals influence the relationship between production and safety. Accident rates are lower for organizations that perform either well above or well below profitability goals (Madsen, 2013, p. 785). Similarly, Gaba and Greve (2019) show how much satisfaction with performance goals affects organizational behaviour related to goal prioritization. In high-risk industries, low levels of safety may threaten organizational survival, so safety goals become more important for less profitable firms (Gaba & Greve, 2019).

Many questions remain regarding how organizational members choose among conflicting goals. Berti and Simpson (2021) question the assumption that individuals have full agency and are able to decide how to engage with paradoxical tensions. They explore power relations restricting individual responses to contradictions. Levinthal and Rerup (2021) highlight the influence of self-enhancement in face of ambiguities at both the individual and organizational levels. By amplifying outcomes considered positive and diminishing aspects considered negative, self-enhancement leads organizational members to interpret conflicting outcomes in a positive light. The authors explain that a "*self-enhancement orientation implies that ambiguity is sought and then later reduced in a direction that is predictable (i.e., more favourable interpretations prevail as ambiguity is reduced)*" (Levinthal & Rerup, 2021, p. 3). Levinthal and Rerup (2021) also suggest, that ambiguity resulting from conflicting goals should be embraced with "wisdom", which implies that organizations should accept and maintain ambiguity to develop more complex understanding and enhance learning. This refers to the need to recognize "*that not all conditions can be expected and prepared for beforehand, and that unexpected conditions are likely to transpire in complex systems*" (Woltjer, 2019, p. 106). However, in spite of these recent developments, scholars call for more research to understand adaptive behaviour in the face of ambiguities linked to multiple goals (Gaba & Greve, 2019; Levinthal & Rerup, 2021), and increased efforts to develop practices and processes that enable ways of thinking and acting to make sense of the ambiguity (Barton et al., 2015, p. 74).

1.1.2.2. Managing two forms of safety: regulated versus managed safety

The evolution of safety studies discussed in Section 1.1, suggests that organizations need to achieve the right balance among the various elements in tension: e.g., a balance between standardization and flexibility (Grote et al., 2009), adherence to rules and openness to innovative responses (Busby & Iszatt-White, 2016; Denyer, Tranfield, & van Aken, 2008; Hale & Borys, 2013a, 2013b; Sutcliffe et al., 2016). In the safety literature, these tensions are crystalized as tension between two forms of organizational safety: regulated and managed (Amalberti, 2021; Besnard et al., 2017; Morel et al., 2008; Oliver et al., 2017). While regulated safety focuses on technical/procedural barriers and predictable outcomes, managed safety refers to the capacity to handle unpredictable and uncertain events through proactive behaviour and appropriate actions.

Complex and technologically tightly-coupled systems, such as nuclear power plants, are heavily regulated in order to prevent the occurrence of unpredictable and potentially high-impact events. Regulated safety is based on technical barriers and prescribed safety rules and procedures to cope with predictable events. This type of regulation enables safety through constraints and prohibitions. Regulated safety, which is normative in nature, is achieved by conformity to top-down prescriptions (Nascimento et al., 2014). In other words, organizations aim to minimize uncertainty through extensive standardization, proceduralization, automation and reduction of human freedom and technology failures (Grote, 2007). While safety science literature discusses different aspects of regulated safety, more research is needed on managed safety (Amalberti, 2021; Besnard et al., 2017; Morel et al., 2008).

In contrast to regulated safety, managed safety is based on operators' knowledge and experience, which allows them to proactively deal with unexpected events. Recent research on safety proposes several definitions of managed safety (Besnard et al., 2017; Daniellou et al., 2010; Morel et al., 2008; Nascimento et al., 2014; Vidal-Gomel, 2017), which are synthesized in Table 1.1**Error! Reference source not found.**.

Table 1.1. Definitions of managed safety

Definition	Reference
"Specific form of safety, managed safety is … the ability to manage **unexpected events** (before, during, and after)". Managed safety is "refers to the ability to recognize, adapt to, and handle **unanticipated perturbations**"	Morel et al., 2008, p.3, 13
Managed safety is "the capacity to anticipate, to perceive and to respond to the failures. It relies on **human expertise**, quality of initiatives… on the management making attention to the reals situation and enabling articulation between different types of knowledge"	Foundation for Industrial Safety Culture (FIISC) Daniellou et al., 2010, p. 64
"Managed safety relies on the **capacity of operators** for initiative, either alone or as a group, when dealing with **unforeseen events** and with the natural variability of the real world. This approach derives from the idea that it is pointless to believe that everything can be foreseen. Human intervention is therefore necessary to ensure reliability"	Nasciemento et al., 2014, p. 96
"Managed safety is based on operators' knowledge and experience"	Vidal-Gomel, 2017, p. 134
Managed safety is "based on the **competence of women and men,** capable to identify the situation "in the here and now" and to develop appropriate responses" Managed safety is "necessary to allow pertinent reaction face to **unforeseen events**"	Institute for Industrial Safety Culture (IISC) Work group "Safety culture" Besnard et al., 2017, p. 21, 24

The definitions in Table 1.1 highlight the core characteristics of managed safety. First, managed safety relies on expertise in human operational practices, performed either individually or collectively. Initially, the definitions of managed safety highlighted the idea of better human-machine cooperation. In this view, risk originates from the dynamic interaction among system components, rather than technical or human factors (Morel et al., 2008). Second, managed safety refers to the capacity to deal with unforeseen events and natural disruptions. In other words, managed safety allows to handle uncertainty. Grote (2007) suggests that organizations manage uncertainty by developing competencies to deal with complex tasks and to enable every member of the organization to handle uncertainty locally. The positive contribution of human adaptive ability for reliability has been highlighted in previous research (Hale & Borys, 2013a; Morel et al., 2008; Nascimento et al., 2014; Vidal-Gomel, 2017).

Therefore, adaptability capacity, highlighted by proponents of managed safety, is based on the operators' expert knowledge and experience to deal with unpredictable events, referring the notion of resilience (further developed in the part 1.2.1.3). Morel et al. (2008) cite "*craftsmanship or native resilience, centred on a familiarity with the environment and the ability to anticipate the changes*" (Morel et al., 2008, p. 13). In sum, managed safety is based on the development of individual capacities, which in turn is based, on professional expertise and knowledge. These capacities focus on the timely management of uncertainty in real-life situations. Weick et al. (1999a, p. 46) refer to "*the…important word 'management' … [which] makes clear that people deal with surprises, not only by anticipation that weeds them out in advance, but also by resilience that responds to them as they occur. Furthermore, to manage a surprise is to contain it rather than eliminate it*".

The tension between regulated and managed safety is closely related to the tension between error prevention and error management, recently discussed by Cowley et al. (2021). These scholars consider error prevention to be aimed at eliminating errors at all costs, through technical barriers, procedures and administrative control. They see error management as the ability to deal with emergent and unexpected issues. In the same line, Perin (2007) distinguish calculated logic (estimating risks) and real-time logic (handling risks). The authors outline the need for some integration of and balance between these elements (error prevention and error management; calculated and real-time logic) (Cowley et al., 2021; Perin, 2007; Vogus & Sutcliffe, 2007; Weick, 2006).

To ensure safety in complex, high-risk environments, regulated and managed safety must develop jointly and be mutually reinforcing. However, the existing theory highlights that the development of regulated safety can jeopardize the development of managed safety (Bourrier & Bieder, 2013; Daniellou et al., 2010; Morel et al., 2008; Oliver et al., 2017)because extensive use of procedures and rules tends to restrict human action to mechanistic and predictable behaviours (Hale & Borys, 2013a; Pidgeon, 1991; Reason et al., 1998). A recent study shows how highly technological systems (regulated safety) can limit the cognitive abilities of actors (managed safety) faced with ambiguous or unexpected situations (Oliver et al., 2017). Therefore, the increasing number of rules aimed at reducing risk and uncertainty can lead to actors being less well-prepared to handle residual uncertainty related to a complex system. In other words, the reinforcement of ways to avoid short-term uncertainty can limit long-term capacity to cope with unpredictable events (Grote, 2007; Oliver et al., 2017). **Therefore, it is essential to understand the deep nature of tensions between regulated and managed safety, and the elements enabling their joint development** (Amalberti, 2021; Cowley et al., 2021; Hannah et al., 2009). Figure 1.2 illustrates this call to find elements that allow effective joint development of managed and regulated safety without their jeopardizing each other.

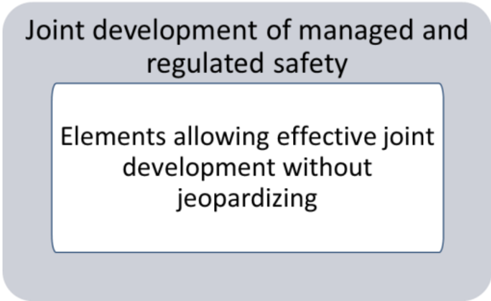

Figure 1.2. Safety management challenge of the joint development of managed and regulated safety

Morel et al. (2008) suggest that where extensive rules govern human actions, operators should have some latitude to adapt their actions to unexpected situations, rather than being forced to strict protocols and guidelines. Organizations need to find a way to respond to predictable events while developing the ability to deal with unpredictable events. The development of this adaptability capacity is possible in organizations where members are allowed to solve problems creatively (Hannah et al., 2009, p. 910). However, in high-risk contexts, organizations "*tend to be highly administrative in their control*" relying on risk management policies and indicators (Hannah et al., 2009, p. 901). Hanna and colleagues call for more research on these inherent tensions between the requirements of adaptability on the front-line level and stability at higher levels (Hannah et al., 2009). High-risk industries, characterized by high reliability and continuous search for responses to inherent uncertainty, are a salient context to explore the implementation of safety management processes, with particular attention to a joint development of regulated and managed safety.

The introduction of the notion of safety culture focuses attention on the need to develop organizational ability to face complexity and uncertainty or to strike an appropriate balance between regulated and managed safety. However, in practice, the implementation of safety culture parallels the implementation of regulated safety (reporting, indicators, formalization, etc.), "*offering an illusion of safety control*" (Besnard et al., 2017, p. 22). In this view, the development of safety culture acts more upon behaviours and attitudes, than on values and deep assumptions, as suggested by (Schein, 1985). Consequently, leadership has to adopt a double role in the development of safety culture. First, leadership has to exert influence at all three levels of culture (artefacts, values and underlying assumptions), rather than only at the observable ones (Schein, 1985). Second, leadership has to ensure that safety culture development favours a joint development of regulated and managed safety.

1.2.Reliability and resilience in high-risk organizations

Strategic prioritization of safety is aimed at avoiding accidents in order to preserve functioning by maintaining ongoing operations (Weick et al., 1999) and, in particular, reliability (du Plessis & Vandeskog, 2020; Pettersen & Schulman, 2019). Reliability is seen as crucial organizational "*capacity to continuously and effectively manage working conditions, even those that fluctuate widely and are extremely hazardous and unpredictable* (Weick, Sutcliffe, & Obstfeld, 1999)" (Bigley & Roberts, 2001, p. 1281). Organizational studies focused on exploring the success of reliability of companies working in highly hazardous contexts and factors that increase reliability. However, more recently, scholarly interest refocused on one specific factor: resilience. In the following sections, we explore the evolution of scholarly interest from reliability to resilience (Section 1.2.1) and, the relationship between interconnected concepts of safety, reliability and resilience (Section 1.2.2.).

1.2.1. From reliability to resilience

1.2.1.1. The theory of High Reliability Organizations

In the 1980s and 1990s, High Reliability Organizations (HROs) became a topic of interest in the field of organizational science (e.g., La Porte & Consolini, 1991; Leveson et al., 2009; Roberts, 1990; Schulman, 1993; Vogus & Welbourne, 2003; Weick, 1987; Weick et al., 1999; Zohar & Luria, 2003). In the 1980s, HROs research was first developed by a group of scholars from the University of California - Berkley (e.g., Rochlin et al., 1987), who began studying a particular type of organization characterized by highly technological and hazardous systems. This stream of research was a response to predominant research stream on disasters, in particular, Normal Accident Theory (Perrow, 1984). Influenced by the Three Mile Island accident (1979), the Normal Accident Theory suggested that, despite all management processes, accidents in complex systems are inevitable. This view put forth that due to the technological complexity and interdependencies in tightly coupled complex systems, even a small failure can cascade into a major accident in unexpected and unmanageable ways. In contrast to this pessimistic view of the inevitability of accidents, the more optimistic HROs research focused on organizations that, despite high risk and high hazard technology, succeed functioning safely and reliably (Barton & Sutcliffe, 2009). The uniqueness of HROs lies on their abilities to both prevent and manage incidents before they escalate into catastrophic failures (Barton & Sutcliffe, 2009), that is, to maintain a balance between regulated and managed.

When searching to define HROs, some scholars initially referred to examples of organizations with a record of small numbers of failures, compared to what might be expected (Rochlin et al., 1987), and their "*nearly accident-free performance*" (La Porte, 1996, p. 60). However, other HROs scholars also defined high-reliable organizations based on a set of organizational characteristics, mainly related to the nature of technology involved, and more specifically, referring to the tight coupling and interactive complexity as specific features of such complex technological systems, suggested by Perrow (1984). Therefore, HROs are characterized by the presence of dangerous interdependent and complex technologies and systems, interacting in and with dynamic environments (La Porte & Consolini, 1991; Roberts, 1990; Vogus & Welbourne, 2003). The problems faced by these organizations are maintenance and management of these technologies by avoiding high-impact errors and preparedness for unpredictable production fluctuations (La Porte & Consolini, 1991). HROs authors point out that the extent of the impact of potential failure (production shutdowns or loss of human health and/or life) explains the intolerance of HROs to errors (La Porte & Consolini, 1991; Roberts, 1990). This approach is accentuated by the environmental pressure to maintain safety and sufficiently invest in reliability. Some examples of high reliability organizations are nuclear power plants, air traffic control, or organizations operating in chemical, pharmaceutical and civil engineering industries.

HROs are also characterized by the specificity of their organizational processes: prioritization of safety while working towards the attainment of multiple goals, attention to organizational design and procedures (decentralization of decision-making and redundancy), limited learning by experimentation, continuous learning through simulations, a culture of vigilance and responsibility for potential accidents (La Porte & Consolini, 1991; La Porte & Rochlin, 1994; Weick et al., 1999). The decision-making process includes reporting and preventing errors, monitoring and control in a climate of autonomy and trust, ensured by mutual coordination and information sharing. As suggested by Boin and Schulman (2008), HROs avoid failure not just by good technological design but also by good management and organizational processes. Drawing on the lessons from HROs literature, Roberts and Bea (2001, p. 70) propose that managers should "*aggressively seek to know what they don't know, design reward and incentive systems to recognize the cost of failure and the benefits of reliability, and communicate the big picture to everyone*".

Relying on the HRO's seminal work (e.g., La Porte, 1996; Rochlin et al., 1987), Weick et al. (1999a) enriched their understanding by offering a reconceptualization of high reliability revealed by processes of collective mindfulness (the key concept of mindfulness is discussed in more detail later in this chapter). Scholars draw attention to the cognitive infrastructure that supports reliable performance and learning simultaneously. They further propose that five processes contribute to high organizational reliability, namely: preoccupation with failure, reluctance to simplify interpretations, sensitivity to operations, commitment to resilience and deference to expertise. Interestingly, Weick and colleagues (1999a) also highlight, that high reliability requires successful handling of both expected and unexpected events. Therefore, HROs should develop both anticipation and resilience (see Wildavsky, (1988).

More generally, research on HROs offers some valuable guidelines to minimize failure by improving reliability. However, this stream of work has attracted some criticism. First, some scholars claim that it lacks objective criteria to identify whether an organization is or is not highly reliable (Sagan, 1995). For example, Boin and Schulman (2008) highlight the conflicts of arguments explaining high reliability: focus on past successes and at the same time focus on forward-looking concerns of future failures but also the difficulty to generalize from findings of single case studies.

Second, HROs characteristics present an ideal, which not all of the studied organizations achieve (Boin & Schulman, 2008; Hopkins, 2014). In response, Vogus and Welbourne (2003) link HROs to a broader set of organizations – "*reliability-seeking organizations*", which operate in uncertain environments. The authors refer to their ability to remain open and flexible to emerging information, and to satisfy reliability requirements through innovation. In the same vein, Bigley and Roberts (2001) underline that while more conventional organizations are increasingly exposed to complex, dynamic, uncertain and ambiguous environment and demanding task situations, HROs provide a generalizable understanding of how to maintain reliability under challenging conditions (Bigley & Roberts, 2001; Weick et al., 1999).

Third, while HROs research defines guiding principles necessary to developing safety culture and, more broadly, organizational reliability (Fiol & O'Connor, 2003; Levinthal & Rerup, 2006; Sutcliffe et al., 2016; Vogus & Welbourne, 2003); however, the translation of safety and reliability principles into operational behaviour remains an open question (Hofmann et al., 2017; Ocasio & Wohlgezogen, 2010; Vogus et al., 2010). Boin and Schulman (2008) criticize the lack of connection between the described HROs processes and characteristics and the level of performance reliability. Understanding the mechanisms of failure avoidance is necessary for in-depth analysis of HROs. Hence, Boin and Shulman (2008) advocate for a continuous research effort, instead of ad hoc analyses following major accidents. **HROs scholars emphasize the need for empirical research on HROs to understand their mechanisms and dynamics** (Boin & Schulman, 2008; Vogus & Rerup, 2018; Wears & Roberts, 2019)**. Although the literature proposes some recommendations** (Roberts & Bea, 2001) **and tools for empirical measurement of the processes aiming at developing mindfulness** (Weick & Sutcliffe, 2007), **research addressing their effective implementation is rare.** To overcome these limits, scholars highlight that future research should focus on explaining the causes underlying reliability by taking into account the complexity of nonlinear causality (Hopkins, 2014). In particular, Weick and colleagues (1999a) stress that while HROs are naturally and sometimes excessively focused on anticipating possible failures, they should also strive to develop **resilience capabilities**.

1.2.1.2. Resilience for dealing with the expected and the unexpected

Recently, scholarly interest in resilience has grown substantially. The concept of resilience originated in engineering science and soon became one of the focal domains of organizational studies (Hillmann & Guenther, 2020; Linnenluecke, 2017), including work on HROs (Boin & Schulman, 2008; Hopkins, 2014; Sutcliffe & Vogus, 2003; Vogus & Sutcliffe, 2007; Weick & Sutcliffe, 2007; Williams et al., 2017). The resurgence of interest in resilience has resulted in it becoming an "umbrella concept" that has been adopted by multiple disciplines and research fields (Hillmann & Guenther, 2020; Linnenluecke, 2017) and applied to different contexts. As we have seen, HROs research (Weick et al., 1999; Weick & Sutcliffe, 2007) highlights the importance of paying attention to organizational capabilities to avoid accumulation and escalation of problems (which can potentially lead to accidents) and to allow handling of "*challenging conditions*" (Vogus & Sutcliffe, 2007, p. 3418). In the stream of work on "resilience as reliability" (Andersson et al., 2019; Linnenluecke, 2017; Zolli & Healy, 2012), resilience is defined as the organizational ability to absorb strain and preserve functioning despite the presence of internal and external adversity (Sutcliffe & Vogus, 2003). In this perspective, resilience involves adjustments and adaptation to avoid accidents or to mitigate the evolution of undesired events (Williams et al., 2017). Even if all definitions of resilience include the notion of response to adversity, certain ambiguities remain unresolved in the literature on resilience. These ambiguities concern: 1) the type and the scale of adversity; 2) the temporality of resilience; and 3) the degree to which adversity is expected and anticipated.

First, in theorizing about 'the type and the scale of adversity', some authors conceptualize it as the organizational 'preparedness for dealing with unforeseen disruptive undesired events' (van der Vegt et al., 2015) while others see it as 'built through daily organizing' (Andersson et al., 2019; Lengnick-Hall et al., 2011; Linnenluecke, 2017; Weick & Sutcliffe, 2007). In the same vein, some researchers on risk management traditionally consider resilience as the capacity to recover from crises or extreme, disruptive external shocks such as the Fukushima disaster (Geoffroy et al., 2016), while others apply and expand this term to small daily variations in organizational reliability and capability to avoid accidents. More recently scholars have developed a more inclusive view of resilience and propose a definition encompassing all types of challenging conditions (Andersson et al., 2019; Duchek, 2020).

Second, 'the temporality of resilience' is considered by Levinthal and Rerup (2006) as the ability to contain and manage the unexpected in real time. Once again, the most recent approaches tend to be more integrative. For example, Williams et al. (2017, p. 742) define resilience as a broad process by which "*an actor (i.e., individual, organization, or community) builds and uses its capability endowments to interact with the environment in a way that positively adjusts and maintains functioning prior to, during, and following adversity*", highlighting its three temporal dimensions. Similarly, Duchek (2020) identifies three stages of resilience: anticipation, coping and adaptation. Resilience prior to adversity relies on proactive communication and coordination (Williams et al., 2017) and can be understood as preparedness for a potential disruptive event (Bechky & Okhuysen, 2011; Kantur & Iseri-Say, 2012). Gould (2019) associates it with the ability to detect weak signals rather than major disruptions, highlighting the role of mindfulness. Resilience during adversity refers to dealing with disruptions in real time to prevent the escalation of small disturbances into crises or, in case of failure, effectively handling the crisis while maintaining a high level of performance. Resilience following adversity refers to the ability to bounce back and learn from the experienced shock. These types of resilience are related to the distinction between <u>precursor</u> and <u>recovery</u> resilience (Boin & van Eeten, 2013; Pettersen & Schulman, 2019). While preparedness to manage small incidents and ability to prevent occurrence of crises correspond to precursor resilience, ability to bounce back from a major crisis refers to recovery resilience.

Third, regarding 'the degree to which adversity is expected and anticipated', previous HROs research suggested that organizations have to deal with both predictable events (through technical systems and procedures) and unexpected situations (through proactivity and adaptability) (Weick et al., 1999; Weick & Sutcliffe, 2007). **Recently, the HROs literature make an analytical separation and clearly distinguish two approaches to deal with uncertainty – anticipation and resilience** (Morel et al., 2008; Sutcliffe & Vogus, 2003; Vogus & Sutcliffe, 2007), echoing the distinction proposed by Wildavsky (1988). In this view,

anticipation is based on prediction and prevention to **diminish rather than cope with the uncertainty** (Grote et al., 2009). Anticipation achieved through risk management practices leads to the reinforcement of rigid technical and regulatory barriers to cover the risk (Scheytt et al., 2006). The difficulty is that organizations operating in risky and dynamic environments must perform reliably despite uncertainty (Barton et al., 2015). By contrast to reducing uncertainty, **they have to cope with uncertainty by developing resilience** capabilities (Barton et al., 2015; Fraher et al., 2017; Weick & Sutcliffe, 2007).

Some scholars put aside the distinction between anticipated and non-anticipated situations (that they do not see as polar opposites) and suggest integrative approach to resilience (Andersson et al., 2019; Duchek, 2020; Lengnick-Hall et al., 2011; Williams et al., 2017), without making a clear distinction between anticipated and non-anticipated situations. While Wildawsky (1988) considers anticipation in opposition to resilience and refers to it as *"knowing what to expect"* (Hollnagel et al., 2006, p. 349), however, in the more integrative view of resilience (Andersson et al., 2019; Duchek, 2020; Kantur & Iseri-Say, 2012) anticipation includes preparedness for and avoidance of unexpected events by their early sensing and adaptation. This points to the fact that some events may lie within a 'grey zone' and cannot be categorized as either totally anticipated or totally unpredictable.

In this doctoral research, we adopt the perspective of scholars who make an analytical distinction between anticipation and resilience (Sutcliffe & Vogus, 2003; Vogus & Sutcliffe, 2007; Wildavsky, 1988). We adopt Wildawsky's (1988) conceptualization of **anticipation** as the capacity to envision the "**known unknown**" and we consider **resilience** as the capacity to deal with the "**unknown unknown**" or highly uncertain hazards. In spite this analytical separation between anticipation and resilience, we acknowledge that there is a degree of interplay between these two concepts.

1.2.1.3. Resilience for dealing with unexpected

In the perspective that distinguishes resilience from anticipation (Morel et al., 2008; Vogus & Sutcliffe, 2007; Wildavsky, 1988), resilience can be considered as a response to the limited capabilities of risk management to anticipate all potential dangers, despite the existence of prevention and preparation mechanisms (Douglas & Wildavsky, 1982). Therefore, resilience involves coping with unexpected events in the present moment, that is, not by anticipation, but by responding to them as they unfold (Weick et al., 1999). In face of challenging conditions, resilient organizations respond and adjust proactively (Barton & Sutcliffe, 2009; Williams et al., 2017).

Recent organizational studies consider resilience as the capacity to understand the specificity of current situations and to switch adaptively (Grote, 2019) among customized responses (Lengnick-Hall et al., 2011), to accept (Duchek, 2020) and to adjust (Williams et al., 2017), and to adapt proactively to an abnormal and unexpected disturbance (Boin & van Eeten, 2013). Contrary to anticipation, resilience requires improvisation, (Wildavsky, 1988) and the ability to creatively leverage the available resources, attention and knowledge to cope with unknown and unpredictable situations (Williams et al., 2017). Therefore, resilient organizations are more efficacious than those based only on rigidity and other deterministic perspectives (Sutcliffe & Vogus, 2003). More precisely, resilience is based on early sensing of weak signals of upcoming events and designing of customized responses (Hardy et al., 2020; Lengnick-Hall et al., 2011; Weick & Sutcliffe, 2007).

In spite of significant advancements in understanding resilience, many questions remain regarding the mechanisms of dealing with unexpected events, leading to resilient outcomes (Linnenluecke, 2017). More research is necessary to better understand "*how organizations actually prepare for unexpected events, accept problems, and learn from them*" (Duchek, 2020, p. 238) in daily organizing (Andersson et al., 2019). For example, some recent studies point to the essential role of structure for the development of resilience (Andersson et al., 2019; Barton & Sutcliffe, 2009; Bechky & Okhuysen, 2011; Duchek, 2020). Finally, recent studies also highlight the need for more investigation of the role of leadership in enabling resilience (Grote, 2019; Sutcliffe & Vogus, 2003; Williams et al., 2017).

Victim of its attractiveness, the concept of resilience has been applied to explain very different phenomena and situations, requiring analytical precision. For example, since resilience is closely related to reliability and safety, these three terms have sometimes been used interchangeably. Thus, in the following section, we feel compelled to try to disentangle these concepts.

1.2.2. The intertwining concepts of safety, reliability and resilience

1.2.2.1. Defining safety

It is important to make a distinction between safety and security. While traditionally safety is understood as the absence of unwanted events (Aven, 2014; Hollnagel, 2008; Leveson, 1995, 2004), it differs from security in terms of the nature of the these events: security relates to intentional events such as burglary, sabotage, terrorist attacks, etc. and safety refers to unintentional accidental events (Aven, 2014).

Understood as the absence of accidents with unplanned and unacceptable consequences, safety can be seen as the opposite of risk (Hollnagel, 2008) or as associated with low and acceptable levels of risk (Aven, 2014). Hollnagel (2014, pp. 1–2) defines safety as "*the system property or quality that is necessary and sufficient to ensure that the number of events that could be harmful to workers, the public, or the environment is acceptably low*". However, this view of safety as the antonym of risk has been criticized and led to calls for a broader approach to uncertainty beyond pure probability-based definitions of risk (Aven, 2014; Möller et al., 2006). Therefore, Aven (2014, p. 16) proposed a more integrative definition of safety as the "*absence of undesirable events and consequences*".

Organizational safety scholars study why high-risk, complex and tightly coupled systems remain safe despite their inherent vulnerability (Barton & Sutcliffe, 2009). In contrast to the Safety-I perspective, which focuses on the negative causes and impacts of unwanted events (by trying to reduce unwanted outputs as much as possible), Hollnagel (2014) proposed the Safety-II perspective, which focuses on the notion of success (to ensure that outputs are as optimal as possible). It therefore appears that, in general, safety science aims to develop knowledge not only about risk management, but also about broad safety-related phenomena, processes and events, to understand how to acknowledge, assess and manage the world for more safety (Aven, 2014).

1.2.2.2. Definition of organizational reliability

High reliability, defined as "*unusual capacities to produce collective products of a given quality repeatedly*" (Hannan & Freeman, 1984, p. 153), is considered to be one of the competencies that favour organizational survival, particularly, in the context of uncertainty. The HROs literature expands the term of reliability to include the ability of the organization to stay ahead of competitors through intense innovation (Vogus & Welbourne, 2003).

Schulman (1993) proposes two approaches to organizational reliability based on the separation between anticipation and resilience (Wildavsky, 1988). The first considers reliability as relying on anticipation and invariance equivalent of predictable, certain and constant performance. This view of reliability refers to lack of unexpected, unanticipated or unexplained variation in performance (Hollnagel, 1993). The second considers reliability in terms of real-time resilience and responsiveness to the unexpected to maintain performance (Schulman, 1993). In this view reliability is based on the "*continuous management of fluctuations*" in performance and organizational interactions (Schulman, 1993, p. 369).

Representing a particular stream of HROs studies, Weick and colleagues (1999a) offer a more integrative view of reliability and the idea that an effective organization develops both anticipation and resilience. In this perspective reliability is achieved through processes of mindful cognition (Weick et al., 1999). However, reliability remains difficult to capture because of its dynamic and invisible nature, requiring attentiveness to ubiquitous “non-events” (Weick, 1987).

1.2.2.3. Defining organizational resilience

Resilience is an “umbrella concept”, whose definition varies depending on the discipline and the context (Hillmann & Guenther, 2020; Linnenluecke, 2017). Recently, Hillmann and Guenther (2020), Linnenluecke (2017) and Raetze et al. (2021) provided reviews of the literature on organizational resilience showing that while initially resilience was seen as the ability to bounce back from failure and the capacity to absorb change and maintain operational activities, the HROs literature redefined resilience as the capacity to cope with surprises in real time (Sutcliffe & Vogus, 2003; Weick et al., 1999), and to adapt proactively (Williams et al., 2017), rather than avoid or survive after an adverse event (Barton et al., 2015). In this view, based the development of appropriate knowledge and capabilities, resilience is considered as ability to prepare for rather than just recover from unexpected events.

Sutcliffe and Vogus (2003, p. 97) see organizational resilience as “*the ability to absorb strain and preserve (or improve) functioning despite the presence of adversity (both internal adversity—such as rapid change, lousy leadership, performance and production pressures—and external adversity – such as increasing competition and demands from stakeholders)*”. In other words, resilience is aimed at maintaining positive adjustments in response to challenging conditions, in order to achieve desired performance. For instance, Levinthal and Rerup (2006, p. 505) define resilience as the capacity “*to contain and manage real-time unexpected events in an adaptive, flexible fashion*”. Recent integrative approaches emphasize the importance of continuous adaptation and consider resilience as the wider ability to adapt and adjust through customized responses to adversity (Andersson et al., 2019; Duchek, 2020; Lengnick-Hall et al., 2011; Williams et al., 2017).

1.2.2.4. Intertwining of key concepts

The boundaries among the interrelated concepts of safety, reliability and resilience are blurred. Continuously evolving literature uses all three terms and distinguishing among them can be difficult.

Safety-Reliability. The field of safety science acknowledges flexible boundaries between safety and reliability and considers them negotiable (Hopkins, 2014; Leveson et al., 2009). The definition of safety exemplifies this lack of clarity. Safety is generally defined as a dynamic non-event (Hollnagel, 2014). However, this definition was proposed by Weick (1987) in relation to reliability. While some scholars see reliability as "*the safety of core activities and processes*" (Farjoun, 2010, p. 206), others consider it to be derived from operational reliability (Zohar & Luria, 2003) and organizational competence to deal effectively with risky situations. Barton and Sutcliffe (2009) use both terms, reliability and safety, interchangeably. Some authors define high reliability as the way "*to function safely despite the hazards of complex systems*" (Barton & Sutcliffe, 2009, p. 1329), that is, they consider reliability to be the result of safety. In contrast, Zohar and Luria (2003) suggest that quality and safety are the result of operational reliability.

Safety-Resilience. Resilience has become a dominant term in the management literature. Work on resilience engineering links safety and resilience: "*Resilience engineering is a paradigm for safety management that focuses on how to help people cope with complexity under pressure to achieve success*" (Hollnagel et al., 2006, p. 6). Morel et al. (2008b, p. 13) consider resilience as an "*adaptive know-how regarding safety*" and Pettersen and Schulman (2019) underline the paradox of adaptation for resilience threatening the wider safety and reliability goals.

Resilience-Reliability. For some scholars reliability and resilience are different concepts with sometimes conflicting properties (Leveson et al., 2009). For example, from an engineering point of view, reliability is the probability that a component complies with specific behavioural requirements, excluding possibility of adaptation. Other scholars, by contrast, use resilience and reliability interchangeably (Hale & Heijer, 2006; Schulman, 1993). Hopkins (2014) points to the lack of clarity in the distinction between reliability (from an HROs perspective) and resilience. Their interconnection is complex since resilience is considered one of five mindfulness HROs processes (Weick et al., 1999). More integrative definitions consider resilience as overlapping with other HROs mindful organizing processes (Hopkins, 2014; Weick & Sutcliffe, 2007). For instance, Sutcliffe and Vogus (2003) see resilience as anchored to the organizational processes of reliability such as competence development, efficiency restoration and adaptability enhancements. However, even if Vogus and Sutcliffe (2007) argue that resilient organizations act similarly to HROs, they also stress that resilience and reliability are different constructs. Specifically, they consider that resilient compared to reliable organization, emphasize speaking out about potential errors even if this might lead to perhaps unnecessary production shutdowns. These authors have called for more research to disentangle and contrast reliability and resilience.

Proposition of disentanglement. Figure 1.3 depicts our proposition to disentangle resilience, reliability and safety. Drawing on the HROs literature, we consider resilience as the ability to manage unexpected events (Weick & Sutcliffe, 2006) by adjusting to changing and difficult conditions (Vogus & Sutcliffe, 2007). From a HROs perspective, resilience allows maintenance of high reliability as capacity to uphold high performance despite challenging conditions. We consider that high reliability contributes to the emergence of safety, understood as the absence of undesirable events.

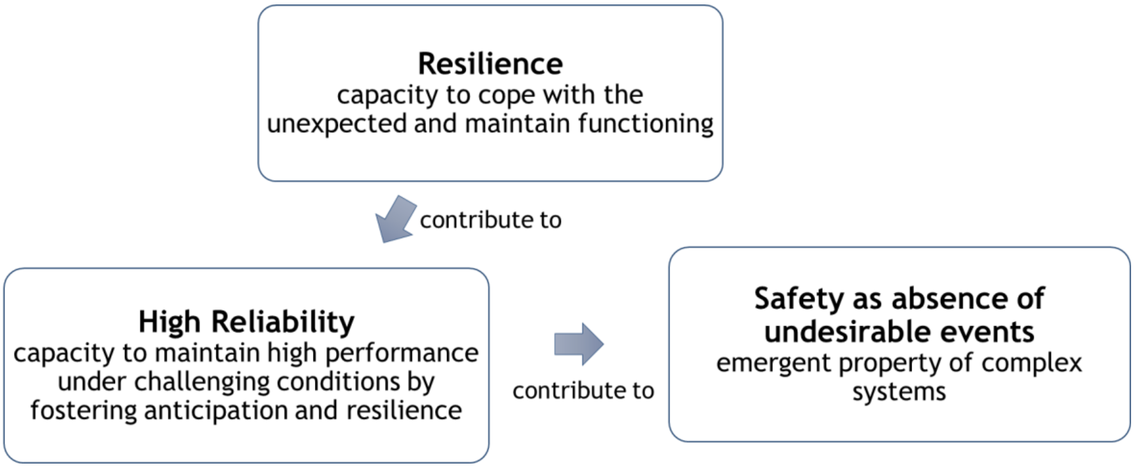

Figure 1.3. Interplay between safety, reliability, and resilience

We chose to follow the separation between two important, but distinctive processes - anticipation (helping to deal with predictable events) and resilience (helping to deal with unpredictable events) (Sutcliffe & Vogus, 2003; Vogus & Sutcliffe, 2007; Wildavsky, 1988). This differentiation is in line with the regulated (organizational technical systems and procedures to deal with predictable events) and managed (organizational capacity to proactively deal with unexpected situations) safety tensions, discussed in Section 1.1.2.2 (Amalberti, 2021; Besnard et al., 2017; Morel et al., 2008; Nascimento et al., 2014). Figure 1.4 combines these two tensions in the search for safety.

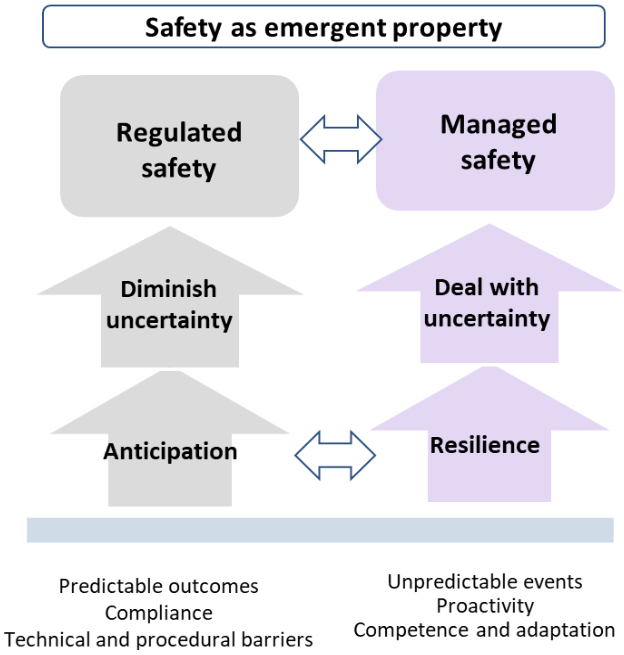

Figure 1.4. Anticipation and resilience for safety

The emergence of safety is therefore possible through a joint development of regulated and managed safety. Their joint development is supported, on the one hand, by diminishing uncertainty thanks to anticipation and, on the other hand, by dealing with uncertainty thanks to resilience. Thus, anticipation and resilience should be reconciled to allow high reliability and safety.

1.3. Key role of cognitive capabilities

The literature points to the quality of cognitive processes as key to reliability (Fraher et al., 2017; Weick et al., 1999), resilience (Duchek, 2020; Williams et al., 2017) and, thus, safety (Vogus & Sutcliffe, 2012). HROs success is related to mindfulness or the capacity to detect and correct errors and adapt to unexpected events before they escalate into catastrophes (Fraher et al., 2017; Weick et al., 1999). There is agreement that resilience is fuelled by mindfulness and sensemaking in daily practices and routines (Fiol & O'Connor, 2003; Vogus & Welbourne, 2003; Weick et al., 1999; Weick & Sutcliffe, 2007; Williams et al., 2017). In Section 1.3.1, we explore the role of individual and collective mindfulness for safety management and the interplay between mindfulness and sensemaking.

Moreover, learning is also critical for the development of cognitive capabilities required for reliability and resilience (Fraher et al., 2017; Weick et al., 1999; Weick & Sutcliffe, 2007).

In Section 1.3.2, we discuss learning and how it interacts with mindfulness, in the context of high-risk organizations (Levinthal & Rerup, 2006) (1.3.2.).

1.3.1. Key role of mindfulness

1.3.1.1. Individual mindfulness as a quality of attention

Mindfulness research is "*one of the most rapidly ascending lines of scholarship today*" (Sutcliffe et al., 2016, p. 56). Mindfulness is not an individual practice and a social collective process (Sutcliffe et al., 2016).

Originating from the Buddhist philosophy, mindfulness is defined as a clear awareness of what is happening with and within the self, in successive moments of perception. In other words, mindfulness relates to a full awareness of reality and can be cultivated through meditative practices (Purser & Milillo, 2015). This notion has been addressed at the individual level, in the psychology literature, in particular, in relation to stress management, improving emotional well-being and increasing employees' performance at work (Hyland et al., 2015; Jamieson & Tuckey, 2017; Walach et al., 2006).

Mindfulness can be understood in different ways. Weick and Sutcliffe (2006) underline the origins of the notion and distinguish between Eastern and Western approaches to mindfulness. Eastern approach is based on Buddhist assumptions about the mind and spirituality and involves mindfulness meditation, which renders the experience less-conceptual. Western approach to mindfulness focuses on psycho-cognitive processes of acquiring and analysing information. In this doctoral research, we adopt the Western approach and explore the cognitive structure of mindfulness and its link to the concept of **attention** (Dane, 2011; Langer, 1989; Weick & Sutcliffe, 2006). From a social psychology perspective, Langer (1989) defines mindfulness as the state of awareness expressed by continuous creation, distinction and refinement of categories, and availability of new information and multiple perspectives. It refers to the construction of meaning from a panel of noticed signals relevant to the object in question and its immediate context, as well as the imagined appropriate, innovative responses, which might be outside established procedures (Langer & Moldoveanu, 2000). Dane (2011, p. 1000) redefines mindfulness as "*a state of consciousness where attention is focused on present-moment phenomena occurring both externally and internally*". By underlying its present moment orientation and a wide attention breadth, the author emphasizes the distinction between the unique concept of mindfulness and practices related to other states of attention. Thus, Dane's definition of mindfulness differs from Langer's, because it does not allow for the creation of new distinctions (cognitive differentiation).

Based on a synthesis of a large body of literature, Sutcliffe et al. (2016a, p. 57) propose a common ground of mindfulness as "*a particular state of consciousness—one in which an individual focuses attention on present-moment events*". Thus, the focus is not necessarily on what is expected, but rather on real-time 'here-and-now' events. This refers to the ability of individuals to focus their attention on a specific object, while simultaneously paying attention to so-called peripheral elements, particularly weak signals, which might reveal future problems or opportunities (Weick & Sutcliffe, 2006). This ability allows the organizational actors to detect and to adapt patterns of activity to manage unexpected events in an adaptive and flexible manner (Fraher et al., 2017; Levinthal & Rerup, 2006).

Thus, mindfulness echoes the quality of attention, studied by the Attention Based View (Ocasio, 1997, 2011), which considers organizations as systems of distributed attention, where attention includes noticing, encoding, interpreting and focusing efforts on an available repertoire of categories and action alternatives to make sense and to act appropriately (Ocasio, 1997, p. 189). Therefore, attention building refers to the way individuals (alone or collectively) select a panel of relevant signals in their environment to construct meaning and develop appropriate responses. Generally, accidents are not sudden events. In many cases there are alarm signals that precede the accident. To notice, encode, interpret and select signals, construct meaning and develop relevant responses, individuals use frames of reference or "category repertories" (Langer & Moldoveanu, 2000). The latter involve "indicator repertories" (to select the signals and to construct meaning) and "response repertories" (to design relevant action plans) (Ocasio, 1997, 2011). The attention given to peripheral indicators and/or weak signals emerging in real time, results in the creation of new categories or extensions to, or refinements of existing "category repertories" (Weick & Sutcliffe, 2006). To stress the importance of creating new categories, Langer (1989) opposes mindfulness and mindlessness. While mindlessness refers to information processes that rely on already existing categories, mindfulness involves high levels of attention to develop the ability to manage new actions in a flexible and efficient manner (Levinthal & Rerup, 2006).

Rerup (2009) and Weick and Sutcliffe (2006) point to two interdependent dimensions/characteristics of mindfulness: stability and vividness. They highlight that attention must be both **stable** and **vivid.** While stability involves maintaining attention to intended objects to achieve a deep awareness, vividness refers to attention on what is happening 'here and now' to allow more complex representations. In this view, stability is synonymous with concentration and a focus on specific homogeneous objects and vividness refers to greater consideration of not-determined-in-advance elements (some of which may be peripheral), to achieve a richer and more complex representation of the analysed object. Mindfulness requires simultaneous involvement of both attentional dimensions. Consequently, cultivating greater stability and vividness implies and results in greater mindfulness (Rouby & Thomas, 2022; Weick & Sutcliffe, 2006).

Several scholars explore the links between and mutual influence of the individual mindfulness and organizational performance (Dane, 2011; Ren & Guo, 2011; Sutcliffe et al., 2016). For example, Dane (2011) investigates how mindfulness affects task performance, and Ren and Guo (2011) show how managerial mindfulness and, more specifically, the problem of limited attention, influence the choice of entrepreneurial opportunities. To achieve 'good' organizational performance, mindfulness must be both an individual and a collective process (Rouby & Thomas, 2022).

1.3.1.2. Collective mindfulness to support high reliability

HROs scholars highlight that high reliability depends on organizational ability to cope with the unexpected by acting mindfully (Weick & Sutcliffe, 2007). Weick and Roberts (1993) emphasize the importance of constructing collective mental processes for reliability. They explore the case of aircraft cockpits and find that heedful interrelating and mindfulness decrease organizational failures (Weick & Roberts, 1993). Mutually shared social processes and comprehensions, linked together by trust, allow to manage complex technology, to cope with emergency conditions and avoid accidents. In their subsequent work, Weick, Sutcliffe and Obstfeld (1999a) emphasize the importance of managing fluctuations in activity within a stable cognitive process and flexible routines to avoid inertia. They put forth the idea of **collective mindfulness,** conceptualized as "*capacity to induce sensitivity to discriminative details and a capacity for action*" (Weick et al., 1999, p. 37). As is the case at the individual level, the stability of cognitive process and extensions to repertoires to face unexpected events contribute to the richness of collective mindfulness.

The distributed and coordinated collective mindfulness processes allow for high reliability based on the ability to notice peripheral elements or weak signals. Weak signals are typical of complex environments (Vogus & Welbourne, 2003) and point to unexpected emergencies and possible future problems. Mindfulness is involved in capturing and interpreting the context, constructing the action appropriate for the situation, and also interpreting the results as part of the learning process. Mindfulness involves **alertness to the context** and **ability to respond to**

unexpected signals from that context, particularly through recognition of analogous action patterns (Levinthal & Rerup, 2006; Weick et al., 1999). However, "*alertness can be compromised by expectations*" (Weick & Sutcliffe, 2007, p. 24); echoing vividness, it requires a capacity to see the 'here-and-now'. Therefore, risk awareness highlights the need to avoid over-confidence and to practice pessimistic thinking about the importance of both already identified and unexpected risks. Alertness implies vigilance towards weak signals, based on their identification, selection of relevant signals and their interpretation in the surrounding environment. However, responding adequately to unexpected signals requires open and flexible thinking. The set of possible actions for quick answers to signals is constituted from the repertories of established routines, by recombining these routines or by creating new ones. Mindfulness depends on continuous updating and reordering of the repertories of categories and actions, in order to interpret weak signals correctly and act upon them effectively (Vogus et al., 2010; Weick & Sutcliffe, 2006, 2007a). When unexpected events occur, collective mindfulness enables more relevant decisions (Fiol & O'Connor, 2003). Mindfulness avoids becoming trapped in "routine" thinking and simplified interpretations (Wieck et al., 1999). Thus, a mindful organization can manage unexpected events in an adaptive and flexible manner (Levinthal & Rerup, 2006).

The development of collective mindfulness within an HROs frame, requires five mindful organizing processes which enable high organizational reliability (Weick, Sutcliffe and Obstfeld, 1999):

- **preoccupation with failure,** which describes a "chronic worry" about possible analytical errors leading to unexpected failures;
- **reluctance to simplify interpretations,** which involves a search for diversity and divergent views in order to avoid interpretation blind spots;
- **sensitivity to operations,** which refers to efforts to achieve a high level of situation awareness, maintenance of attention to real-time operational information;
- **commitment to resilience,** which involves the capability to cope with the unexpected, in the 'here and now', to maintain functioning;
- **underspecification of structures or deference to expertise**, which involves flexibility and adaptation in dealing with a wide range of problems.

In sum, collective mindfulness can be defined as "*the collective capability to discern discriminatory detail about emerging issues and to act swiftly in response of these details*" (Sutcliffe et al., 2016, p. 56). However, many questions remain about how to develop collective mindfulness and, particularly, how to translate individual mindfulness into a more collective process (Fraher et al., 2017; Sutcliffe et al., 2016).

1.3.1.3. Mindfulness and sensemaking: two related notions

Hargadon and Bechky (2006, p. 486) highlight the importance of “mindful interpretation” and “mindful generation of appropriate actions” for collective mindfulness, thus pointing to a **sensemaking** process. Barton and Sucltiffe (2009, p. 1331) define sensemaking as “*the act of reassessing an ongoing situation and giving meaning to our actions*”. Sensemaking is both an individual and a collective process (Barge & Fairhurst, 2008; Sandberg & Tsoukas, 2015; Weick et al., 1999) that helps actors develop an understanding of “*ongoing events from which they extract cues and make plausible sense retrospectively while enacting more or less order into those ongoing events*” (Weick, 2001, p. 463).

The concept of sensemaking is close to that of attention: both include three elements related to signals: selection, interpretation and action. However, while attention perspective presents these elements sequentially (Ocasio, 2011), sensemaking perspective provides a more combined and integrated view and can involve extracting sense, making sense and acting simultaneously. Also, the role of action is critical in the concept of sensemaking. In considering sensemaking as the interplay between action and interpretation, Weick (2005) introduces the concept of **enactment** - the social process of construction and activation of meaning while acting. Weick (1988) highlights a dilemma: acting can facilitate understanding and sensemaking, but, if this acting is based on ‘preconceptions’ applied for a new or ambivalent situation, it can have catastrophic consequences. In this view, in unexpected environments, cycling between interpretation and action allows some ordering of these environments, which in turn allows for the identification of further cues (Maitlis & Christianson, 2014).

While it has been acknowledged that collective mindfulness and sensemaking privilege cognitive focus, some recent studies nuance this understanding. For instance, in addition to cognition, some extend mindfulness to include emotional, relational and structural processes (Vogus & Sutcliffe, 2007; Vogus & Welbourne, 2003). Sandberg and Tsoukas (2015, 2020) propose that sensemaking be considered not as solely a cognitive process, but also as a social action-related phenomenon embedded in the organizational context, routines, interactions, practices and artefacts.

Just as there is mindful attention, there is **mindful sensemaking**. In the particular context of HROs, sensemaking is seen as a “*mindful engagement with unfolding events*” (Barton & Sutcliffe, 2009, p. 1352). Similarly, Sutcliffe et al. (2016) emphasize the interplay between mindfulness and perception and interpretation. More specifically, individuals may monitor and interpret their environment, but mindful sensemaking relies on stability and vividness of interpretation of weak signals (Weick & Sutcliffe, 2006). Therefore, mindfulness allows the construction of more nuanced and complex sensing of events (Sutcliffe et al., 2016) and, such mindful sensemaking, contributes to the identification of better adapted responses to real-time events (Dane, 2011, 2013; Rerup, 2009; Sutcliffe et al., 2016).

While organizational ability to deal with unforeseen and uncertain work situations relies on how organizational members interpret cues and make sense of their environment (Barton & Sutcliffe, 2009; Sutcliffe et al., 2016; Vogus et al., 2010; Weick et al., 1999; Weick & Sutcliffe, 2007), recent studies have highlighted the need for a better explanation of how mindfulness and related practices and processes actually operate in organizations (Kudesia, 2019).

More specifically, the literature points to the essential role of learning in the development of mindfulness (Hutzschenreuter et al., 2014; Levinthal & Rerup, 2006; Rerup, 2009; Weick & Sutcliffe, 2006).

1.3.2. Key role of learning

1.3.2.1. Organizational learning mechanism and its barriers

Organizational learning can be defined as "*a change in the organization's knowledge that occurs as a function of experience*" and which is manifested in changes in cognition or behaviour (Argote & Miron-Spektor, 2011, p. 1124). Learning is based on interpreting experience, accumulated by performing or trying or perform a task (Argote & Miron-Spektor, 2011; Echajari & Thomas, 2015). The knowledge resulting from organizational learning based on experience is embedded in the context and affects future experience (Argote & Miron-Spektor, 2011). Learning mechanism is history-dependent and involves encoding of past events into knowledge, embedded in routines or practices, which then guide behaviours. Individuals, groups and organizational units learn directly from their own experience (learning by doing) and indirectly from the experience of others (learning by transfer) (Argote & Miron-Spektor, 2011; Levitt & March, 1988).

Learning from direct experience explains performance improvements over repetition and adjustments to technology and practices (Levinthal & March, 1993). Experiential learning is conceived as a process of local search (Denrell et al., 2004), in which individuals evaluate outcomes on the basis of their aspiration levels (Levinthal & Rerup, 2006). The search process can take different forms, depending on the type of task and the working environment: selection of routines (by setting and adopting better alternative routines), combination of routines, trial and error experimentation (by adopting experienced successes) (Levitt & March, 1988). Learning can occur, also, through indirect experience or the experience of others (Argote & Miron-Spektor, 2011); it relates to knowledge transfer including both explicit (codified knowledge) and tacit (difficult-to-articulate) knowledge.

Learning from direct or indirect experience is affected by the organizational context, which includes the organization's structure, culture, technology, identity, memory, goals, incentives and strategy (Argote & Miron-Spektor, 2011). Organizational learning occurs in internal and external organizational contexts and interacts with experience to create knowledge (Wenger-Trayner & Wenger-Trayner, 2020). The acquired knowledge changes the context (Argote & Miron-Spektor, 2011), pointing to the role of managers and leaders in modifying the context. For example, Hernes and Irgens (2013) show that managers have the power to impose some continuity or change on organizational activities, thus influencing organizational learning.

However, organizational learning may face barriers, especially in complex and dynamic environments: "*learning has to cope with confusing experience and the complicated problem of balancing the competing goals of developing new knowledge (i.e., exploring) and exploiting current competencies in the face of dynamic tendencies to emphasize one or the other*" (Levinthal & March, 1993, p. 95). Therefore, there may be some limitations to organizational learning embodied in temporal, spatial, failure myopia, complexity and superstitious learning.

Temporal myopia. Short-term learning is frequently privileged over long-term learning (Levinthal & March, 1993). A short-term vision allows to simplify the understanding of the environment, which makes learning easier to enact. In addition, a short-term learning may produce positive outcome in a short term but create difficulties to organizational adaptive capability in a long-term. Due to continuous positive feedback between experience and competence, it may also introduces the possibility of a competency trap, resulting from the frequent use of familiar, but non optimal procedures that produce successful outcomes, but at the same time block the use of new, more adequate procedures (Levitt & March, 1988). From the competency trap perspective, failure can be interpreted as lack of compliance with a frequently used procedure, rather than as a signal that the procedure is inappropriate.

Spatial myopia. This refers to a phenomenon whereby the interpretation of the broader picture of an experience is ignored in favour of the spatially close situation. Organizational learning is not a sequential set of isolated individual learning, but is embedded in the organizational process of simultaneous learning by multiple actors, which creates a noisy and a difficult to interpret environment (Levinthal & March, 1993). The buffers between organizational actions allow for a simplification of the learning environment, but limit the opportunities for learning in tightly coupled systems (Levinthal & March, 1993). Learning by focusing attention on a narrow set of competences relates to specialization.

Failure myopia. If the organization privileges learning from success (Levinthal & March, 1993), the focus on successes rather than failures may lead to over-confidence. Over-confidence and self-assurance based on successful experience influence positive expectations and interpretation of outcomes (Levinthal & March, 1993). Thus, perception of the risks of failure can be underestimated. To overcome this bias in high-risk environments, Weick and colleagues (1999a) stress the importance of preoccupation with failure.

Complexity. Learning from complex experience involves considering its specificity (Echajari & Thomas, 2015; March, 2010; Zollo & Winter, 2002). Heterogeneous and complex experiences are difficult to interpret. Since complexity leads to causal ambiguity between actions and results, learning can no longer rely only on experience. Required interpretation of complex experiences should be based on the “bigger picture” (March, 2010), which includes both internal and external sources of knowledge (Echajari & Thomas, 2015). However, spatial myopia is a barrier to the recognition of cause-and-effect links and temporal myopia prevents the results of learning from being applied to the long-term. Therefore, complexity reinforces different types of myopia (March, 2010).

Superstitious learning. Learning from experience is qualified as superstitious learning if a persuasive subjective experience misspecifies the causal relationship between actions and outcomes (Levitt & March, 1988; Zollo, 2009). This highlights the challenge of relevant interpretation. The cognitive limits to interpreting confusing experience constrains learning (Levinthal & March, 1993). Individuals can make systematic errors in encoding historical interferences by overestimating the probability and importance of events (Levitt & March, 1988). However, experience may not only be difficult to interpret, but it may also generate misinterpretations and have negative effects on learning outcomes (Hutzschenreuter et al., 2014; March, 2010). In noisy, ambiguous and changing environments, experiential learning can more easily produce superstitious learning (Denrell et al., 2004; Levitt & March, 1988; Zollo, 2009). Indeed, noise, causal ambiguities related to mis-specification of the connection between actions and outcomes (Levitt & March, 1988), outcome ambiguity (Zollo, 2009) and delay between actions and outcomes (Denrell et al., 2004) increase the chance of superstitious learning. In complex and dynamic environments, the construction of meaning from a small number of experiences is difficult, in particular, due to ambiguity and the problems related to the difference between success and failure and their causes (Levitt & March, 1988).

Overcoming these barriers and preventing superstitious learning requires deliberate learning (Zollo, 2009).

1.3.2.2. Deliberate learning

To overcome learning barriers, particularly in complex and dynamic environments, learning by doing should be accompanied by more deliberate articulation and codification of collective knowledge learning processes (Zollo & Winter, 2002). Deliberate learning is the result of intentional, systematic efforts and induces reflection-on-action that occurs outside, rather than within ongoing operations (Jordan et al., 2009). Therefore, knowledge articulation allows individuals to express, confront and integrate their beliefs and experiences in the broader picture. This sharing and integration improve understanding of the causal links between actions and outcomes and leads to adaptive adjustment to routines (Zollo & Winter, 2002). This adjustment may be accompanied by knowledge codification, registering articulated knowledge into written tools (artefacts). Deliberate processes of articulation and codification require effort and investment but help to confront causal ambiguity and avoid superstitious learning and learning myopia (Zollo, 2009). However, since learning is context-dependent, the particularities of high-risk contexts should be acknowledged in the case of deliberate learning efforts.

1.3.2.3. Organizational learning in the context of high-risk organizations

Limited "trial and error". The HROs literature emphasizes the crucial importance of learning for reliability and safety (La Porte & Consolini, 1991; Ray et al., 2011; Rerup, 2009; Roberts & Bea, 2001; Sutcliffe & Vogus, 2003; Weick, 1987; Weick & Roberts, 1993). While experience is the first source of learning (March, 2010), HROs operations are rich in potential errors, whose consequences limit learning through experimentation. This trial-and-error learning requires a high degree of autonomy for experimentation, which is dangerous in high-risk environments. Thus, in organizations operating in these environments, trial-and-error learning is limited (La Porte & Consolini, 1991; Weick, 1987; Weick et al., 1999).

However, despite high reliability and limited experimentation, HROs face incidents and accidents (La Porte & Rochlin, 1994), which means that **failure may become an opportunity for learning** (Weick, 1987; Weick et al., 1999). Weick et al. (1999a) underline the need for adaptive learning to manage sources of vulnerability through complex processes and technologies. Some authors conceptualize the mindfulness process of preoccupation with failure and suggest the following learning strategies: treatment of all failures to maintain safety and reliability; analysis of near misses; and a focus on the liability of success (Weick et al., 1999, p. 39). A preoccupation with failure requires solid reporting systems and failure analyses (Carroll, 1998; Schulman, 1993).

High-risk organizations operate in complex environments, which makes deliberate learning particularly important for them (Echajari & Thomas, 2015; Roberts & Bea, 2001). HROs know that failures and human error can occur, so they invest more than other organizations in learning how to identify and control anomalies, including simulating failures (Roberts & Bea, 2001). This learning provides them with the ability to react and resolve novel situations. However, Weick (1987) warns of possible counterproductive effects of training for preventing failure, pointing, for example, to the lack of requisite variety (a situation whereby the variety of complex systems exceeds the variety of people who manage the systems). This echoes Carroll's (1998) proposal that difficulties require different logics based on different mental models to allow learning in high-risk organizations. However, Zohar and Luria (2003) argue that to avoid limited system operator cognitive resources, organizations implement "meta-scripts" (requests for tasks and actions in order to pursue operational goals within the shared representation of the environment) that are supported by continuous learning, and address the complexity of the system. The use of script-language (verbs and action phrases with a meta-script meaning and corresponding contingencies) with basic categories of actions, reduces the number of varied tasks to cognitively acceptable proportions. Continuous learning allows the transformation of these possible scripts into a repertoire of available pathways, referring to mindfulness. Shared scripts enable the construction of a common analytical framework for the interpretation of situations and events through mental representations, referring to collective mindfulness (Weick et al., 1999).

Experience from rare events. Failure presents opportunities for learning (Weick et al., 1999). However, by definition HROs do not experience many failures (La Porte & Consolini, 1991; Rochlin et al., 1987) and, consequently, have only a limited access to this type of learning. Therefore, HROs must also acquire knowledge from external sources (Argote & Miron-Spektor, 2011; Cohen & Levinthal, 1990; Echajari & Thomas, 2015). Therefore the attention should be focused on rare events, which present opportunities for learning (Echajari & Thomas, 2015; Edmondson, 2003; Garud et al., 2011; Lampel et al., 2009; Levinthal & Rerup, 2021; Madsen, 2009). If an accident occurs, it is recorded in organizational memory, reinforcing the cultural value of safety (Roberts & Bea, 2001). Depending on the potential impact and relevance of an event, it can lead to transformative change, reintegrative learning or narrow and transitory learning (Lampel et al., 2009; Madsen, 2009). Lampel et al. (2009)

examine how rare events enhance learning processes during (e.g., Christianson et al., 2009) or after a rare event (Echajari, 2018).

Learning after a rare event must be deliberate and engaging a larger audience, that solely the organization that experienced a rare event (for example learning from the Chernobyl and Fukushima accidents). However, organizational learning from rare events is difficult due to the problems related to interpreting unusual events (T. E. Beck & Plowman, 2009). Beck and Plowman (2009) point to the impact of cognitive biases and the hierarchical context on organizational interpretations of rare events and highlight the role of middle managers in overcoming these barriers. Levitt and March (1988) particularly underline the difficulties related to 'low probability-high consequence' events. Authors point to two challenges: 1) the limited number of occurrence and 2) the influence of event significance on the complex interferences done by different stakeholders. Levitt and March (1988) suggest to create hypothetical histories of the events to respond to these issues. However, organization learn from rare events not only through direct experience, but also through vicarious experience of disasters (Madsen, 2009; Maslach et al., 2018).

As we have seen, the literature points to the importance of cognitive capabilities in the quest for high reliability, achieved both through anticipation and resilience (Levinthal & Rerup, 2006, 2021; Vogus & Sutcliffe, 2012; Weick et al., 1999; Williams et al., 2017). However, mindfulness, sensemaking and learning are tightly interconnected (Levinthal & Rerup, 2006; Rerup, 2009; Weick et al., 1999) and are difficult to implement in high-risk environment. Consequently, the interplay between these elements to enhance both regulated and manged safety, should be further elucidated.

1.4. Key challenges of safety management in the joint development of regulated and managed safety in high-risk organizations

There are different challenges involved in safety management aiming at the joint development of regulated and managed safety. In this section, we start by highlighting three types of key challenges: cognitive (Section 1.4.1), structural (Section 1.4.2) and their interplay (Section 1.4.3). Then, we explore the role of two factors that affect the resolution of these challenges for the joint development of regulated and managed safety. In Section 1.4. 4. we discuss a constraining factor – organizational limits and in Section 1.4.5 we discuss an enabling factor – effective leadership.

1.4.1. Cognitive challenges

1.4.1.1. Interplay of mindfulness and mindlessness

The interplay between mindfulness and mindlessness has attracted attention of many management scholars (Elsbach & Hargadon, 2006; Kudesia, 2019; Langer, 1989; Levinthal & Rerup, 2006; Weick & Sutcliffe, 2006). Mindfulness describes a state of awareness and consciousness in which the attention is focused on the ‘here-and-now’ (Dane, 2011; Langer, 1989). On the contrary, mindlessness refers to reliance on categories and meanings based on past experience, which block openness and the capacity to discern unique characteristics (Kudesia, 2019; Langer, 1989). Mindlessness is “*expressed in behavior that is rigid and rule-governed rather than rule-guided*” (Langer, 1989, p. 139). The overuse of mindlessness results in “automatic pilot” routines (Weick et al., 1999).

Thus, the difference between mindlessness and mindfulness is the quality, rather than the quantity of informational processing. Capacity increasing as opposed to capacity fixing, mindfulness requires considerable effort to maintain attentional quality and, therefore, it is impossible to be mindful in all types of tasks and situations (Langer, 1989). Interactions between these two modes is needed. **The effort is not to maintain mindfulness and constrains mindlessness, but rather to switch between modes.**

However, mindfulness and mindlessness are highly intertwined and interdependent.

Levinthal and Rerup (2006) highlight the interconnection and complementarity between mindful and mindless processes. They point to two ways that mindlessness (less mindful behaviours) complements mindfulness. First, repertories and routines built previously and stored in less mindful behaviours, constitute the “building blocks” of recombination which characterizes mindful behaviours (Bigley & Roberts, 2001; Levinthal & Rerup, 2021; Weick et al., 1999). Established action repertories, embedded in routines and roles and built on previous experience, enhance mindful responses to new situations. Therefore, mindlessness reflects a continuous preservation of accumulated experience, while mindfulness brings novelty to face changing and unique situations. Second, mindlessness allows economies of time and scarce attentional resources (Bargh & Chartrand, 1999; Levinthal & Rerup, 2021). Levinthal and Rerup (2006) also highlight a deeper effect: the development of routinized practices and structures may be directed to sustaining mindfulness (e.g., routinized process of monitoring, regular audits, procedure updates to enhance vigilance to weak signals) (Levinthal & Rerup, 2006; Schulman, 1993; Weick & Sutcliffe, 2007). Automatic, routine-based behaviours allow to save time and energy, which can be devoted to other tasks. In addition, routine tasks lead to the accumulation of organizational experience (Bargh & Chartrand, 1999; Levinthal & Rerup, 2006). On the contrary, mindfulness allows to recognise particular contexts in order to make choices among and enact appropriate routines (Levinthal & Rerup, 2006; Schulman, 1993). More specifically, existing routines are the foundations providing building blocks for new action patterns and can be recombined in novel ways to construct appropriate answers to particular context requirements (Rerup & Levinthal, 2014). Despite a potential danger of such creativity in HROs, characterized by limits of trial-and-error learning, Rerup and Feldman (2011) underline the potential value of recombination in situations where it will not affect critical systems. This refers to constrained improvisation (Bigley & Roberts, 2001) and renegotiation of routines (Schulman, 1993) to develop high reliability.

While some authors consider that routines are part of mindless behaviours (Langer, 1989; Levinthal & Rerup, 2021), the complexity of some routines may lead to considering them as non-automatic accomplishments (Giddens, 1984, p. 86), which underlines the variability and contingency of routines (Feldman & Pentland, 2003; March & Olsen, 2011; Weick & Sutcliffe, 2006).

Weick and Sutcliffe’s (2006b) response to Levinthal and Rerup (2006) differentiation between mindful and less mindful approaches, highlights theoretical tensions, particularly between behavioural and cognitive approaches. Weick and Sutcliffe's (2006, p. 515) view of mindfulness “*is grounded in patterns of interrelation among processes of perception and cognition that ‘induce a rich awareness of discriminatory detail and a capacity for action’ (Weick et al. 1999, p. 88)*”. Weick and Sutcliffe (2006) advocate meta-level conceptualization which considers routines and mindfulness as a continuum rather than as elements in tension.

In order to capture and resolve cognitive tensions, scholars have proposed metacognition (cognition about cognition), which allows for monitoring of and adjustment to informational proceeding (Fernandez-Duque et al., 2000; Kudesia, 2019; Nelson, 1996). Kudesia (2019, p. 405) suggests a move to a higher level of information processing and considers mindfulness as a “*metacognitive process by which people adjust their mode of information processing to their current situation*”. Metacognition represents an higher level of mental processes where the interpretation of events (cognitive level) is monitored and adjusted, according to existing beliefs and strategies (metacognitive level) (Kudesia & Lang, 2020; Nelson, 1996).

1.4.1.2. Mindfulness-learning interplay

The literature suggests complex and recursive links between mindfulness and learning (Carroll et al., 2006; Levinthal & Rerup, 2021; Levinthal & Rerup, 2006). Mindfulness is both a prerequisite for and an outcome of learning.

On the one hand, learning from complex experience, especially in dynamic work settings, should be deliberate and requires a mindful approach to processing experience to adapt by generalizing and discriminating between past experience and the current situation (Hutzschenreuter et al., 2014; Levinthal & Rerup, 2006; Zohar & Luria, 2003). The learning literature points out that, in complex and dynamic environments characterized by ambiguity, a mindful approach to processing experience requires explicit efforts to achieve a deep understanding of the meaning of experience (Hutzschenreuter et al., 2014; Levinthal & Rerup, 2021). Mindfulness, based on interpreting and encoding ambiguous stimuli, plays the role of learning and evolution of routines (Levinthal & Rerup, 2006; Weick & Roberts, 1993). In line with Greve and Gaba (2017), Levinthal and Rerup (2021) suggest that there is a pressing need to better understand the role of meaningful interpretation in learning processes.

Moreover, knowledge transfer can be achieved through socialization or, more deliberately, through codification, storage and diffusion of knowledge. Socialization allows individuals to acquire mainly tacit knowledge through observation, imitation, practice and dialogue (Nonaka, 1994). Dane (2011) outlines the key role of socialization for learning in HROs. However, in dynamic and complex environments, learning through socialization requires effective dialogue based on shared mental models or collective mindfulness (Curtis et al., 2017).

On the other hand, the literature on attention outlines the role of learning to increase mindfulness (Roberts & Bea, 2001; Sutcliffe et al., 2016; Vogus & Sutcliffe, 2012; Weick et al., 1999). Brykman and King (2021) highlight that learning activities are resource-enhancing and allow preparation for future challenges.

In addition of cognitive challenges, related to mindfulness and learning, high-risk organizations face structural challenges for joint development of regulated and managed safety.

1.4.2. Structural challenges

1.4.2.1. Interplay of specialization and process approach

Specialization is one of the means to handle complexity (March et al., 1993; Simon, 1996). The complexity of high-risk organizations requires **specialization**, necessary to handle individual cognitive limits and to facilitate learning (Levinthal & March, 1993; March, 2010). However, specialization stemming from a division of labour can fragment situational representations of the context and create multiple and divergent understandings (Bigley & Roberts, 2001), echoing the spatial myopia of learning (Levinthal & March, 1993). The literature on reliability highlights the importance of a shared understanding of the operating system (Bigley & Roberts, 2001; Weick et al., 1999; Weick & Roberts, 1993). This involves alignment and integrity of **operational representations,** such as individual perceptions of the activity system and its environment, which enables a balance between standardized and emergent forms of structuring (Bigley & Roberts, 2001; Weick & Roberts, 1993). Collectively shared and coordinated representation helps to avoid individual cognitive and attentional overload and enhances effective and mindful interactions (Bigley & Roberts, 2001; Rerup, 2009; Weick & Roberts, 1993). In addition to the challenge of integration of the different views and mental representations, structural **coordination** is essential to construct a valuable shared sensemaking (Bigley & Roberts, 2001; Levinthal & Rerup, 2006; Weick, 1993).

A process approach provides a transversal view of the organization and helps to build a shared representation of the bigger picture. As such, it enables a more flexible coordination. In this perspective, the process can be described as a "*collective activity combining local activities which involve distinct competence*" (Lorino, 2009, p. 87). Such organizational architecture, which originated in the quality management literature, is based on processes as a "*set of interrelated or interacting activities that use inputs to deliver an intended result*", such as an output (product or service) (ISO, 2015). In other words, "*a process is a set of logically related tasks performed to achieve a defined business outcome*" (Davenport, Thomas H. E. & Short, 1990). A process perspective leads to a more dynamic modelling of organizational activities, regrouped on the basis of their complementarities rather than their similarities (Lorino, 2009). These activities are related in the process by strong coordination links and information flows. Lorino (2009) highlights two characteristics of the process of collective activity: interaction (heterogeneous actors interact within the process) and transaction (production of an intended output/result). The coherence between the transactions and the interactions depends, to a certain extent, on the rules and norms drawn from collective experience, but adapted dynamically to the situation.

Both modes of organizing – highly specialized and processual – have advantages and organizations operating in high-risk and complex environments seeking reliability must strike the right balance between them. Each mode of organizing contributes to the development of resilience, but at different levels. *Situated* resilience emerges thanks to specialization in frontline operations and refers to short-term micro-level adaptation and intelligence to mobilize resources, and detect and handle unexpected and non-routine events. *Structural* resilience is a long-term meso-level process involving examination of organizational practices and purposeful reallocation of resources (Macrae, 2019).

1.4.2.2. Interplay between standardization and flexibility

Another structural challenge is the interplay between standardization (stable order) and flexibility (improvisation and under-specification of structure). It echoes the debate on the joint development of regulated and managed safety. **Standardization** implies bureaucratic systems characterized by formalization (regulation, procedures, policies), specialization and hierarchy with formal authority that guarantees stability. Despite the advantages of a stable order, this form of organizing impedes organizational flexibility and ability to cope with complex and changing environments (Bigley & Roberts, 2001). By contrast, **flexibility** increases adaption to a wide range of problems (Weick et al., 1999). Formal systems of standardized control are based on the premise that complexity can be handled by reducing uncertainty; however, the organization should also be able to cope with uncertainty (Grote et al., 2009), echoing two forms of social ordering – *controlling* and *sensing* – suggested by Maguire and Hardy (2013).

Role of rules. Standardization depends on rules. **Rules** play an essential role in the coordination in organizations (Giddens, 1984; Reynaud, 1988) and can be defined as a virtual storage and registration of collective knowledge, including two aspects – the normative elements and the codes of signification (Giddens, 1984, p. xxxi). They imply limits to variation in social systems (normative aspect), but also define features and forms of activity, in which individuals and organizations engage (construction of meaning). Rules are organizational artefacts – entities designed and implemented to guide actions and to help organizational members make sense (Busby et al., 2004; George et al., 2012). As part of the social structure, rules are both enabling and constraining by virtue of the inherent relation between structure and agency (Archer, 2004; Giddens, 1984). The literature proposes two commonly recognized rule models: 1) rules formulated *in extension*, aimed at ensuring operators follow procedures; and 2) rules formulated *in comprehension*, which provide a more dynamic and flexible framework that allows some degree of interpretation of the rules by operators (Reynaud, 1988; C. Thomas, 2003),in particular, organizational rules within complex organizational dynamics (Denyer, Tranfield, & van Aken, 2008; Romme & Endenburg, 2006; van Aken, 2004). Rules are sometimes incomplete and constitute only a general direction for action. Incomplete rules require a certain degree of interpretation (C. Thomas, 2003). However, rules *in extension* are formal, explicit and give a limited freedom for interpretation which leads to a strict step-by-step implementation.

Safety rules. High-risk industries are traditionally highly regulated. In contexts, where the potential consequences of failure could be catastrophic, high-risk organizations rely on **safety rules and compliance** to restrict individual behaviours to avoid human error and non-compliance (Dekker, 2003; Hale & Borys, 2013a; Hale & Swuste, 1998; Nascimento et al., 2014). Safety rules and safety procedures, as a form of rules, are aimed at establishing and maintaining a safe zone of operation – a state of a system or a way of behaving to improve safety or achieve a required level of safety (Hale & Borys, 2013a; Hale & Swuste, 1998). Thus, safety rules serve to: 1) define the control measures needed to navigate within the boundaries of the safe zone, 2) avoid crossing those boundaries (as defined by the rules) and in the case of an emergency 3) to recover from a position outside these boundaries (Hale & Borys, 2013a). The formalization of safety rules to establish a safe zone depends on how uncertainty is managed: 1) minimizing it or its effects through control, tight planning and automation, which reduces the freedom of the individuals responsible for implementing the plans; or 2) handling uncertainty locally to allow for feedback and some degree of freedom to adapt action in the 'here and the now' (Grote et al., 2009). In this view, rules are understood primarily as a resource for situated action and not as a centrally determined and monitored action. In this case rules are defined in comprehension.

Most high-risk systems make efforts to minimize uncertainty (Hale & Borys, 2013a). Standardization and control are means to minimize risk, encode lessons from experience (Levitt & March, 1988) and achieve safety (Reason et al., 1998). Standard operating procedures can be very detailed and are aimed at streamlining human actions, referring to the action rules (Grote, 2007). Ocasio (2005) underlines the constraining role on safety outcomes of the vocabulary used to describe safety rules. Moreover, in highly regulated environments, audit, certification and regulatory control systems support the search for easily detectable (lagging and leading) indicators of uncertainty (Dekker, 2014; Erikson, 2009; Hale & Hovden, 1998;

Hopkins, 2009; Lingard et al., 2017; Patriarca et al., 2019). Control based on numbers and digital tools enables anticipation by making sense of the past, the present and the future (Flyverbom & Garsten, 2021). The introduction of overriding indicators is indicative of confidence in quantification as an objective and a neutral way to measure performance and control deviations. Use of indicators lead to the creation of "templates for anticipatory governance", such as statistical reports, key performance indicator scorecards, future development scenarios and guiding management practices (Flyverbom & Garsten, 2021). In this perspective, the safe zone is defined by procedures or rules in extension. Making visible the boundary to safe operations is desirable in theory, but problematic in practice (Hale & Borys, 2013a)

Limits to the implementation of safety rules in practice. Despite the need for safety rules, the safety and reliability literature (Bourrier & Bieder, 2013; Grote, 2007; Grote et al., 2009; Hale & Borys, 2013a, 2013b) highlights some of the limits to their implementation in practice in HROs. This echoes the concept of decoupling of the formal rules and actual practices (de Bree & Stoopendaal, 2020). Several studies have explored why employees do not follow all the rules (e.g., Alper & Karsh, 2009; Amalberti et al., 2006; Besnard & Greathead, 2003; Busby & Iszatt-White, 2016; Drach-Zahavy & Somech, 2010; Hale & Borys, 2013a) and propose the following reasons: rules are not understood or are perceived as incoherent or unrealistic and rules can be perceived as a mean of control and blame. In addition, the quantity of rules and procedures in high-risk environments can become a barrier to their use and to the compliance (Hale & Borys, 2013a; Schulz, 1998). Interestingly, Amalberti (2001) warns about the existence of the limit to the efficacy of rules and regulations, beyond which rules create a danger for safety. For example, in complex multi-level organizational structures, regulation may result in a higher level of specialization, which brings about compilation of multiple levels of rules. This can reduce the sense and salience of rules (Kudesia et al., 2020).

Hale and Borys (2013a) conceptualize four categories of rule violations: 1) *routine violations* which have become the normal and accepted way of behaving because rules are perceived as overly restrictive or out of date, and because monitoring and discipline are weak; 2) *optimizing violations* which appear to solve trade-offs between safety and other objectives (e.g., production pressure) or explore the boundaries to the system and, on these bases, identify new solutions; 3) *situational violations* which are related to specific situations where the existing rules are not relevant; 4) *exceptional violations* which occur in completely new never before experienced situations, where the consequences of violation cannot be anticipated (Hale & Borys, 2013a).

These limits of rules highlighted by Amalberti (2001), Hale and Borys (2013a) refer to the notion of organizational limits, and more particularly limits of managerial action proposed by Farjoun and Starbuck (2007), which will be developed in the section 1.4.4. of this chapter 1.

Ways to reconcile standardization and flexibility. Reconciling standardization and flexibility involves an effective implementation of rules and procedures. To avoid rule violations, organizations needs to manage rule elaboration and rule formalization (Grote et al., 2009; Hale & Borys, 2013b). Besides the rules themselves, the process of generating and modifying rules is also crucial for providing or impeding flexibility and safety improvements. **Elaboration of rules** can be imposed in a top-down manner or can be bottom-up and participative. Participative elaboration of rules enables adaptation to the rules to maintain consistency with and relevance to practice and a better understanding of the rules by all the actors concerned. Hale and Borys's (2013b) model highlights the advantages of rules derived from enacted routines and not vice versa. Schulman's (1993) study of the Diabolo Canyon power plants highlights that organizations value the capacity for real-time discovery as much as the ability to impose standardized control by anticipation: continuous management of fluctuations in **real-time renegotiation of formalized procedures** allows resilient adjustment to respond to dynamic operational problems and to maintain safety and reliability (Schulman, 1993). However, the process of changing rules should remain transparent and maintain the overall coherence with the existing system of rules. The right balance is needed between an imposed and a participatory approach to the elaboration of rules. In the same vein, **interactions among the different levels of regulation, to elaborate and implement rules,** is essential (Hale & Borys, 2013b). Kudesia et al. (2020) explore how stakeholders from organizational eco-system participate in rule elaboration; in particular they analyse the interactions between external regulators and front-line operators to increase standardization without diminishing operator autonomy, characterized by simultaneous processes of control and learning.

Because the use and the meaning of rules depends on specific contexts, scholars point to the importance to study the **rule formalization** (Busby & Iszatt-White, 2016; E. Fairhurst, 1983; Grote et al., 2009). Safety literature describes rules in extension as promoting rule-following behaviours and compliance (Dekker, 2003; Hale & Borys, 2013a). An organization that aspires to being flexible and adaptable, favours rules formulated in comprehension. However, in high-risk environments, the organization must aim for both stability and adaptation capabilities (Weick et al., 1999). Consequently, rules need to be flexible, but at the same time they need to clarify limits and suggest ways to maintain activities within these limits (Grote et al., 2009). Process-oriented rules, which define the decision-making process, and goal-oriented rules, which focus on goals (Grote, 2007), illustrate the logic of rules in comprehension. In the same vein, Le Bris et al. (2019) propose the notion of meta-rules of reliability, defined as a set of lower-level rules aimed, primarily, at maintaining the vital functions of the managed entity; they allow a global vision and faster decision-making. The rules in comprehension acknowledge system complexity and allow for the interpretation of weak signals and the application of experience-based learning. Therefore, they provide the opportunity to reconcile standardization and flexibility, which are is needed to face uncertainly (Grote et al., 2009; Hale & Borys, 2013a). Such rules promote bottom-up, dynamic and contextualized behaviours, based on the user's competence to adapt to a diversity of local circumstances.

In this perspective, rules are considered to be resources rather than safety guarantees (Dekker, 2003; Hale & Borys, 2013a). This approach to rules avoids the mismatch between rigid procedures and real-life practices. Avoiding this mismatch is especially important in complex and dynamic environments, characterized by uncertainty and ambiguity, where there is a strong need for improvisation (Dekker, 2003; Grote, 2007; Hale & Borys, 2013a; Leplat, 1997). Grote et al. (2009) underline the need for flexible routines and rules to deal with uncertainty, but, in extreme contexts, degrees of freedom and margins of tolerance in coordination are small (Bourrier & Bieder, 2013; Grote et al., 2009) to avoid disastrous potential consequences of failure (Hannah et al., 2009; La Porte & Consolini, 1991; Leveson et al., 2009). Even if conceptually well-argued and attractive, in practice, elaboration and implementation of **limitedly-flexible rules** remains unresolved. This view of rules redirects attention to practices and practical problems (E. Fairhurst, 1983; Gherardi, 2018).

In addition to rule elaboration and formalization, the literature suggests other ways in which standardization can reinforce flexibility for reliability and safety (Bigley & Roberts, 2001; Schulman, 1993). In their study of incident command systems, Bigley and Roberts (2001) explore how the copresence' of bureaucratic structure and organizational flexibility (Bigley & Roberts, 2001, p. 1293) is enabled by system modularity, which allows appropriate restructuring, constrained improvisation and cognition management in order to respond to challenging and uncertain situations. In particular, several authors (Bigley & Roberts, 2001) underline the effect of **role switching** (i.e., switches between tasks) and **authority migrating** (from hierarchical authority to operational expertise), which refers to under-specification of the structure (Weick et al., 1999), guided by the functional requirement for a concrete context. Similarly, informal decision-making authority can emerge and endow technically qualified people with decision-making responsibility.

Constrained improvisation also allows effective incident control in face of an unpredictable event (Bigley & Roberts, 2001; Hale & Borys, 2013a). Bigley and Roberts (2001, p. 1294) suggest that appropriate improvisation contributes to resilience and organizational reliance on "skilled, knowledgeable and resourceful people" to deal with an uncertain and dynamic task environment. Constrained degree of freedom to improvise implies the open choice or adjustment of existing routines, creation of new responses, transformation or violation of rules and standard operating procedures in face of a unique condition.

Rule renegotiation, role switching, authority migrating and constrained improvisation rely on competence and experience and are legitimated by achievement of organizational goals (Bigley & Roberts, 2001; Hale & Borys, 2013b; Schulman, 1993; Weick et al., 1999). This echoes the mindfulness-mindlessness challenge: individuals tend to perform highly standardized routines in a mindless mode, while flexible routines require mindfulness. **Therefore, adaptation to high-risk environments should be accompanied by mindfulness and deliberate learning. Also, leadership is crucial for understanding and implementing rules to manage safety, using a mix of standardization and flexibility** (Schulman, 1993, 2021)**.**

1.4.3. Stability and change challenge

In the previous sections we have discussed the cognitive and structural challenges related to reconciling notions, which are traditionally presented as opposite (mindfulness versus mindlessness, specialization versus process, standardisation versus under-specification of structure). Neither the cognitive nor structural challenges prioritize one or other opposite but aim at achieving a balance and mutual reinforcement of reliability and safety. Farjoun (2010) explores the interaction among the elements, that could be considered as elements of **stability** (routines, institutions, control, hierarchy with objective of predictability and regularity) on one side and elements of **change** (mindfulness, openness, imagination with objective of adaptability and flexibility) on the other. Such elements refer both to cognition and to structure. Farjoun (2010) proposes the idea of duality (rather than dualism), underlying, despite contradictory character, the interdependence and possibility for mutual reinforcement (change for stability and stability for change).

Farjoun (2010) demonstrates the possible complementarity among these elements. On the one hand, he underlines how stability can enhance change; for example, higher levels of specialization allow the transfer of scarce attention and resources and more flexible responses to peripheral aspects. He also points out that existing rules and routines constitute a basis from which to exploit surprises and design new artefacts by improving existing ones (Farjoun, 2010). Therefore, existing configurations of safety processes and procedures become the building blocks for new designs and recombination, better adapted to deal with the unexcepted, as demonstrated by Bigley and Roberts's (2001) study of incident control systems. Kudesia et al. (2020) provide an example of how high-reliability organizational safety rules become the context for interaction and learning about metacognitive beliefs and, therefore, provide an infrastructure for the and maintenance of mindfulness (Kudesia & Lang, 2020). This emphasizes the interaction between cognitive and structural elements.

On the other hand, elements of change enable stability. More specifically, mindfulness fosters continuity by allowing identification and the resolution of small failures by avoiding potentially bigger problems (Weick & Roberts, 1993; Weick & Sutcliffe, 2006). Moreover, moderated experimentation allows small failure to take advantage of the limited trial-and-error learning. The capturing and analysis of small failures and experimentation with near-misses, contribute to discover uncertainty and improve safety (Edmondson, 2003; Starbuck & Farjoun, 2005; Vaughan, 1999). In addition, mindfulness and learning allow successful use of rules, specifically, rules formalized in comprehension. Sufficient experience and mindful sensemaking of the rules and of the current situation allow effective adaptation (Hale & Borys, 2013b; Levinthal & Rerup, 2006; Zohar & Luria, 2003).

It therefore appears that the interplay between the elements of stability and change may be both mutually enhancing and mutually constraining. In high-risk organizations, the cognitive and structural challenges of joint development of regulated and managed safety are difficult to manage. Such organizations establish and implement systems, structures and routines to increase organizational capabilities for resolving these problems. However, despite good managerial capacity to set the pace of such solutions, their implementation can be constrained by the existence of organizational limits.

1.4.4. Constraining factor: organizational limits

1.4.4.1. Definition and types of organizational limits

Organizational limits are worthy of attention because they complement the understanding of goals, capabilities and processes (Farjoun & Starbuck, 2007). Limits are defined as "*factors that together restrict the overall ability of an organization to meet the demands made upon it*" (Oliver et al., 2017, p. 2). Some goals and capabilities are beyond the organization's capacity and the theory highlights the danger of an "overreach" (Oliver et al., 2017, p. 5). Exceeding existing limits has unintended consequences that can be positive (discover new solutions) or negative (unintended constrains and danger). As mentioned by Farjoun and Starbuck (2007, p. 544) some of limits "*are invisible to organizational members and possibly to outsiders as well, until events reveal their existence. People discover these limits when their actions no longer have any effects, or they have very unexpected effects*".

This understanding of organizational limits is especially important for HROs, because the unintentional exceeding of invisible limits may become a systemic source of accidents (Farjoun & Starbuck, 2007). This is also mentioned by Perrow (1999, p. 123), who underlines that accidents are sparked not only by complexity and tight coupling but also "*because those in charge continue to push the system to its limits*", e.g., pushing the limits to maximize performance threatens safety (Le Coze, 2015). Therefore, organizations operating in high-risk contexts should be alert to the fact that exceeding limits can have undesirable and dangerous outcomes and catastrophic consequences.

The theory of organizational limits (Farjoun & Starbuck, 2007; Oliver et al., 2017) identifies exogeneous and endogenous limits (Oliver et al., 2017). **Exogenous** limits originate from constraints on the organizational environment (legislation, governmental regulation, norms). They can be societally defined limits, which result in laws or market mechanisms, or natural physical, scientific constraints. The influence of regulation and public perception is recognized in HROs theory (La Porte & Rochlin, 1994; Weick et al., 1999).

Endogenous limits originate in cognitive capabilities and managerial actions. Oliver et al. (2017, p. 3) emphasize that endogenous limits refer to the limits to what an organization is able to do, given its characteristics and capabilities. First, **cognitive limits** are linked to the difficulty of paying attention to many things simultaneously. Second, limits can be **produced by managerial actions and polices** (budget allocations, planning, policies), aimed at developing organizational capabilities. In addition, limits can originate from unreliable or inefficient **technology**, which characterizes both exogenous (constraint imposed by the external environment) and endogenous (constraint imposed by organization) limits (Oliver et al., 2017).

The limits described may affect organizational processes in general, and reliability and safety processes in particular. For example, cognitive limits constrain the capacity to recognize, interpret and conceive appropriate responses to events. This affects sensemaking and mindfulness, referring to the necessary ability of organizational members to make sense of an ongoing experiences (Weick & Roberts, 1993; Weick & Sutcliffe, 2007).

Managerial control actions are not purely enabling or constraining; however, exceeding the limits, for example, of excessively rigid resource allocation, can produce unintended effects. Managerial limits help to make situations more predictable, but this restricted attention risks reducing the cognitive capacity to respond to unexpected situations. Similarly, technology, designed for greater predictability, may introduce restrictions on cognition that, ultimately, affect members' capabilities to face complex situations and deal with unusual events (Oliver et al., 2017).

Organizations may have direct influence only on the endogenous limits of cognition, managerial control and use of technology, although how they apply this influence depends also on the exogenous limits. Organizations aim to stretch their endogenous limits by developing the relevant capabilities (Starbuck & Farjoun, 2005). However, limits are revealed to managers only if they are exceeded. Reaching beyond organizational limits have one specific manifestation - managerial actions do not produce any positive effects and their effect may lead to negative consequences (Farjoun & Starbuck, 2007).

Since reliability relies on structure and cognitive and behavioural capabilities (developed by managerial actions), it is important to understand the endogenous limits relative to the development of resilience capabilities required for successful safety management. Managerial control is aimed at influencing both structure (definition of roles, rules, coordination) and cognitive capabilities (attention quality, sensemaking). Limits originated from managerial control may underpin attention, sensemaking and many fundamental organizational processes.

1.4.4.2. Danger of unintended effect of exceeding limits

In their examination of the Columbia shuttle accident, Starbuck and Farjoun (2005) explored exceeding of organizational limits in search for reliability and provide examples of threats related to time pressures (i.e. deadlines that becoming dysfunctional when they become ends rather than enabling coordination); fragmentation (becoming disordered and destroying the connections between actions and their outcomes); and blind compliance with rules, which may become inappropriate (Weick, 1993). In the same line, Oliver and colleagues' (2017a) recent study of the Air France 447 disaster explores how exceeding and cascading of technological and cognitive limits led to a catastrophe.

The particular danger comes from the fact that not all limits are directly observable, and not all are directly related to safety; while "*most limits depend upon decisions about goals, policies, or resource allocation*" (Farjoun & Starbuck, 2007). Some limits are revealed only after the negative consequences of having exceeded them emerge (Farjoun & Starbuck, 2007).

This explains why studies that adopt a limits perspective, focus on post-accident analysis of the systemic sources of catastrophes. However, the presence and influence of the organizational limits on normal daily activities, have been underexplored. A proactive approach might enable a better understanding of how capabilities develop and highlight the danger of exceeding limits before negative outcomes occur.

Farjoun and Starbuck (2007) highlight the difficulties related to anticipating the cascading consequences of exceeding endogenous limits. This is especially crucial in the context of high-risk organizations seeking to develop resilience. Such organizations must understand their limits and how to deal with them in normal day-to-day activities to avoid accidents.

There have been several calls for further case studies on high reliability environments (Oliver et al., 2017, 2019). Exploration of organizational limits in day-to-day practices and the particular focus on cascading effects are interesting avenues for future research (Farjoun & Starbuck, 2007).

1.4.5. Enabling factor: effective leadership for safety

Leadership is one of the main factors that emerges in studies as essential for improving safety in organizations (Christianson et al., 2009; Clarke, 2013; Inness Michelle et al., 2010; Katz-Navon et al., 2020). From early conceptualizations of high reliability theory to current understandings, research on reliability points increasingly to the role of leaders in the development of safety (e.g., Atkins, 2008; Barton et al., 2015; Fiol & O'Connor, 2003; Hannah et al., 2009; Hofmann et al., 2017; Roberts & Bea, 2001; Weick & Roberts, 1993; Williams et al., 2017). The enabling role of leadership is underlined in relation to developing safety values and cognitive capability allowing construction of sense, as well as coordination among individuals.

Developing safety values. The functions and organization of leaders' activities in HROs have been the subject of research since the 1990s (Guy, 1990; Roberts, 1990; Weick et al., 1999). Early work focused mainly on the role of leadership in disseminating safety values (Flin & Yule, 2004; Guy, 1990; Turner et al., 1989). For example, Guy (1990) highlights the role of managers for providing employees with a set of values and priorities to guide their decisions and encourage an organizational culture. Weick et al. (1999b) suggest that effective leadership implies developing safety values, vigilance, continuous learning and trust. For example Tucker and Turner (2015) highlight the importance of promoting safety and sharing safety-related ideas. Motivating and inspiring leadership (Clarke, 2013; Hofmann et al., 2017; Zohar & Luria,

2003) can enable the translation of safety values into corresponding behaviours and attitudes (Flin & Yule, 2004).

Develop cognitive capabilities to construct sense. The role of leadership in sensemaking has been highlighted (Atkins, 2008; Barton et al., 2015; Fiol & O’Connor, 2003; Hannah et al., 2009; Roberts & Bea, 2001; Vogus et al., 2010; Williams et al., 2017). The redirecting attrition to safety is usually considered one of the main ways that leaders use to enable safer practice (Roberts & Bea, 2001; Vogus et al., 2010; Zohar, 2002b). Fiol and O'Connor (2003b) emphasize the importance of leadership for paradoxical reasoning: setting goals for success while being aware of potential dangers. Barton et al. (2015) highlight the crucial role of leaders for framing uncertain situations through proactive sensemaking and influencing behaviours that lead to effective management of such situations. These leadership behaviours favour effective recognition and resolutions of potential problems (Williams et al., 2017). Several authors suggest the need for more research on the characteristics of attention and the mindfulness abilities of leaders (Atkins, 2008; Fiol & O’Connor, 2003; Ray et al., 2011) and leadership methods of learning to share information and values (Roberts & Bea, 2001; Tucker et al., 2016; Zohar & Luria, 2003). They call for research on the interplay of the mindfulness of leaders and the mindfulness distributed through individuals within the organization. (Fiol & O’Connor, 2003). The studies cited above point to the enabling role of leadership in solving cognitive challenges.

Act to coordinate individuals. The literature highlights the role of leadership in coordination (Geoffroy et al., 2016; Grote, 2019; Hale & Borys, 2013b; Zohar, 2002b). Leadership can enhance reliability by finding a balance between centralization and decentralization of safety management (Weick et al., 1999), and using delegation where relevant (Hale & Borys, 2013b; Klein et al., 2006; Vogus et al., 2010). Geoffroy et al. (2016) emphasize the importance of leadership to organize and maintain the connections among different actors in the systems in the face of adversity. It is important to create a climate of “harmony and unity” in order to mobilize and direct resources (Zohar, 2002b). The unique position of middle managers to bridge between strategic decision making and operational reality for safety is underlined (T. E. Beck & Plowman, 2009; Flin & Yule, 2004; Ray et al., 2011). Also, Grote (2019) clearly emphasizes the role of leaders for perceiving, understanding and proactively addressing simultaneous stability and flexibility demands. The literature on the role of leadership for safety refers to structural challenges.

However, more research is needed to explore how leaders can design their organizations to promote reliability (Williams et al., 2017) and, more specifically, to explore the tension between managed and regulated safety. Although several studies focus on the role of leadership during crises or rare events (Bavik et al., 2021; T. E. Beck & Plowman, 2009; Maitlis & Sonenshein, 2010; van der Giessen et al., 2021; Weick, 1988; Williams et al., 2017), more research is need on the role of leadership for safety in daily activities.

1.5.Conclusion of Chapter 1

The literature on safety management and reliability highlights the importance of both to deal with expected and unexpected situations (Andersson et al., 2019; Sutcliffe & Vogus, 2003; Vogus et al., 2010; Williams et al., 2017), and stresses the **need for a joint development of regulated and managed safety** (Amalberti, 2021; Besnard et al., 2017; Morel et al., 2008; Oliver et al., 2017). HROs are unique in terms of their abilities to prevent predictable dangers and to manage unexpected real-time situations before they cause catastrophic failure (Barton & Sutcliffe, 2009; Weick et al., 1999). To achieve a high-level of reliability requires regulated and managed safety. While regulated safety relies on procedures, traditional risk management tools and managerial control, managed safety relies on adaptability and flexibility to cope with unpredictable situations (Amalberti, 2021; Hale & Borys, 2013b; Morel et al., 2008). Both safety aspects are important and are closely intertwined; thus, safety and reliability **involve more than ability to switch between managed and regulated safety, but rather include their joint development, which can be challenging.** However, such joint development of regulated and managed safety is challenging.

The review of the literature helped identify two main interrelated challenges to the joint development of regulated and managed safety. These involve the **cognitive and structural issues and their interaction, which affects the duality between organizational stability and organizational change** (Farjoun, 2010). Our investigation of these challenges emphasizes the need to strike a balance between the elements in tension (e.g., mindfulness-mindfulness or standardization-flexibility). A deeper analysis of the literature highlighted an interesting dynamic: elements that need to be reconciled may be opposed but can at the same time have a mutually reinforcing effect benefiting safety. For example, repertories and routines built on and learned from previous experience, can become the building blocks for innovative mindful reaction to unexpected situations. Also, standardized rules, renegotiated by mindful and knowledgeable agents, can contribute to greater flexibility and increase reliability and safety (Schulman, 1993). The literature points to the advantages of mutual enabling between these elements (Bigley & Roberts, 2001; Farjoun, 2010; Grote et al., 2009; Hale & Borys, 2013b;

Schulman, 1993), but **does not provide solutions to these challenges.** Consequently, scholars continue to stress the need for a better understanding of the mechanisms through which reliability is achieved and how organizations design control mechanisms to respond to unexpected disturbances (Barton & Sutcliffe, 2009; Vogus & Sutcliffe, 2007; Williams et al., 2017).

Our investigation highlights some crucial elements allowing for a joint development of managed and regulated safety in complex and high-risk environments. First, cognitive challenges point to the crucial role of **mindfulness** (as a continuum with routines) for awareness and consciousness and an adapted response (Weick & Sutcliffe, 2006). Mindfulness promotes the development of flexibility and adaptability within regulated environments, with respect to existing stable elements (Barton & Sutcliffe, 2009; Sutcliffe et al., 2016; Vogus & Rerup, 2018; Weick et al., 1999). Second, **deliberate learning** allows the development of a mindful approach to effectively face uncertainty (Levinthal & Rerup, 2006, 2021). Deliberate learning enables the development of organizational capability to both better anticipate (regulated safety) and be resilient (managed safety). Third, structural challenges underline the importance to manage elaboration and formalization of rules (Grote et al., 2009; Hale & Borys, 2013b), echoing **managerial control and coordination.** Rule monitoring and adaptation maintain the relevance of rules and increase the understanding and facilitate the implementation of rules and compliance to guarantee reliability and safety. By creating better rules, organization may reinforce stability (anticipation), but also allow for the development of capability to face the unexpected (resilience).

Figure 1.5 presents the elements related to solutions to cognitive and structural challenges and enhancement of mutual enabling of stability and change.

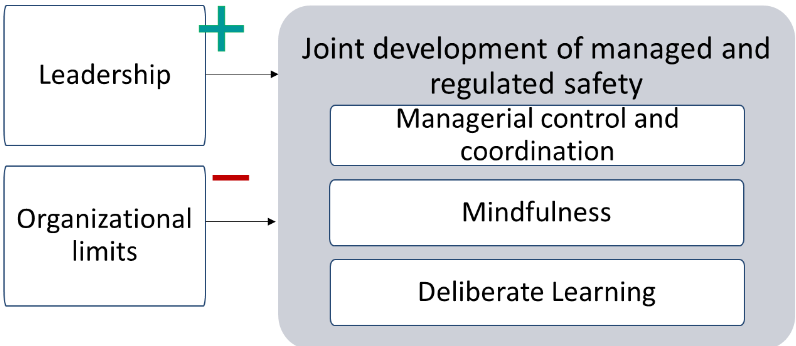

Figure 1.5. Mechanisms of joint development of managed and regulated safety

Managerial control and coordination, mindfulness, and deliberate learning, suggested by the literature, could be viewed as generative mechanisms allowing effective joint development of managed and regulated safety.

However, more research needs to be conducted to understand how these mechanisms of control, mindfulness and deliberate learning are activated in practice (e.g., Fraher et al., 2017; Williams et al., 2017). More specifically, in addition to post-accident analyses (e.g., Oliver et al., 2017; Starbuck & Farjoun, 2005; Weick, 1993) and analyses of responses to crises (Bigley & Roberts, 2001; Williams et al., 2017), more research is needed on daily practices to discover mechanisms explaining high reliability in complex, uncertain and risky environments (Boin & Schulman, 2008; Hannah et al., 2009). Some high-risk industries do not face critical incidents on daily basis, but rather perform more mundane activities with a risk of occurrence of critical incidents (Hannah et al., 2009). A nuclear sector is a good example: despite the danger of incidents and accidents due to high-risk and complexity of socio-technical system, the main organizational goals guiding day-to-day activities is electricity production.

The activation of the mechanisms of joint development of regulated and managed safety can be constrained by organizational limits (Farjoun & Starbuck, 2007) and enabled by leadership (Fiol & O'Connor, 2003; Williams et al., 2017). The constraining role of invisible organizational limits should be acknowledged to focus attention on the possible unintended consequences of exceeding these limits (Farjoun & Starbuck, 2007; Oliver et al., 2017).

Figure 1.5 depicts the enabling role of leadership. While, leadership is considered an enabling factor of improving safety and reliability (e.g., Atkins, 2008; Christianson et al., 2009; Fiol & O'Connor, 2003; Hannah et al., 2009; Hofmann et al., 2017; Katz-Navon et al., 2020; Roberts & Bea, 2001; Weick & Roberts, 1993; Williams et al., 2017), its role in the elaboration, understanding and implementation of rules, as well as in stimulating mindfulness and deliberate learning needs further investigation.

2. Leadership for safety

The review of the literature on safety management and resilience in high-risk environments, conducted in Chapter 1, pointed to the importance of leadership for tackling safety management challenges. However, before going any further in exploring the importance of leadership in the context of organizational goal of safety, we suggest to start by developing a better understanding of the phenomenon of leadership.

As a domain of research, leadership is interdisciplinary and complex. In spite of the existence of many different approaches and perspectives, research on leadership tends to converge on two aspects. First, there is a consensus that leaders have influence over the individual and group understanding of and adherence to organizational goals, and that leaders have influence over ways to achieve these goals (Bergeron, 1979; Fiedler, 1996; Godon & Yukl, 2004; Linda Parris & Peachey, 2013). Second, leadership scholars agree that this influence is exerted through the leader's interactions with his/her socio-technical environment (Fiedler, 1996; Yukl, 1989). In contrast to classical, leader-centric approaches, more recently scholars conceptualized leadership as "*a process whereby intentional influence is exerted over other people to guide, structure, and facilitate activities and relationships in a group or organization"* (Yukl, 2013, p. 18), pointing to a shift in focus from the leader' personal traits and behaviours towards leadership as process. This shift highlighted the need for a causal explanation of the relationship between leaders' behaviours and organizational results (Dinh & Lord, 2012; Fischer et al., 2017), captured by leadership mechanisms.

There is a growing strand of work on leadership in the context of organizational safety. Although early work in this stream was focused on particular leadership styles, more recent research highlights the need to identify the mechanisms of leadership that affect safety (M. A. Griffin & Hu, 2013; Pilbeam, Doherty, et al., 2016). In both the general leadership literature and the strand or work focused on leadership for safety, these mechanisms are poorly defined and, often, are indistinguishable from other practices. Therefore, we suggest taking advantage of critical realism perspective, offering strong mechanisms conceptualization, to explore leadership, and more particularly leadership for safety.

Hence, in Chapter 2 we review research on leadership and analyse its evolution from a leader-centric to a more processual approach (Section 2.1). Section 2.2 introduces the idea of leadership for safety and discusses key elements and the limitations of the existing research. In

Section 2.3, we adopt the critical realism lens to explore leadership for safety and its associated mechanisms.

2.1.Leadership: from the leader to the leadership process

The definition of leadership continues to be the subject of debate amount the research community. More specifically, there is no consensus on the overlap between leadership and management (Yukl, 1989, 2013). This section begins with a contribution to this debate (sub-section 2.1.1). Despite the lack of consensus on the definition of leadership, research in this area focuses on a few key themes, including leadership roles and styles, the influence of context, recognition of autonomy, decision-making and, more recently, leadership in complex environments. In subsection 2.1.2, we point to the limitations imposed by a leader-centric approach and introduce the notions of a collective and contextual perspective on leadership (subsection 2.1.3) and complexity leadership (subsection 2.1.4). This section concludes with the introduction of a processual perspective on leadership (subsection 2.1.5).

2.1.1. Leadership and management overlap

Leadership tends to be intertwined with other concepts, such as management (Antonakis & Day, 2017; Ashford & Sitkin, 2019; Bedeian & Hunt, 2006; Fiedler, 1996), although the "*degree of overlap is a point of sharp disagreement*" among leadership scholars (Yukl, 1989, p. 253). The lack of agreement on the difference between leadership and management is brought to surface repeatedly in the leadership literature (Bedeian & Hunt, 2006; Yukl, 2013). Gardner and Schermerhorn (2000) synthesize and classify three basic perspectives: 1) leadership as equal to management (Drucker, 1988); 2) leadership and management as separate, but complementary processes (Bass, 1985; Kotter, 1990; Quinn, 1988); and 3) leadership and management as fundamentally different processes (Zaleznik, 1977). In addition, some scholars propose to consider leadership as a dimension of management (Bedeian & Hunt, 2006; R. W. Griffin, 2016; Mintzberg, 1973)

Some authors, such as Zaleznik (1977), consider leadership and management to be mutually exclusive: leaders differ from managers in terms of their perception, sensemaking, attitudes and relations with others. Zaleznik (2004) considers that "*the distinction [between managers and leaders] is simply between a manager's attention to how things get done and a leader's to what the events and decisions mean to participants*."

A less extreme position is to consider leadership and management as distinct, but not mutually exclusive processes (Bass, 1985; Kotter, 1990, 2001; Mintzberg, 1973; Quinn, 1988).

Kotter (1990, 2001) distinguishes between management aimed at promoting stability, predictability and order (through planning, budgeting, staffing, control and problem solving), and leadership aimed at promoting adaptation and organizational change (by setting directions, aligning people and motivating). In this view management and leadership are complementary and both are necessary requiring an appropriate balancing (Kotter, 1990, 2001).

In this thesis, we adopt the moderate perspective proposed by Kotter (1990). We accept the distinction between the notions of leadership and management, but do not consider them mutually exclusive. Thus, we consider that management refers to task-oriented activities and that leadership refers to a relationship-oriented processes of influence to attain organizational goals. While for Kotter (1990, 2001) leadership is related closely to the setting of a strategic vision and a direction, this might imply some almost mystical beliefs about spiritual, heroic, outstanding leaders. Such examples exist but are rare and are contrasted with mundane leadership phenomena. Leadership scholars tend to criticize this romantic approach to leadership (Collinson et al., 2018; Kotter, 1990; Zaleznik, 1977) and instead propose to view leaders in the context of their sense of vision and strategy, and embodiment of management messages.

Ashford and Sitkin (2019) suggest that although both management and leadership involve some level of influence, it is performed differently. Management influence is enacted through organizational design, task separation and coordination, incentives and communication systems. Leadership influence is demonstrated through interpersonal relationships and promotion of a vision that takes account of management systems. Leadership can "*enable groups of people to work together in meaningful ways*" (Day, 2000, p. 582) by influencing the ways in which they understand and adhere to organizational objectives defined by management. Leadership focuses on relational practices that aim to influence the way individuals and groups understand, adhere to and achieve the goals defined by managers, through interactions in particular contexts. Thus, leadership practices work to exercise influence and enable management practices to be effective. Along similar lines, Denyer and Turnbull (2016, p. 264) refer to *influential acts* of *leading*.

According to Yukl (2013, p. 18) "*a person can be a leader without being a manager (e.g., an informal leader), and a person can be a manager without leading*". However, leadership and management may be two co-shaping processes, performed by the same individual (Antonakis & Day, 2017; Bergeron, 1979; Denison et al., 1995; Yukl, 2013). Leadership is present at all organizational levels and, potentially, any actor in the organization may perform leadership; however, depending on the leader's position in the organization, his/her zone of influence will be different. We adhere to the conceptualization of leadership as "*more than either formal authority or power*" (Bedeian & Hunt, 2006, p. 191); everyone in organization may exercise leadership, but their influence as a leader will differ in line with their position in the organization. Organizational context and position in the organization affect the scope of their influence (Beer et al., 2016), which attracts attention to multi-level leadership research (Batistič et al., 2017).

2.1.2. Limits of leader-centric approaches

In the classical approach, the roles, traits and behaviours of leaders have been analysed through individual leadership style lenses (Bergeron, 1979; Kahn, 1956; Mintzberg, 1973; Yukl, 1989). Despite some interesting advances, most of these behavioural perspectives are based on the hypothesis that leaders have direct influence on followers and organizational outcomes. However, according to Dinh and Lord (2012b), this direct effect has been overestimated and, at the same time, these views overlook other aspects, such as the collective aspect of leadership (Pilbeam et al., 2017). To try to fill this gap, some leadership scholars have proposed the notion of distributed leadership (Buchanan et al., 2007; McKee et al., 2013; Pilbeam, Doherty, et al., 2016; Pilbeam et al., 2017; Rydenfält et al., 2015) or adaptative dispersion of the leadership role over space and time (Pilbeam et al., 2017). This behavioural approach emphasizes the need to combine roles and behaviours according to the particular context (Dinh & Lord, 2012) and has led to a focus on the contexts in which leadership unfolds (Denis et al., 2010; Oc, 2018; Osborn et al., 2002; Porter & McLaughlin, 2006), including in safety studies (Christian et al., 2009; Conchie et al., 2013; Mirza & Isha, 2017; Pilbeam et al., 2019).

Traditional leader-centric research does not explain the link between leaders' characteristics and organizational outcomes and argues for the need for a better understanding of roles and behaviours in specific contexts (Dinh & Lord, 2012). This matters especially in the case of complex environments characterized by interactions, emergencies, and nonlinear causalities.

2.1.3. Contribution of collective and contextual perspectives

Recent research related to collective and contextual perspectives on leadership for safety, goes beyond traditional approaches, focused on individual leadership styles, and aims, more specifically, to capture the organizational embeddedness of the leadership phenomenon. This allows explicit consideration of a broader set of organizational dynamics (Day et al., 2014;

Kempster & Parry, 2011; Osborn et al., 2002; Pilbeam et al., 2019; Vogus & Sutcliffe, 2011). Studying leadership as an embodied organizational process, requires account to be taken of the particular context in which it unfolds. The context influences leadership (G. T. Fairhurst & Uhl-Bien, 2012; Lord & Dinh, 2011; Ospina & Foldy, 2016; G. Thomas et al., 2013), while leadership participates simultaneously in creating and modifying the context (Fiedler, 1996; Journé & Raulet-Croset, 2008). It is therefore necessary to focus on understanding the processes of the leaders' influence over individuals and the organization, in the context of a complex and interactive organizational dynamic.

From a similar perspective, the literature suggests that leadership is the result of social interactions (Alvesson & Blom, 2015; Barker, 1997; Collinson, 2005; Derue & Ashford, 2010; G. T. Fairhurst & Uhl-Bien, 2012; Gemmill & Oakley, 1992; Kempster & Parry, 2011). This relational perspective highlights that leadership cannot be understood without an analysis of its collective dynamics. For example, research on evolving forms of work shed new light on the role of teams' and subordinates' autonomy (Pearce & Barkus, 2004). This strand of work argues for shared dynamic processes, in which group members interact and influence one another, to achieve group and organizational objectives. In this view, a leader's effectiveness is no longer evaluated in terms of his/her ability to influence organizational performance, but rather by his/her ability to influence followers through collective interactions. This applies, particularly, to innovating organizations, operating in uncertain environments, were emergent effects complicate predictions. In this case, collective leadership requires "*contextual orientation, comfort with ambiguity and paradox, and commitment to continuous learning*" (Ospina & Foldy, 2016, p. 6).

The theoretical shift from a leader-centric to a processual and contextual view of leadership also requires analysis of the complex dynamics of leadership as a process. Notably, acknowledgment of leadership as part of a broader collective organizational dynamics is crucial for the design of leadership training (K. Nielsen et al., 2010; Schwatka et al., 2020; Tafvelin et al., 2019).

2.1.4. Complexity leadership perspective

One recent approach to leadership, which tries to respond to the issues described above, is the complexity leadership approach (Bäcklander, 2019; Lichtenstein et al., 2006; Murphy et al., 2017; Uhl-Bien et al., 2007; Uhl-Bien & Arena, 2018). This stream of work draws on complexity science (i.e., study of the behavior of systems comprising a large set of interconnected units that produce emergent effects) (Coveney, 2003, p. 1058). Complexity leadership theory (Marion and Uhl-Bien, 2001; Uhl-Bien *et al.*, 2007), which considers leadership to be a dynamic, complex, and interactive process, has resulted in a stream of highly-cited and contemporary research on leadership (Antonakis *et al.*, 2014, Batistic *et al.*, 2017). A 2007 Special Issue of *The Leadership Quarterly,* raised questions about the role of leadership in complex interactive dynamics (Marion and Uhl-Bien, 2007). This research marks the shift from a focus on traditional hierarchical leadership (individual leaders focusing on controlling and alignment) to work on the complex behaviours of agents, interacting in nonlinear, emergent dynamics.

This strand of work sees leadership as no longer an act of influence over individuals, but rather as a part of a complex game among multiple interacting forces; it is a dynamic, complex and interactive process (Uhl-Bien et al., 2007). Complex systems are characterized by uncertainty, emergent dynamics and recursive causalities, which tend to limit prediction (Osborn et al., 2002; Uhl-Bien et al., 2007). According to Marion and Uhl-Bien (2001, p. 395) the implications of complexity theory on understanding of leadership are the following:

> 1.Leaders cannot predict future behavior of ensembles, nor can they closely control futures with current interventions; leaders must foster interactive conditions that enable a productive future. 2. Leaders can have a limited foreseeable and controllable impact on organizations because of correlation (this may be more so in some types of organizations than others). 3. Leaders cannot determine or control the ultimate futures of complex organizations.

The "complexity leadership" literature identifies three key interrelated elements of leaders' actions: managing tensions between conflicting forces; fostering organizational flexibility and adaptability; empowering followers and developing followers' adaptability through learning.

A complex environment is inherently uncertain; it offers a multitude of potentially contradictory (paradoxical) paths (Denison et al., 1995; Osborn, 2008). Leaders act in situations of tension, derived from both internal (agent heterogeneity) and external (expectations of the organization and its environment) origins. This requires adaptive action (Uhl-Bien et al., 2007). The multiple paradoxes involved include simultaneous management of differentiation and integration, orientation towards both production and human aspects, considering existing structures and initiating new ones, vertical and horizontal interactions, internal and external constraints, creativity and routine, and formal and informal factors (Denison et al., 1995). A high tolerance for ambiguity (Uhl-Bien & Arena, 2018) is one of the main characteristics of leadership in relation to adaptability. Also, complexity leadership scholars have introduced the notion of fitness, defined as the "mix of variables related to the organization's survival", which depend on the organizational environment (Osborn et al., 2002, p. 803). A leader's effectiveness is based on his/her cognitive and behavioural ability both to recognize and to manage tensions and contradictions. However, these capabilities must not be confined to the leader: they need to be embedded in all of the members of the operational team.

All of the individuals in the organization are required to respond actively to complexity – they need to establish new social constructs and help influence the organizational context (Osborn, 2008). The resulting distributed leadership is defined as a dynamic and interactive process, in which group members interact and influence one another to achieve the organization's goals (Rydenfält et al., 2015). Dynamic delegation (Klein et al., 2006) contributes to empowering followers and enables collaborative sense-making based on richer behaviour repertories. Dynamic and complex environments increasingly call for adaptability, which leadership should enable by creating a space for ideas and introducing tensions to allow the emergence of innovative solutions (Uhl-Bien & Arena, 2018).

Leadership in complex environments seeks to identify and explore behaviours conducive to creativity, flexibility, and adaptability. Cognitive abilities that support flexibility and adaptability are acquired through learning. Consequently, leaders have a dual role: they must develop knowledge at both the individual and organizational levels (Brusoni & Rosenkranz, 2014; Von Krogh et al., 2012).

Complexity leadership theory provides a salient framework for studying leadership as a dynamic and contingent process within uncertain and non-linear organizational dynamics. However, this leadership approach focuses mainly on innovation and overlooks other organizational goals, such as safety. Also, empirical research that employs complexity leadership is scarce –due to the difficulties involved in capturing complex dynamic organizational processes and their mutual influence (Tourish, 2019).

2.1.5. Leadership as influence process

Starting in the early 1990s, researchers began to propose a processual approach, which acknowledged the complex, dynamic nature of leadership (e.g., Hunt, 1999; Parry, 1998; Yukl, 1989). An integrative processual approach is aimed precisely at uncovering the mechanism explaining the causal relationship between leadership actions and organizational results (Fischer et al., 2017). To appreciate the leader's direct effect on the organization (Dinh & Lord, 2012), it is important to identify the patterns linking leadership behaviors and organizational objectives (Hannah & Pearce, 2016; Oc, 2018; Osborn et al., 2002; Ospina & Foldy, 2016). Hence, a process approach "*acknowledge[s] rather than reduce[s] the complexity of the world*" (Langley & Tsoukas, 2017, p. 6). Calls for a processual approach are not new, but continue to be challenging, as we discuss below.

2.1.5.1. Leadership as process: definition and characteristics

It has been suggested that the leader's direct effect on organizational outcomes tends to be overestimated (Collinson et al., 2018; Dinh & Lord, 2012). This has led to calls for a stronger focus on leadership as a process and a range of definitions of leadership (see Table 2.1) (e.g., Antonakis & Day, 2017; Day, 2000; Dinh & Lord, 2012; G. T. Fairhurst, 2017; Fischer et al., 2017; Kempster & Parry, 2011; Lord & Dinh, 2011; Parry, 1998).

Table 2.1. Definitions of leadership as process

Reference	Definition
Parry (1998) p. 87	"Leadership is a social influence process that occurs naturally within a social system and is shared among various members of that social system. This implies that leadership needs to be researched as a process, rather than through the study of leaders alone."
Day (2000a) p. 582	"Leadership processes are those that generally enable groups of people to work together in meaningful ways, whereas management processes are considered to be position- and organization-specific."
Osborn et al. (2002) p. 805, 832	"There actually are systematic dimensions in addition to those unique to a given individual, issue, time, and setting…, We see leadership as a series of attempts, over time, to alter human actions and organizational systems"
Kan and Parry (2004) p. 468	"Leadership is a dynamic process occurring in dynamic contexts: process by which managers lead their associates through organizational changes to attain positive outcomes for their organization,"
Gordon and Yukl (2004) p. 363	"The missing link in most leadership research is mediating variables that explain the processes underlying relationships. The challenge for leadership researchers is to spend more time examining "black box" of leadership in order to explain why leadership is important and how leaders can influence followers or organizational performance. In addition, there is a need for theories that explain leadership as influence process."
Lichtenstein et al. (2006) p.2	"We propose that leadership (as opposed to leaders) can be seen as a complex dynamic process that emerges in the interactive "spaces between" people and ideas."
Uhl-Bien et al. (2007) p. 289	"Complexity science suggests a different paradigm for leadership—one that frames leadership as a complex interactive dynamic from which adaptive outcomes (e.g., learning, innovation, and adaptability) emerge."
Kempster and Parry (2011b) p. 108-109	"Key aspects of significance are the emphasis on social, contextual, processual and relational aspects of leadership…Leadership is a contextually based process of social influence."
Yukl (2013) p. 23	"Leadership is the process of influencing others to understand and agree about what needs to be done and how to do it, and the process of facilitating individual and collective efforts to accomplish shared objectives."
Fischer et al. (2017) p. 1727	"Leadership is a social and goal-oriented influence process, unfolding in a temporal and spatial milieu."
Langley and Tsoukas (2017) p. 21	"Leadership can be defined as situated sequences of activities and complexes of processes unfolding over time"
Antonakis and Day (2017) p.5	"Leadership a formal or informal contextually rooted and goal-influencing process that occurs between a leader and a follower, groups of followers, or institutions."

All of the above definitions have some common features. First, leadership is **goal-oriented** and underline the main point of leadership as influence on others (directly or indirectly) (Antonakis & Day, 2017; Ashford & Sitkin, 2019; Fiedler, 1996). This notion of leadership, captured in terms of goal-oriented influence, distinguishes leadership from authority (Ashford & Sitkin, 2019).

Second, leadership is **dynamic** in nature, implying changes over time (G. T. Fairhurst, 2017; Kan & Parry, 2004; Parry, 1998; Uhl-Bien et al., 2007). Fisher et al. (2017b) strongly emphasize the temporal dimensions of the leadership processes.

Third, leadership is a **social process** because leadership influence is exerted via interactions (Osborn et al., 2002). In recognizing that "*defining leadership as a process supports the notion that leadership is more than a linear, mono directional event*", Kan and Parry (2004, p. 468) seek, also, to extend the definition "*beyond the formally designated leader to include anyone taking on a leadership role*".

Fourth, leadership is **embedded in the organization**, which demands the acknowledgment of multiple simultaneous dynamic processes within the organization (Fischer et al., 2017; Fleishman et al., 1991; Tourish, 2014). As Fleishman et al. (1991, p. 256) argue, "to understand leadership behavior as an organizational phenomenon, one must begin by considering the nature of organizations". An effective leadership process requires ability to understand organizational complexity and convey to others the options related to achievement of organizational objectives (Bess & Goldman, 2001; Dinh & Lord, 2012; Fleishman et al., 1991; Mumford et al., 2000). Leadership is not just an act of direct influence, it is also a fragment of a complex web of influence among many interacting forces (Uhl-Bien et al., 2007). Therefore, depending on one's position in the organization, leadership influence will have a different impact. Recognizing the interaction between organizational context and leadership is crucial for a better understanding of how leaders exert influence (Hernandez et al., 2011).

Fifth, leadership is **simultaneously observable and non-observable**. Indeed, leadership cannot really be seen; only its effects may be observed or perceived (Endres & Weibler, 2017; Kempster & Parry, 2011; Parry, 1998; Tourish, 2014). Opening the 'black box' of influence (Gordon & Yukl, 2004) involves searching for **"*the mechanisms that explain the causal relationship between inputs (e.g., leader behaviours) and outputs (e.g., performance), following an input-process-output logic*"** (Fischer et al., 2017, p. 1727). However, in this view, leadership as process is also subject to ambiguity; for example, some considerations refer to practices or events (observable), whereas others emphasize underlying mechanisms (not easily observable). This confusion extends to the connections between leadership as process and leadership as practice (G. T. Fairhurst, 2017; Kempster et al., 2016). One thing is certain - studying non-observable leadership mechanisms is problematic.

2.1.5.2. Leadership as an influence process: challenges related to identifying the underlying mechanisms

Research on leadership in complex environments shows that, in many cases, the effects of leadership have unanticipated emergent effects that stem from the combination of intra- and inter-personal processes (Lichtenstein et al., 2006; Uhl-Bien et al., 2007). Empirical research on leadership is difficult (Hannah et al., 2009), due, in part, to the novelty of the field and, in part, to the problems related to studying not-easily observable context-dependent phenomena (Parry, 1998). **This highlights the importance of investigating the underlying mechanisms of leadership influence**

One of the common development avenues for recent leadership research approach is the search of the mechanisms that could explain causal relations between the leadership influence on followers and the organization (Batistič et al., 2017; Dinh & Lord, 2012; Hannah et al., 2009; Hazy & Uhl-Bien, 2015; Hernandez et al., 2011; Oc, 2018; Osborn et al., 2002). A processual approach reveals how leadership contributes to "*acknowledge rather than reduce the complexity of the world*" (Langley & Tsoukas, 2017, p. 6). Process studies help to uncover and clarify the causal mechanisms of leadership as a process, going beyond observable effects (Fischer et al., 2017), and to capture the organizational embeddedness of leadership phenomena (Kempster & Parry, 2011).

The extant literature defines leadership mechanisms according to the causal relationships they promote between leadership influence and outcomes. Several scholars refer to '*mechanisms*' (Gu et al., 2020; Gutermann et al., 2017; Hernandez et al., 2011; Humphreys et al., 2012; Pilbeam et al., 2019), but others prefer terms such as '*process*', '*mediating construct*' (Fischer et al., 2017; Zaccaro et al., 2001), '*mediation pathways*' (Peng & Kim, 2020) or '*mediators*' (Gottfredson & Aguinis, 2017; Young et al., 2020). These various studies also, explicitly or implicitly, identify different leadership mechanisms, which explain the effects of leadership interventions on performance (see Table 2.2).

Table 2.2. Selection of leadership mechanisms identified in prior literature

Mechanisms	Type of Relationship	Key Reference
Identification, self-efficacy, empowerment, LMX, justice	General: effect of leader traits or behaviors on performance-related outcomes	Fischer et al. (2017)
Affect, cognition, behaviours, traits	General	Hernandez et al. (2011)
Objective performance, perceptual and attitudinal constructs, group processes, motivation, organizational citizenship behaviour, emotions. Constructs which are explanatory in nature, describing the specific mechanisms through which leadership may lead to performance	General	DeChurch et al. (2010)
Cognitive, motivational, affective, coordination	Team leadership on team performance	Zaccaro et al. (2001)
Informal storytelling as sensemaking and sensegiving mechanism	Leadership on innovation and creativity	Humphreys et al. (2012)
Affective, motivational, identification, social exchange, justice enhancement, all mediated by LMX (Leader-member exchange)	Transformational leadership on employees' job performance	Ng (2017)
LMX mediating mechanisms (self-congruence, empowerment, positive affect, trust, person–job fit, core job characteristics, work engagement)	Leadership behaviors (e.g., consideration, initiating structure, contingent rewards, transformational leadership) and follower performance (e.g., task performance, organizational citizenship behaviours)	Gottfredson & Aguinis (2017)
LMX, ethical culture assessing social learning, organizational identification, trust	Ethical leadership to normative conduct	Peng & Kim (2020)
Connecting goal clarity and public values: clear goals as promoting public values	Transformational leadership on public value involvement	Stazyk & Davis (2020)
Participation and social capital	Transformational leadership on innovation	Cortes & Hermann (2020)
Coordination/control, awareness, contingent rewards, role modelling, competency, perceived organizational support, trust	Leadership intervention on safety	Pilbeam et al. (2019)
Motivational mechanisms: LMX and psychological empowerment	Transactional leadership on followers' performance	Young et al. (2020)
Leaders' voice expectation and employees' voice role perception	Transformational leadership on employee voice behavior	Duan et al (2017)
Team knowledge goal generation and team knowledge goal striving	Transformational leadership to team knowledge exchange	Burmeister et al (2020)

Table 2.2 shows the diverse nature of the identified mechanisms. First, some mechanisms, such as traits (Hernandez et al., 2011), behaviours (DeChurch et al., 2010), and Leader–Member Exchanges (LMX) (Ng, 2017), are observable, while others, such as cognition (Hernandez et al., 2011), sensemaking-sensegiving (Humphreys et al., 2012), motivation (Mumford et al., 2000) and trust (Peng & Kim, 2020), are not. Second, the mechanisms occur

at different levels. Trust (Peng & Kim, 2020), affect (Hernandez et al., 2011), organizational identification (Peng & Kim, 2020) and psychological empowerment (Young et al., 2020) refer mainly to the individual level, whereas coordination (Zaccaro et al., 2001), social learning (Peng & Kim, 2020) and social capital (Cortes & Herrmann, 2020) operate mostly at the collective level, such as among teams, organizations or communities. Third, leadership mechanisms are studied both broadly (DeChurch et al., 2010; Fischer et al., 2017; Hernandez et al., 2011) and in relation to a particular style of leadership such as transformational (Gottfredson & Aguinis, 2017; Ng, 2017; Stazyk & Davis, 2020), ethical (Peng & Kim, 2020) or transactional (Young et al., 2020), alongside their influence on specific outcomes such as innovation (Cortes & Herrmann, 2020; Humphreys et al., 2012), knowledge (Burmeister et al., 2020) or safety (Pilbeam et al., 2019).

This review points to the fact that the conceptualization of leadership mechanisms is vague and requires further theorizing. Figure 2.1 depicts the call to identify those elements that might explain the causal relationship between leadership practices and followers' outcomes, consistent with organizational goals.

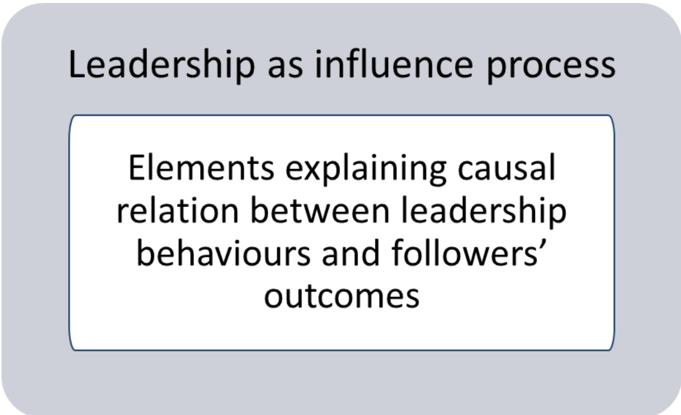

Figure 2.1. Leadership as influence process

Also, understanding the processual and contextual nature of leadership requires methodological approaches more able to capture the invisible mechanisms underlying the leadership process (Fischer et al., 2017; Hazy & Uhl-Bien, 2015; Kempster & Parry, 2011; Osborn et al., 2002).

2.1.5.3. Call for multi-level and interdisciplinary approach to leadership

Leadership scholars recognize the need for greater conceptual and methodological clarity to enable the study of leadership as complex process of influence. Multiple attempts to categorize leadership theories recognize that leadership is a multi-dimensional phenomenon (Batistič et al., 2017; Hernandez et al., 2011; Meyer et al., 2005). A growing recognition of the social nature of leadership has resulted in calls for more research, from a process perspective of leadership (Antonakis et al., 2014), on leadership as a multi-level and dynamic phenomenon (Collinson, 2005; Gemmill & Oakley, 1992; Parry, 1998; Uhl-Bien et al., 2007).

Scholars propose two main interrelated research avenues capable to fully acknowledge the complex and contingent nature of leadership: first, integrating multi-level approach (Batistič et al., 2017; Hazy & Uhl-Bien, 2015; Meyer et al., 2005; Ospina & Foldy, 2016); second, mobilizing interdisciplinary theoretical approaches (Oc, 2018; Osborn et al., 2002). To achieve an understanding of the complexity of leadership, authors invite to reach beyond the limits of the leadership literature and to integrate various theories allowing to understand organizational phenomena in all their complexity.

Despite these various pleas for more research and different conceptualizations of leadership, its meaning and the mechanisms underlying it remain semantically unclear. Similarly, the relationship between these mechanisms and the related concepts (processes, practices, structures) are also unclear. In Section 2.3, we adopt a critical realist ontology to try to clarify the concept of generative mechanisms and their influence on practices and behaviours.

In sum, the conceptualization of leadership mechanisms is crucial for a better understanding of the process of leadership influence (the "how") and how this process of influence guides followers' behaviour (the "what") to meet management's organizational objectives (the "why"?). Considering these dimensions of leadership and their relationships is important for leadership studies (Carter et al., 2020). Depending on the objective (e.g., safety, innovation, creativity, sustainability, etc.), how the influence is exerted will differ. The focus of the present thesis is on the organizational goal of safety.

2.2. Leadership for safety: key elements and limits

Chapter 1 discussed the particular role of leadership for safety development (e.g., Atkins, 2008; Barton et al., 2015; Hannah et al., 2009; Roberts & Bea, 2001; Weick & Roberts, 1993; Williams et al., 2017) and a specific stream of work on leadership for safety emerged. In this section, we start by defining leadership for safety (2.2.1) and then discuss some of the main propositions and limitations in the literature on leadership for safety (2.2.2) and calls for more processual approaches.

2.2.1. Defining leadership for safety

2.2.1.1. From safety management to safety leadership

The terms “safety management” and “safety leadership” have regularly been used together in academic articles (Wahlström, 2018), institutional guidelines, and standards (Pilbeam et al., 2017), which has led to some confusion about the extent to which leadership and management overlap (Antonakis & Day, 2017; Kotter, 1990; Yukl, 1989). In subsection 2.1.1, we discussed how management tends to refer to task-oriented activities, while leadership relates to the underlying influence processes that facilitate the achievement of specific objectives (Kotter, 1990). Thus, management and leadership overlap and can be performed by the same individual (Antonakis & Day, 2017; Denison et al., 1995). Pilbeam et al. (2017) point to the problems related to clarifying the profile of leaders, for safety in particular. In their review, they highlight historical “sliding/shifting” in the terminology used in safety publications over the course of 30 years and highlight that, since 2000, the focus has changed from “managing safety” to “safety leadership”.

Although some authors clearly distinguish between “managing safety” and “safety leadership” (e.g., Moon & Hamilton, 2013; Wahlström, 2018), most – including the most recent - articles are less clear. For example, Grill and Nielsen (2019) use the term “managerial leadership”, while Stiles et al. (2018) refer to “managerial behaviours” and “leadership” interchangeably. Also, Pilbeam et al. (2016) consider the concept of safety leadership from three dimensions: safety coaching; safety caring; and safety controlling. While coaching and caring are relationship-oriented and are focused more on leadership, controlling refers to a task-oriented managerial role. Thus, the distinction between the terms *safety management* and *safety leadership* remains unclear. This might be due to how academic thinking about the complex phenomenon of leadership per se has evolved (e.g., Antonakis & Day, 2017; Yukl, 2013). The overlap between safety management and leadership for safety, and the overemphasis on the leadership style at the expense of leadership as process, contribute to the absence of conceptual clarity related to leadership for safety (Pilbeam, Doherty, et al., 2016; Pilbeam et al., 2017).

To provide some clarification, we discuss some of the feedback from scholars and experts working on this subject as one of the outcomes of the first international, multidisciplinary workshop of the European Leadership for Safety Education (ELSE) project, funded by the European Union. The January 2020 ELSE workshop held in Nice (France), gathered 35 safety experts from 11 countries, 22 researchers from 15 universities and management schools, and 13 nuclear industry experts from 11 international institutions. ELSE Workshop participants also underlined the use of both terms. Figure 2.2 shows that in attempting to define leadership for safety, participants' answers emphasized two distinct, but interconnected concepts: (1) safety management as a system of principles, rules, design and organizational artefacts referring to risk management and safety culture; and (2) leadership as a process of intentional influence that guides and facilitates activities and relationships. Therefore, leadership for safety refers to the exercise of leadership influence in the domain of safety management. Their influence allows leaders to resolve the tensions inherent in safety management. Figure 2.2 allows to disentangle two key concepts of safety management and leadership for safety.

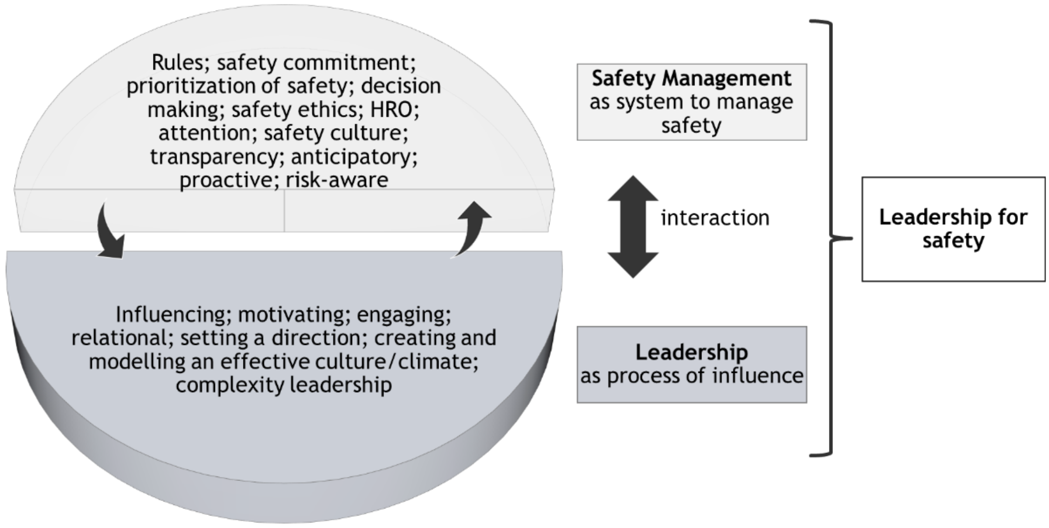

Figure 2.2. Leadership for safety keywords derived from ELSE workshop participants' responses

2.2.1.2. "Leadership for safety" or "safety leadership"

Prior literature linking leadership to safety uses the terms "*safety leadership*" and "*leadership for safety*". The objective of the ELSE scientific workshop was to close the research/practice gap by achieving a consensual definition of leadership for safety, analysing the organizationally embedded tensions inherent in safety management, faced by leaders and understanding the implications of leadership for safety practices and research (European Leadership for Safety Education (ELSE) Workshop Scientific Report, 2020).

One of the objectives of the ELSE workshop was to establish which term most accurately reflected the key topic. In the responses to a questionnaire, administered to workshop participants before the workshop, only 23% stated a preference for the term "safety leadership" which highlights the link between ways of managing and the resulting safety. The workshop participants also considered that the term safety leadership highlighted particular safety roles as opposed to other organizational roles. However, the majority of participants (63.3%), whether researchers (56%) or nuclear sector practitioners (75%), considered leadership for safety to be more relevant due to its focus on leadership as the phenomenon of interest and safety as the final goal of the exercise of leadership. Rather than applying the specific construct "safety leadership", participants suggested instead to simply address existing leadership construct in the context of safety. A participant from academia stated that: "Leadership comes first. Safety should be an integrated part of business policies, procedures and practice—and not treated as an isolated (leadership) silo, separated from other business processes". The participants felt that safety leadership better captured the emergent nature of safety in complex systems and that safety was integral to organizational processes and not an isolated leadership responsibility.

2.2.1.3. Definition of leadership for safety

Despite a growing interest, the construct of leadership for safety is poorly defined (Clarke, 2013; Pilbeam et al., 2017), which highlights the related lack of conceptual clarity (Suddaby, 2010), which Pilbeam et al. (2016) suggest can be explained, in part, by the difficulty related to defining the construct of leadership more generally. Scholars of leadership for safety tend to avoid formally defining this term and resort to descriptions of leadership skills, behaviours and styles affecting safety(Pilbeam, Doherty, et al., 2016). For example, Conchie et al. (2013) conceive leadership for safety based on leaders' actions (styles) that have a positive impact on employees' safety behaviours. Schawtka et al. (2020) define leadership for safety in terms of a safety climate and skills such as leading by example, empowering, active listening, communication, teaching, feedback, etc. Studies that adopt a behavioural approach to leadership for safety draw on Griffin and Hu's (2013, p. 200) definition of leadership for safety as "*specific leader behaviors that motivate employees to achieve safety goals*". Cheung et al. (2021) also emphasize leadership for safety as leadership behaviors that have a positive impact on employees' safety behaviours, by focusing only on a constructive approach to leadership (M. B. Nielsen et al., 2016).

To our knowledge, the articles that propose explicit definitions of leadership for safety (Kim et al., 2021; Stiles et al., 2018; C. Wu et al., 2016; T. Wu et al., 2011) cite the more processual definition proposed by Wu (2008): that is, leadership for safety as "*the process of interaction between leaders and followers, through which leaders can exert their influence on followers to achieve organizational safety goals under the circumstances of organizational and individual factors*" (C. Wu et al., 2016, p. 790). The relationships between organizational and environmental conditions, management and leadership influence safety (Osborn, 1999). Leadership for safety in high-risk contexts implies non-linearity, high levels of variability in outcomes, emergencies due to amplifying effects and tensions between conflicting forces (Hällgren et al., 2017; Hannah et al., 2009). Therefore, leadership for safety as an influence process is embedded in organizational dynamics and the ability to exercise this process of influence depends on understanding the organizational dynamics and the organizational context, such as safety culture and safety climate (Clarke, 2013; Zohar, 2002b). Some recent studies include calls for deeper exploration of the dynamics affecting followers' sensemaking and reactions to safety cues (Katz-Navon et al., 2020), keeping in mind that the sense accompanied by the leadership should be aligned with the sense disseminated by organizational artefacts (procedures, manuals, documentation, systems of indicators) (Sandberg & Tsoukas, 2020; Steigenberger & Lübcke, 2021).

The combination of insights from the literature, especially Wu's (2016; 2008b) definition, and ongoing discussion within the safety community on leadership for safety (European Leadership for Safety Education (ELSE) Workshop Scientific Report, 2020), allows us to define leadership for safety as resulting from the cross-fertilization between theoretical and empirical knowledge (Hamer et al., 2021; Rae et al., 2020). We propose the following definition of leadership for safety:

Leadership for safety is a process of influence over individual and collective cognition and behaviours in the way to meet safety management expectations.

2.2.2. Key propositions and limits of the existing literature

2.2.2.1. Safety-specific leadership styles

Although there is a substantial body of work on leadership for safety (Christian et al., 2009; M. A. Griffin & Talati, 2014; Vogus et al., 2010; Zhang & Wu, 2014; Zohar, 2002b), most studies focus on the behavioural aspects of leadership styles (Hofmann & Morgeson, 2004; Huang et al., 2004; Pilbeam, Doherty, et al., 2016). A systematic review of the leadership for safety literature (see, e.g., Lekka & Healey, 2012; Pilbeam, Doherty, et al., 2016; Pilbeam et al., 2019) shows that most authors prefer style - and behaviour - based approaches to the study of safety, focusing on leaders' general traits and behaviours and their abilities to increase organizational safety. They frequently cite transformational leadership as the safety-related leadership behavior that produces a climate of safety, encourages safety participation and inspires care for individual needs (Barling et al., 2002; Conchie et al., 2013; Flin & Yule, 2004; M. A. Griffin & Talati, 2014; Inness Michelle et al., 2010; Kapp, 2012; Katz-Navon et al., 2020; J. E. Mullen & Kelloway, 2009; T. D. Smith et al., 2020; Zohar, 2002b, 2002a). Specific behaviours include encouraging employee participation in decision-making and a climate of safety, defining shared goals and promoting consideration of individual needs. The four components of transformational leadership (intellectual stimulation, personalized consideration, idealized influence, and inspiring motivation) focus on the direct influence on followers (Barling et al., 2002; Flin & Yule, 2004; M. A. Griffin & Talati, 2014; Kark et al., 2015; J. E. Mullen & Kelloway, 2009; Zohar, 2002a, 2002c). Some researchers emphasize the complementarity between transactional (non-individualized and hierarchical) and transformational (highly individualized and inspirational) leadership and the influences on followers' safety (compliance and participative) behaviours (Clarke, 2013; Flin & Yule, 2004; Katz-Navon et al., 2020; Martínez-Córcoles & Stephanou, 2017; Pilbeam, Doherty, et al., 2016; Zohar, 2002a). For example, Pilbeam et al. (2016b) mention extrinsic motivation to follow the rules, developed by transactional leadership through control and reward; and intrinsic motivation, encouraging voluntary engagement in compliance with rules, developed by transformational leadership. There are also other leadership styles that can enable or maintain safety, such as high-quality LMX (Graen & Uhl-Bien, 1995; Hofmann et al., 2003; Klein et al., 2006; Zohar, 2002b), empowering leadership (Gracia et al., 2020; Lee et al., 2019; Martínez-Córcoles et al., 2021; Pilbeam et al., 2019; Zwetsloot et al., 2017), authentic leadership (Eid et al., 2012) and ethical leadership (Parboteeah & Kapp, 2008).

In their review of the leadership literature, Pilbeam and colleagues (2016c) note that the majority of leadership for safety practices are considered behaviour and style, and focus on general leader traits and behaviours to motivate and increase team and organizational commitment and safety communication (Huang et al., 2004), measured using generic scales (Multifactor Leadership Questionnaire-MLQ and LMX). However, although interesting, these views on leadership suggest a direct interpersonal influence and tend to ignore the complexity of the processual and contextual nature of leadership (Dinh & Lord, 2012; Osborn & Ashforth, 1990). Although leadership influence on safety behaviours interests researchers (Christian et al., 2009; Fugas et al., 2012; M. A. Griffin & Talati, 2014; Vogus et al., 2010; Zhang & Wu, 2014c), most work focuses on styles rather than on process-approaches to leadership.

The linear relationship between leadership style and followers safety outcomes raises questions about and calls for more nuanced causal explanations (Epitropaki & Turner, 2020; Katz-Navon et al., 2020; Katz-Navon et al., 2005). For example, Katz-Navon et al. (2020) find a curvilinear relationship: leadership has a stronger impact if it includes high levels of perceived clarity and consistency of their leadership style (Katz-Navon et al., 2020). Also, Clarke (2013) stresses the need for more research on the mechanisms related to active positive leadership and its effect on safety behaviours. Therefore, the evolution of leadership for safety studies follows the evolution of leadership studies in general, discussed in the subsection 2.1.5, strengthening the call to more processual approach. A processual approach to leadership for safety might reveal sustainable causal relationships between leadership behaviours and safety outcomes. However, only a few papers focus on the mechanisms enabling an effect on organizational factors and, specifically, leadership on safety (M. A. Griffin & Neal, 2000; J. Mullen, 2004).

2.2.2.2. Adopting a processual lens to study leadership for safety

Some studies explore the process of leadership for safety, by studying the elements linking leadership actions to organizational outcomes, referring implicitly to the mechanisms of social learning (Zohar, 2010), knowledge sharing (Lee et al., 2019), role modelling, social identification (Eid et al., 2012), communication (M. B. Nielsen et al., 2016), safety consciousness (Barling et al., 2002), and followers' situational promotion or prevention focus (Kark et al., 2015).

Several papers underline that a safety climate mediates leadership influence on safety (Clarke, 2013; Eid et al., 2012; Hofmann et al., 2003; Hofmann & Morgeson, 2004; Katz-Navon et al., 2005; M. B. Nielsen et al., 2016; Tucker et al., 2016; Zohar, 2002a, 2002b). However, a safety climate represents only an instantaneous surface perception of priorities, struggling to capture the alignment between enacted and espoused proprieties (Zohar, 2010). Despite Neal and Griffin's (2000) framework, suggesting that motivation and safety knowledge mediate safety climate effect on safety performance, existing theories on safety climate struggle to explain the underlying causality between leadership and safety behaviours (Zohar, 2010), Also, organizational embeddedness is not sufficiently explored in these studies.

Building on the links between leadership behaviours and safety results, some studies of leadership for safety have begun to apply a more processual perspective to explain the mechanisms of influence on safety (M. A. Griffin & Neal, 2000; M. B. Nielsen et al., 2016; Pilbeam et al., 2019; Tucker et al., 2016). Safety performance depends on followers' safety behaviours, such as safety compliance and safety participation (M. A. Griffin & Neal, 2000). Nielsen and colleagues (2016) consider leadership as a process of social influencing and recognize the importance of examining how leadership is related to safety over time. While some authors acknowledge the dynamic nature of the leadership process, they apply a classical leader-centric vision based on testing the time-lagged relationships between classic (constructive, laisser-faire, tyrannic) leadership types and safety climate. Thus, they overlook the deeper underlying mechanisms explaining the causality of the leadership effect on safety. Tucker et al. (2016) attempt to explore the mechanisms underlying an indirect effect of top management on safety. The authors draw on the concept of collective social learning to explain how promotion of a safety climate cascades to all organizational levels. They focus on chief executive officers, justifying their choice by the particularity of their positional power to achieve organizational goals. Thus, this study represents the overlap between managerial position and leadership.

In their review of safety interventions deployed by leaders, Pilbeam et al. (2019) advance knowledge by investigating the generative mechanisms and explaining how safety is achieved. They build on Denyer et al. (2008) suggestion and integrate context, interventions, mechanisms and outcomes in a single framework, to explore the processes that shift safety behaviours and reduce accidents. Pilbeam et al. (2019) theorize about the mechanisms of coordination/control, awareness, trust, contingent rewards, role modelling, competency and perceived organizational support, which can be seen are heterogeneous in nature. First, some elements (e.g., coordination and control, and contingent rewards) are related more to management than to leadership. This confusion between management and leadership is evident in the statement that "*managers (or leaders) in organizations have at their disposal interventions to influence behaviors*" (Pilbeam et al., 2019, p. 353). Second, while some elements are related closely to leadership in general (e.g., trust, role modelling), others (e.g., awareness) clearly refer to safety management.

Similarly to the literature on leadership in general, there is a lack of conceptual clarity about the mechanisms related to safety management and to leadership for safety. Moreover, some of the most recent studies on leadership for safety simply confuse management and leadership (e.g., Cheung et al., 2021; Grill & Nielsen, 2019; Kim et al., 2021; Pilbeam et al., 2019). Consequently, in order to capture the leadership for safety process, we need a more precise distinction between easily observable leadership practices and behaviours (M. A. Griffin & Hu, 2013) and invisible mechanisms that explain the effects of these behaviours.

Traditional epistemological paradigms fail to capture the mechanisms underlying these complex dynamics. Thanks to its focus on the discovery of mechanisms, critical realism provides an interesting epistemological framework to achieve theory-method consistency in an investigation of leadership as a process in complex environments. First, by disentangling leadership and management, leadership practices and leadership mechanisms, a critical realist approach resolves existing confusions and clarifies the mechanisms of leadership for safety. Second, as proposed by our definition of leadership for safety, leadership is aimed at influencing behaviours in order to satisfy safety management expectations, critical realism perspective allows to construct a multi-level model of leadership for safety and responds to the challenges related to leadership and safety management, discussed in Chapter 1, by reinforcing the understanding of its organizational embeddedness.

2.3. Exploring leadership for safety through the critical realism lens

In response to repeated calls for an investigation of leadership for safety mechanisms (e.g., Clarke, 2013; Epitropaki & Turner, 2020; Hannah et al., 2009; Katz-Navon et al., 2020; Zohar, 2010), we propose to adopt a critical realism framework to study leadership as a process aligned to a specific organizational objective – safety.

In the subsection 2.3.1 we first explore the main postulates of critical realism, including its emphasis on mechanisms. Then, through an in-depth literature review, we disentangle leadership mechanisms from observable leadership practices to build a critical realism-informed framework of leadership as an influence process (2.3.2). Critical realism's focus on underlying mechanisms in a multi-level reality, promotes an integration of diverse relevant theories in a single coherent theoretical framework to improve our understanding of leadership for safety as a process. We follow Kempster and Parry (2011), who propose critical realism as an alternative epistemology to study context-based leadership, therefore we suggest a construction of a critical-realist integrative framework as a key step in the study of leadership for safety. We then discuss the application of this integrative framework to study leadership for safety (2.3.3)

2.3.1. Critical realism postulates

2.3.1.1. Stratified reality

Leadership studies are dominated by positivist and interpretivist traditions. In line with Kempster and Parry (2011), we believe that the critical realism epistemological framework, developed initially by Roy Bhaskar (1978), offers a solid foundation for further research on leadership, due to its relevance for processual and contextualized leadership approaches. More specifically, critical realism recognizes the emergent properties of the social realm, with particular attention devoted to non-deterministic causality (Bhaskar, 1978). In this conceptualization of the world, more or less obvious causal powers, mechanisms and structures exist "*independently from, but capable of producing [the] patterns of events that we observe*" (Avenier & Thomas, 2015, p. 68). The resulting stratified view of the world spans three domains: the real, the actual and the empirical. The real domain comprises generative mechanisms and structures with causal powers, such that they behave in particular ways under certain conditions (Bhaskar, 1978). The activation and interaction of causal powers generates events that compose the actual domain. Finally, the empirical domain includes experienced events, which represent a small subset of the actual domain (Brannan et al., 2017; Mingers, 2004; Mingers et al., 2013; Mingers & Standing, 2017).

2.3.1.2. Definition of mechanisms

Advances in sociology towards understanding the nature of mechanisms (Bhaskar, 1998b; Coleman, 1986; Collier, 1994; Gross, 2009; Hedström & Swedberg, 1998; Reskin, 2003; Stinchcombe, 1998; Tilly, 2001) reflect consistent efforts to explain the relationship between cause and effect (i.e. 'why'). This has led to much disagreement about the definition of mechanisms. One of the main controversies is related to the nature of mechanisms, which may be defined as a process (Reskin, 2003) or as a "model that represents a causal process" (Stinchcombe, 1998: 267), a "structure" or a "process" (Hedström and Swedberg, 1998: 288), as an aspect of the structure (Collier, 1994), or even as an event (Tilly, 2001). Gross (2009, p. 364) synthesizes these ideas in following definition: "*social mechanism [that] is a more or less general sequence or set of social events or processes*".

Adopting a critical realist perspective to mechanisms may allow for their finer-grained definition because of the clear distinction made between mechanisms, structures, contexts and processes, and, most importantly, their interrelations. Owing to their essential properties, mechanisms exert causal powers and generate flows of events in the actual domain (Mingers & Standing, 2017). Mechanisms exist independently of the known or observed social world. Regardless of whether they are non-material or are observable, they have causal effects.

Mechanisms have the irreducible property of always acting in a specific way, even if the consequences might be different, depending on the countervailing forces of other intervening mechanisms (Mingers, 2004; Tsoukas, 1989). Circumstances and interactions trigger activation of the causal power of mechanisms. Generative mechanisms might remain dormant for long periods or might be counteracted by opposing mechanisms (Tsoukas, 1989), leading to the presence or absence of actual events (Mingers, 2004). That is, the mechanisms always exist, but their activation and effects may differ, depending on the context or their combination with other mechanisms. For example, "*control and cooperation are two opposite generative* *mechanisms whose respective realization is dependent on contingent circumstances facing organizations*" (Tsoukas, 1989, p. 552). Thus, particular structures might give rise to certain causal powers or specific ways of acting (Mingers et al., 2013), such as favouring cooperation at the expense of control or vice versa. Finally, in the social world, the causal chain includes intentional agency (Hartwig, 2015; Psillos, 2015), which requires consideration of the effects of interpretation and hermeneutics (Mingers & Standing, 2017).

2.3.1.3. Social structure

In a critical realist approach, social structures cannot be directly observed; they consist of "*a set of simultaneously constraining and enabling rules and resources that are implemented in human interaction*" (Tsoukas, 1989, p. 554). According to Archer (1998b), social structures reflect distinct allocations of (1) productive resources to persons or groups and (2) persons and groups to functions and roles. In organizations, these allocations are embodied and transcribed in artefacts such as rules, procedures and processes. They include cultural systems constituted by all things capable of being understood or known. Archer (1998a) also notes the potential existence of contradictory or complementary cultural subsystems. Social structures enable and constrain human actions; humans constantly reproduce and transform these structures (Fleetwood, 2014). Figure 2.3 shows that the individual (action) and collective (structure) levels interact recursively, and that these structures are both ever-present conditions and continually reproduced outcomes of human agency (Bhaskar, 1998a).

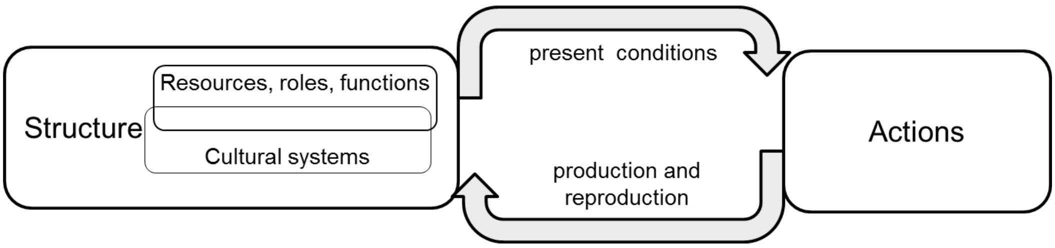

Figure 2.3. Dual nature of social structure

Social structures have emergent properties (causal powers) that are irreducible to their constituent parts (Tsoukas, 1989), but which interact with other objects that also possess causal powers. This interaction generates non-predictable, but still explicable, outcomes (Archer, 1998b). The same mechanism can exist in multiple structures, and the same structure may be produced and reproduced by various mechanisms (Hartwig, 2015; Psillos, 2015). For example, supply and demand mechanisms in a market structure can take multiple forms, depending on the levels of regulation and market concentration. Similarly, control and coordination mechanisms may result in hierarchical organizational forms.

2.3.1.4. Interactions among context, structure and mechanisms

Critical realism is aimed at exploring the structures, generative mechanisms and contextual conditions, responsible for patterns of observed events. Based on observed contexts and events (empirical level), some researchers have investigated the deeper causal mechanisms and structures that generate these events (Brannan et al., 2017). In this case, abduction (or *retroduction* in Bhaskar's terminology) appears the most appropriate mode of reasoning (Boisot & McKelvey, 2010; Brannan et al., 2017; Mingers, 2004). Bhaskar (1998a) proposed a four-step - Describe, Retroduce, Eliminate, Identify (DREI) – methodology involving the following: describing the events of the phenomenon of interest, retroducing explanatory mechanisms, eliminating false hypotheses and identifying correct mechanisms. The causal explanation for a given phenomenon results from the discovery of how mechanisms, structures and contexts interact to generate observed events (Avenier & Thomas, 2015; Brannan et al., 2017; Fleetwood, 2004; Kempster & Parry, 2011; Mingers et al., 2013; Mingers & Standing, 2017; Tsoukas, 1989).

An abductive reasoning process uses existing knowledge. Generative mechanisms are often already identified in the literature, so the goal is primarily to explain their activation modes. Critical realism research results in the accumulation of knowledge, through iteration between a specific empirical case and a general theory, and back to another case and so on (Pawson & Tilley, 1997). In this perspective, proposing a coherent framework is important to facilitate knowledge reuse. To reflect the stratified nature of reality, the framework should include multiple levels. Therefore, we decided to disentangle under-conceptualized leadership concepts and integrate them into a coherent framework following a critical realist approach by differentiating among context, practices, structure and mechanisms.

2.3.2. Building an integrative framework of leadership

To clarify leadership mechanisms and their relationships with related concepts (practices, behaviours, structure, process), we conducted a comprehensive literature review, informed by critical realism. Ashford and Sitkin (2019, p. 456) suggest that, to account for sloppy and siloed conceptualizations, "*drawing on the related work of others (rather than reinventing it or ignoring its potential) is actually a pretty efficient way of getting familiar with and exploring potential new boundary areas where our own work can be extended*".

We begin by clarifying and disambiguating leadership practices (observable events) and mechanisms (unobservable and deep causal powers). We reinsert practices and mechanisms into an integrative, multilevel framework. Embedding the process of leadership in a set of organizational dynamics, captures the depth and complexity of leadership as a process.

2.3.2.1. Clarifying leadership practices and mechanisms

To recognize the interaction between practices and mechanisms, we need first to disentangle them. Practices are observable events, whereas mechanisms are not directly observable and are embedded in organizational dynamics.

Leadership practices

In relation to the leadership practices identified in the literature, we propose to regroup them into four general categories—meaning-making, demonstrating, relational monitoring and learning development—each of which activates one or several mechanisms of leadership influence: sensegiving, mutual trust, motivating and learning.

Meaning-making practices. The meaning-making activities of leadership (Foldy et al., 2008; Smircich & Morgan, 1982), include resolving uncertainty (Parry, 1998), identifying and reconciling paradoxes (Kan & Parry, 2004), making events meaningful for followers (Yukl, 1999), and aligning others around a vision (Bass & Avolio, 1994). For example, leaders might engage in systematic search for and organization of information about team goals and operations, interpretation of tasks or translation of senior managements' vision and strategic intent into collective action (Zaccaro et al., 2001). Sense-giving also another important leadership task (Foldy et al., 2008, p. 516). Leaders can provide organizational members a sense of meaning, in order to create a richer, more accurate understanding of the organizational challenges (Hannah et al., 2009) and to create cognitive shifts in thinking or perception (Foldy et al., 2008, p. 514).

Meaning-making practice that activates "sensegiving-for-others" is a process of disseminating a new understanding to the audience to influence their "sensemaking-for-self" (Gioia & Chittipeddi, 1991, p. 444). The presence of different internal and external organizational audiences underlies the many different cognitive leadership activities that might shape audience cognition, in ways that advance organizational goals (Foldy et al., 2008).

Demonstrating practices. Demonstration of practices involves providing examples and demonstrating coherence among values, meanings and practices (Sosik et al., 2004). The exemplar of the leaders' behaviour is crucial, "*because leaders serve as role models for* *followers and set norms and expectations that influence the thoughts and behaviors of followers*" (Hannah et al., 2017, p. 561). Demonstration of practices can involve personal risk taking, engagement in unconventional or self-sacrificing behaviour in the interests of the ultimate mission, image building (Shamir et al., 1993), acting genuine and being transparent towards others, showing self-awareness and exercise of moral standards and values (Neider & Schriesheim, 2011). It is related to doing what is right, being fair, showing integrity, guiding others ethically (Brown & Treviño, 2006; Dionne et al., 2014, p. 14), communicating honestly, abiding by promises and commitments, acting in ways consistent with espoused values and admitting and accepting responsibility for mistakes (Yukl, 2013). If leaders demonstrate these positive behaviours, "*followers are likely to personally identify with the leader's values or with what they perceive the leader as representing*" (Ng, 2017, p. 389; see also Ashforth & Mael, 1989).

Several streams of the literature on leadership, point to the need to demonstrate moral components, such as those that describe authentic (Avolio & Gardner, 2005; Michie & Gooty, 2005), charismatic, transformational (Bass, 2008; Bass & Avolio, 1994; Shamir et al., 1993) or ethical (Bavik et al., 2018; Brown & Treviño, 2006; Dionne et al., 2014) leadership. Demonstrating practices also underlines the leader's commitment to organizational goals (Sosik et al., 2004) and influences followers' perceptions of the leader's competence, loyalty, justice and fairness, all of which are related closely to trust (Ng, 2017; Uhl-Bien, 2006). Hannah et al. (2017, p. 565) suggest that leaders should create "*a context where followers are more likely to perceive that they can openly espouse their beliefs and manifest their beliefs in behaviours, expecting that those behaviours will be met with a positive reaction from the leader and others in the environment*".

<u>Relational monitoring practices.</u> Monitoring practices are generally associated with managerial, task-oriented behaviours, aimed at controlling task accomplishment. We focus on relational monitoring leadership practices linked to followers' welfare that promote increased performance (Bass, 2008; Ng, 2017). From a collective perspective, scholars of shared leadership refer to the broader notion of social support, "*defined as team members' efforts to provide emotional and psychological strength to one another*" (Carson et al., 2007, p. 1222). Specifically, relational monitoring practices would include paying attention to others (Sosik et al., 2004), feedback, encouragement, rewarding, listening (Tucker & Turner, 2015; Zohar, 2002a), supportive voice (Carson et al., 2007; W. Liu et al., 2010) and fostering a climate that allows constructive airing of disagreements (Zaccaro et al., 2001). Relational monitoring practices are closely related to aspects of transformational leadership such as individualized

consideration and intellectual stimulation (Barling et al., 2002; Bass & Avolio, 1994; Bednall et al., 2018; Menges et al., 2011; Pearce & Barkus, 2004).

Learning development practices. Learning development involves acting as a coach or mentor (Ng, 2017; Scandura & Schriesheim, 1994), such that "*an individual with more advanced experience and knowledge (mentor) … assists a less-experienced and knowledgeable individual (protégé) with personal and professional development*", in either formal or informal interactions (Sosik et al., 2004, p. 244). Kram (1985) underlines two broad functions of mentors: career development and psychosocial support. Learning development practices include human development and assistance, and providing instructions and guidance related to tackling difficult assignments, acquisition of new knowledge and skills, and achieving a good professional-personal life balance (Sosik et al., 2004). They may also include encouraging and facilitating development of individual confidence and ability (Yukl, 2013). They allow learning about values by providing knowledge on the organization's specific norms and values (Lankau & Scandura, 2002).

Although these four practice categories are analytically distinct, when implemented in daily life, they are closely interrelated. For example, a key principle of learning is to express a genuine concern about the personal development and career progress of subordinates can be achieved through relational monitoring practices (Yukl, 2013, p. 80). Table 2.3 presents some examples of concrete leadership practices by category.

Table 2.3. Examples of practices by category

Practice categories	Examples of practices
Meaning-making	Systematic search and organization of information regarding team goals and operations; interpreting tasks; Translate the vision and strategic intent of company executives into collective action *(Zaccaro et al., 2001)* Keep people informed about actions affecting them; interpret events to explain the need for change, open discussion *(Yukl, 2013)* Rich and meaningful interactions *(Lichtenstein & Plowman, 2009)* Providing ideological explanation; emphasizing collective identities; reference to history *(Shamir et al., 1993)*
Demonstrating	Express confidence that a person or group can perform a difficult task; use symbols, ceremonies, rituals, and stories to build team identity; communicate in an open and honest way; keep promises and commitments; act in ways consistent with espoused values; admit and accept responsibility for mistakes; do not attempt to manipulate or deceive people *(Yukl, 2013)* Taking personal risk; engaging in unconventional behaviours; image building of self-sacrificial behaviour in the interest of the mission *(House & Shamir, 1993)* Being genuine, transparent to others, and self-aware and possessing moral standards and values *(Neider & Schriesheim, 2011)*

Relational Monitoring	Provide support and encouragement to someone with a difficult task; socialize with people to build relationships; encourage mutual trust and cooperation among members of the work unit; enjoy helping others, so be willing to take risks or make sacrifices to protect or benefit others; put the needs of others ahead of own needs; volunteer for service activities that require extra time and are not part of the formal job requirements; treat others with respect, avoiding status symbols and special privileges; admit limitations and mistakes, showing modesty about achievements; emphasize contributions by others when a collective effort is successful; help others cope with emotional distress; encourage acceptance of diversity; act as a mediator or peacemaker by encouraging forgiveness and reconciliation after a divisive conflict *(Yukl, 2013)* Listening *(Tucker & Turner, 2015; Zohar, 2002b),* Giving personal attention to others *(Sosik et al., 2004),* Supporting voice *(Carson et al., 2007; Liu et al., 2010)* Fostering a climate where disagreements can be aired constructively *(Zaccaro et al., 2001)* Expression confidence in followers *(Shamir et al., 1993)* Regular meeting around peripheral activities; open discussion; encouraged to honestly assess the problem *(Lichtenstein & Plowman, 2009)*
Learning development	Consults with others about decisions that will affect them, provides appropriate amount of autonomy and discretion to subordinates, shares sensitive information, encourages them to express concerns or dissenting views without becoming defensive *(Yukl, 2013)* Develop personnel learning, human development, helping, instruct to take on challenging assignments, acquire new knowledge, skills, and abilities, or to creatively balance one's professional and personal life, challenging job assignment, coaching for achieving goals *(Sosik et al., 2004),* Creation of positive learning environments *(Day et al., 2014)*

Leadership influence mechanisms

Since leadership as a process involves influence, we focus on mechanisms with causal power over influence. In line with a critical realism approach, we undertake a comprehensive analysis of the literature to identify generative mechanisms of leadership influence: sensegiving (Cornelissen et al., 2014), mutual trust (Brower et al., 2000), motivating (Michie & Gooty, 2005) and learning (Hannah & Lester, 2009). Leadership becomes effective once these mechanisms are activated. They are present in all leadership goal-oriented activities and contexts, including safety.

Sensegiving Mechanism. Sensegiving influences the construction of meaning, individually and collectively (Barge & Fairhurst, 2008; Sandberg & Tsoukas, 2015; Weick et al., 1999). This construction relies on how *"people ... engage [in] ongoing events from which they extract cues and make plausible sense retrospectively while enacting more or less order into those ongoing events*" (Weick, 2001, p. 463). Yet sense-giving is not sufficient. As part of a broader sensemaking process (Foldy et al., 2008, p. 519), it is "*concerned with the process of attempting to influence the sensemaking and meaning construction of others toward a preferred redefinition of organizational reality*" (Gioia & Chittipeddi, 1991, p. 442). Leadership practices give sense, but also allow for sensemaking. Gioia and Chittipeddi (1991, p. 442) argue that "*sensemaking has to do with meaning construction and reconstruction by the involved parties as they attempt to develop a meaningful framework for understanding*". Accordingly, leadership is associated, largely, with the management of shared meanings (Bess & Goldman, 2001; Day, 2000; Foldy et al., 2008; Kan & Parry, 2004; Smircich & Morgan, 1982). Leaders are concerned with organizational symbolism and need to develop interpretative strategies as part of their communication processes (Bryman, 2004, p. 731). Their efforts to "*structure experience in meaningful ways*" (Smircich & Morgan, 1982, p. 258) and, thereby, build "*shared meaning systems and mutual commitments among communities of practice*" (Day, 2000, p. 605), can lead to maximum "*consensual commitment*" (Rowland & Parry, 2009, p. 551).

In complex and dynamic environments, change emerges through actions, in ways not necessarily intended by the leaders (Lichtenstein & Plowman, 2009; Plowman et al., 2007), which makes sensemaking particularly crucial. Erroneous sensemaking processes, under pressure, can amplify crisis (Hannah et al., 2009; Weick, 1988). This risk is one of the reasons for particular scholarly attention to the role of leader in activating sensegiving mechanisms (Lichtenstein & Plowman, 2009; Marion & Uhl-Bien, 2001; Mumford et al., 2000; Murphy et al., 2017; Osborn & Hunt, 2007), which occurs usually through meaning-making practices. Leaders perform sensegiving by contributing to the development of a shared understanding of problems, goals, events, actions and values (Lichtenstein & Plowman, 2009; Marion & Uhl-Bien, 2001; Murphy et al., 2017; Plowman et al., 2007; Shamir et al., 1993; Zaccaro et al., 2001). However, sensegiving mechanisms can be activated by other practices, such as learning development practices for intellectual stimulation (Shamir et al., 1993) or demonstrating practices that establish the coherence among values, moral purposes, meanings, and behaviours (Lord & Hall, 2005; Shamir et al., 1993).

<u>*Mutual Trust Mechanism*</u>. Leadership rests on a foundation of mutual trust and respect (Day, 2000; Day et al., 2014), where "*trust refers to a person's willingness to be vulnerable to another group member's (i.e., leader, subordinate, or peer) actions, based on a sense of confidence in the group member's competence to meet role requirements and the character to behave cooperatively*" (Sweeney et al., 2009, p. 244). Followers who trust their leader's directives are more likely to maintain focus and sustained effort towards achieving the mission (Hannah et al., 2009; Sweeney et al., 2009). Studies of charismatic (Conger & Kanungo, 1987; Shamir et al., 1993, 1998), authentic (Avolio & Gardner, 2005; Hannah et al., 2017) and transformational (Menges et al., 2011; Ng, 2017; Podsakoff et al., 1990) leadership indicate

that trust and loyalty to leaders influence the quality of the leaders' relationships with followers (Brower et al., 2000; Graen & Uhl-Bien, 1995; Uhl-Bien, 2006).

In particular, mutual trust engenders confidence and protection, which can facilitate experimentation and lead to more innovative responses. In complex, uncertain environments, trust is necessary to promote innovative, sometimes disruptive behaviours. For example, trust in leaders is required for agents to refer to weak signals perceived in the environment. Practices related to the protection of dissident voices (Heifetz & Laurie, 2001) or protection of actors from external politics and top-down directives (Marion & Uhl-Bien, 2001), promote trust mechanisms which permit disruptive and innovative responses (Murphy et al., 2017). Mutual trust can be activated by demonstrating practices, such as displaying transparent, open, fair and loyal behaviours (Avolio & Gardner, 2005; Brower et al., 2000; Ng, 2017; Uhl-Bien, 2006; Walumbwa et al., 2008; Yukl, 2013). Also, the quality of LMX depends on trust (Brower et al., 2000), which highlights the importance of relational monitoring practices, such as recognition and rewards, team-building activities, freedom to express thoughts and feelings (Walumbwa et al., 2008), supportive behaviour (Shamir et al., 1998) and trust-based exchanges (Avolio & Gardner, 2005; Yukl, 2013) and fairness (Ng, 2017; Pillai et al., 1999). Trust can also be activated by meaning-making (Yukl, 2013) and leadership development practices (Avolio & Gardner, 2005).

Motivating Mechanism. Explaining the part played by leaders in motivating followers continues to be a central challenge for both psychologists and management scholars (Berson et al., 2015), who have employed multiple motivation theories to explore this link (Dionne et al., 2014, p. 17), including path–goal theory (House, 1971), intrinsic and extrinsic motivation, the Pygmalion effect (Duan et al., 2017; Eden, 1992; White & Locke, 2000), the motivational model of leadership (Winter, 1991) and the motivational roots of leadership (Gottfried et al., 2011). Motivating mechanisms work to unite employees around the pursuit of a particular goal (Antonakis & Day, 2017). Motivation is linked to values such as social justice, equality, honesty, loyalty, equality, emotional intelligence and affect (e.g., Avolio & Gardner, 2005; Naidoo, 2005; van Knippenberg et al., 2004). At the individual level, motivating mechanisms are related to job satisfaction, affective organizational commitment, job self-efficacy, work engagement and sense of justice (Ng, 2017). At the group level, they are aligned to a sense of cohesion (value of group membership) and collective efficacy (Zaccaro et al., 2001), which, in turn, are based on convincing followers that they are an important part of the larger organization or mission (Bass, 2008; Hannah et al., 2009).

To activate motivating mechanism, leaders need to acknowledge the emotional sensibility of their followers (Lord & Hall, 2005; Naidoo, 2005) and demonstrate concern over their welfare (Bass, 2008) by enacting relational monitoring practices. In the context of role models (Shamir et al., 1993) and paying attention to interpersonal processes (Zaccaro et al., 2001), leaders act as motivators by linking the value of followers' efforts to their self-concepts. Ng (2017) suggests that the quality of reciprocal social exchanges improves LMX (Graen & Uhl-Bien, 1995) and perceived organizational support (Eisenberger et al., 1986), which can incentivize followers to put more effort into achieving organizational goals. Demonstrating practices, such as example setting (Bass, 2008) or adjustments to core values, which reveal the leader's identification with such values (Lord & Hall, 2005), may also activate motivation. In addition, meaning-making practices such as rendering events as meaningful, linking present behaviours to past events by citing historical examples, using labels and slogans, providing an image of the future, outlining expectations (Lord & Hall, 2005; Shamir et al., 1993) and enhancing a sense of both individual (Shamir et al., 1993) and collective (Zaccaro et al., 2001) efficacy can also promote motivation. Finally, self-efficacy and confidence can be enhanced by vicarious learning and verbal persuasion from leaders (Ng, 2017).

Learning Mechanism. Leadership is aimed at encouraging professional and personal development over time, through mutual learning (Sosik et al., 2004). Provision of learning opportunities can improve communication and enhance relationships (Chen et al., 2008), including LMX (Yukl, 2013). The resulting *"important work relationship ... can serve as a forum for personal learning*" (Lankau & Scandura, 2002, p. 779). Learning involves "*the discovery of relevant new knowledge, diffusion of this knowledge to people in the organization who need it, and application of the knowledge to improve internal processes and external adaptation*" (Yukl, 2009, p. 49). Fostering employee autonomy (Lord & Hall, 2005; Zaccaro et al., 2001) is one means used by leaders to influence followers and encourage learning. Studies of the influence of leaders on learning have evolved from direct, linear and top-down models to more processual and shared approaches (Argyris & Schön, 1997; Berson et al., 2006; Mumford et al., 2002; Vera & Crossan, 2004; Von Krogh et al., 2012; Yukl, 2009). What matters is creating the conditions conducive to facilitating and sustaining effective collective learning, to enable the creation and sharing of knowledge (Hannah & Lester, 2009; S. Liu et al., 2014).

First, learning mechanism may be activated by practices, such as encouraging personal learning (Sosik et al., 2004; Yukl, 2009), guidance regarding how to integrate knowledge (Berson et al., 2006) and he development of underlying individual and team capabilities for self-regulation (Kozlowski, 1998; Lord & Hall, 2005). Leadership practices can include provision of constructive suggestions and feedback. “Pre-briefs” and “post-action” reviews can facilitate team learning cycles (Zaccaro et al., 2001). Second, related meaning-making practices can influence learning by identifying priorities and showing how knowledge can be used (Berson et al., 2006; Yukl, 2009). Third, relational monitoring practices provide social support and creation of a positive organizational culture that encourages personal learning (Sosik et al., 2004).

Table 2.4 presents examples of leadership mechanisms and the leadership practices that activate them. It shows the interrelations among mutually reinforcing mechanisms.

Table 2.4. Mechanisms of leadership

Mechanism	Findings/Components	Link with Other Mechanisms or Structure	Main Practices that activate or disactivate mechanisms	Type of Leadership	Key References
Sensegiving	Certain individuals emerge as leaders because of their role in framing experience in a way that provides a viable basis for action, such as by mobilizing meaning, articulating and defining what has previously remained implicit or unsaid, inventing images and meanings that provide a focus for new attention, and consolidating, confronting, or changing prevailing wisdom.		Meaning-making	General	Smircich & Morgan (1982)
	Acting as sensemakers is one of the mechanisms used by complex leaders to enable emergent self-organization. A common or shared understanding of the system helps give meaning to unfolding events and actions that might otherwise go unnoticed. Leaders explain and repeat specific language and symbols to foster the development of a shared understanding and become catalysts for specific actions.		Meaning-making	Complexity leadership	Lichtenstein & Plowman (2009); Plowman et al. (2007) ; Marion and Uhl-Bien (2001); Murphy et al. (2017)
	Sensemaking reflects ‘embodied cognitions’: understanding of a leader by followers may be driven not just by cognitive, but also by emotional and behavioural reactions.		Meaning-making, demonstrating	Leadership identity	Lord & Hall (2005)
	Leadership influences a team sensemaking process by developing a shared understanding of team problem parameters and objectives, using individual and shared knowledge structures to define solution alternatives, and evaluating and reaching consensus on acceptable solutions.	Learning	Meaning-making	Team leadership	Zaccaro et al. (2001)
	By helping people develop shared mental models about cause-effect relationships and the determinants of performance and/or articulating an inspiring vision to gain support for innovative changes, leaders enhance organizational learning.	Learning	Meaning-making	Leadership for learning organizations	Yukl (2009)
	Leadership gives meaningfulness to work by infusing work and organizations with moral purpose and commitment through, for example, visionary and inspirational messages or intellectual stimulation of followers; confidence.	Mutual trust, Motivating, Learning	Meaning-making, Demonstrating, Learning development	Charismatic leadership	Shamir et al. (1993)
Mutual trust	A model of relational leadership is based on a review of leader-member exchange (LMX) and interpersonal trust. The LMX relationship is built through interpersonal exchanges in which parties to the relationship evaluate the ability, benevolence, and integrity of each other.		Demonstrating	Relational	Brower et al. (2000)
	In the idiosyncrasy credit (IC) model, a “credit-building” process is a function of the followers' perceptions of the leader's competence and loyalty displays that engender follower trust in the leader.		Demonstrating	Relational	Uhl-Bien (2006)
	Relational transparency, openly sharing information, and expressions of true thoughts and feelings promote trust.		Demonstrating, Meaning-making, Relational monitoring	Authentic leadership	Walumbwa et al. (2008)

	Leader supportive behaviour is strongly related to trust in the leader.		Relational monitoring	Charismatic leadership	Shamir et al. (1998)
	Leaders can increase mutual trust by articulating an appealing vision of team accomplishment; using promoting symbols and rituals; conducting team-building activities; and making contingent recognition and rewards.	Sensegiving	Demonstrating, Meaning-making, Relational monitoring	Team leadership	Yukl (2013)
	Trust in the leader and trust in the organization indicate the extent to which employees are willing to be vulnerable to the actions of the leader and organization. Trust mediates the relationships between perceptions of fairness/justice and employee performance outcomes.	Motivating	Demonstrating, Relational monitoring	Transformational leadership	Ng (2017)
	Followers are motivated by transformational leaders to perform beyond expectations because followers trust and respect them.	Motivating		Transformational leadership	Podsakoff et al. (1990)
	Under extended and extreme stress, followers' performance will be influenced by their trust in the leader (built prior).	Motivating		Leadership in extreme context	Hannah et al. (2009)
	Authentic leadership development involves ongoing processes whereby leaders and followers gain self-awareness and establish open, transparent, trusting, and genuine relationships, which may be shaped and impacted by planned interventions such as training.	Motivating	Demonstrating, Relational monitoring, Learning development	Authentic leadership	Avolio & Gardner (2005)
	Transformational leadership may operate by enhancing the fairness of rules and procedures. But trust in the leader does not necessarily translate into a greater commitment to the organization or general job satisfaction.	Structure, Motivating (+ or -)	Demonstrating, Relational monitoring	Transformational leadership	Pillai et al. (1999)
Motivating	The consistency of emotional and motivational orientations may be an important determinant of effective leadership.		Relational monitoring		Naidoo (2005)
	Leaders should develop a more flexible understanding of how some individuals are more sensitive to positive or negative emotions.		Relational monitoring	Leadership identity	Lord & Hall (2005)
	Transformational leadership can augment performance by displaying care for follower welfare, inspiring through leading from the front, and by convincing followers they are part of a larger entity and mission.		Relational monitoring, Demonstrating	Transformational leadership	Bass (2008)
	The motivational mechanism suggests that leaders, through intellectual stimulations inspire and motivate followers to have greater self-efficacy, feel confident about doing well in their jobs, be willing to dedicate time and extra effort to their work, and persist in the face of setbacks, which contribute to greater job performance. Verbal persuasion and vicarious learning are key to enhancing self-efficacy.	Learning	Relational monitoring, Learning development	Transformational leadership	Ng (2017)
	Leaders increase the intrinsic value of efforts and goals by linking them to values involving followers' self-concepts and harnessing the motivational forces of self-expression, self-consistency, self-esteem, and self-worth; leaders change the salience hierarchy of values to implicate in action. Leaders contribute to motivation by role modelling and framing alignment behaviours.	Sensegiving	Meaning-making, Relational monitoring	Charismatic leadership	Shamir et al. (1993)
	The motivation derives from the cohesion of the team (shared commitment to valued goals) and from its sense of collective efficacy. The team performance model reflects not only a cognitive process but also an interpersonal process across team members.	Sensegiving	Relational monitoring Meaning-making	Team leadership	Zaccaro et al. (2001)
	If leaders are perceived as chameleon-like rather than being authentic, trust and willingness to follow may diminish. Leadership can influence others by recounting stories or experiences that reveal central aspects of their identities and symbolize underlying values.	Mutual trust	Demonstrating	Leadership identity	Lord & Hall (2005)

Learning	Leaders are responsible for developing the underlying individual and team capabilities that enable teams to self-manage their actions.		Learning development	Team leadership	Kozlowski (1998)
	Expert leaders may increase their effectiveness by building relevant knowledge and self-regulatory capacities in others, rather than in themselves, thus making possible the delegation of some leadership tasks to others.		Learning development	Leadership identity	Lord & Hall (2005)
	Leaders provide contextual support in the organization and obtain the resources needed for learning to occur. They enable and enhance the integration of learning across group and organizational levels by providing a foundation of shared understanding of needs and purpose at different levels and provide the guidance to cross boundaries and integrate what is learned. Leaders integrate new and existing knowledge in the organization's policies and practices.	Structure, Sensegiving	Learning development, Meaning-making		Berson et al. (2006)
	Some examples of ways for leaders to enhance organizational learning: encourage questioning of traditional methods and experimenting; facilitate the acquisition of skills needed for collective learning; articulate an inspiring vision; strengthen values consistent with learning from experience; help people recognize when important learning has occurred and to understand the implications for the team or organization; and help people develop shared mental models about cause-effect relationships and the determinants of performance for the team or organization.	Sensegiving	Learning development, Meaning-making	Leadership for learning organizations	Yukl (2009)
	Leaders may enable the development of followers by increasing their motivation and ability to approach learning experiences. Learning efficacy reflects not only individuals' assessment of their learning abilities but also a motivational component. This increased motivation contributes to engagement in learning tasks. Leaders may promote the diffusion of knowledge within and across social networks by influencing the structure and functioning of knowledge networks.	Motivating, Structure	Learning development	Multi-level leadership interventions	Hannah & Lester (2009)
	Transformation leadership is a key mechanism of learning. Inspirational motivation performed by mentors entails communicating high performance expectations that activate self-fulfilling prophecies, such that protégés can be accepted as important organizational contributors. Establishing and maintaining an organizational culture that encourages learning may result in stronger dyadic bonds, thus fostering personal learning, work satisfaction, and commitment.	Motivating, Structure	Learning development, Relational monitoring	Transformation al leadership	Sosik et al. (2004)

In line with a critical realism approach, several mechanisms may interact, reinforce or counteract one another (Tsoukas, 1989). The literature highlights the strong interrelations among the identified leadership mechanisms. The most frequently mentioned relations are between sensegiving → motivating, sensegiving → learning, learning → motivating, motivating ←→ trust and sensegiving → trust. Some relationships are mostly unidirectional; others are recursive.

First, sensegiving favours the activation of motivating, by revealing the meaningfulness of work, efficacy or changes to the work environment, and by adapting mental models (Shamir et al., 1993; Zaccaro et al., 2018). Second, sensegiving can facilitate learning through development of and adjustment to shared mental models (Berson et al., 2006; Shamir et al., 1993; Yukl, 2009; Zaccaro et al., 2001). Third, learning can enhance motivation (Ng, 2017). Fourth, motivating is reinforced by mutual trust, which, in turn, reinforces self-awareness (Avolio & Gardner, 2005) and self-confidence (Hannah & Lester, 2009; Shamir et al., 1993). Fourth, at the same time, readjustment to motivating values can promote trust (Lord & Hall, 2005). Fifth, mutual trust is reinforced by sensegiving, based on the promotion and diffusion of symbols, rituals and a team vision (Yukl, 2013).

Several scholars highlight the links between leadership mechanisms and structures, which underlines the organizational embeddedness of leadership. The interaction between the mechanism of mutual trust and structure can enhance the fairness of rules and procedures (Pillai et al., 1999; Sweeney et al., 2009). By activating mentoring mechanisms, leaders can influence structure by reallocating resources (Berson et al., 2006) and changing the culture (Hannah & Lester, 2009) in order to enhance learning. An organizational culture that encourages learning increases motivation (Hannah & Lester, 2009).

Analyses of leadership need to take account of how leadership practices unfold within the larger web of organizational dynamics that involve the interplay between structure and mechanisms. In other words, leadership influence is the result of the interactions between practices and mechanisms, which are mediated by social structures. In the next sub-section, we integrate these elements to propose a multilevel framework of leadership as a complex social influence process.

2.3.2.2. Integrative multilevel framework of leadership as a process

To reflect the complexity of leadership as a process, it is important to identify the interactions among practices, contexts, structures and mechanisms. Figure 2.4 depicts the different elements and their interrelations. In a critical realism perspective, the elements are ordered according to their level of reality to which they belong: from surface (observable) to deep real (not observable).

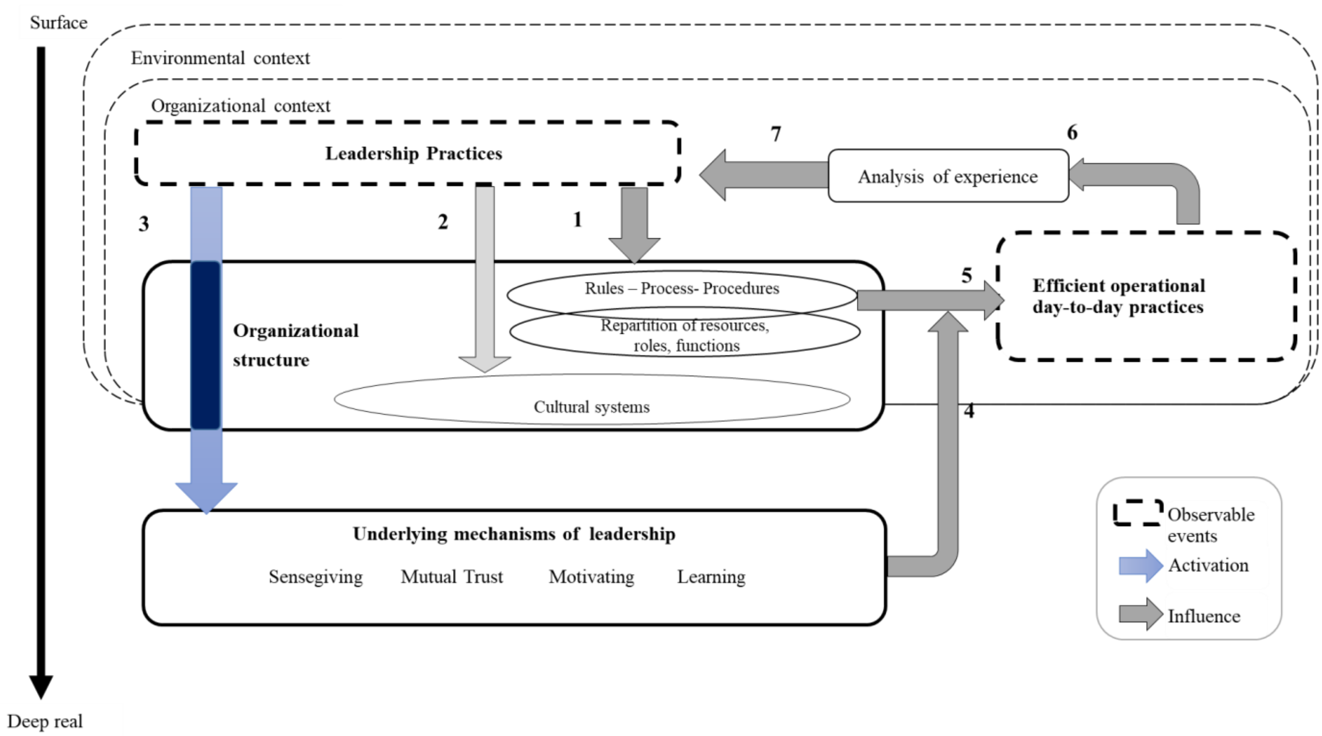

Figure 2.4. Integrative framework of leadership as process[1]

Environmental and organizational contexts. The organizational context is part of the broader environmental context (e.g., complex or extreme). It influences leadership practices and the organizational structure. Culture, which is part of the organizational structure, is embedded in the broader system (industry, country), and must be accounted for in the framework (Eydieux et al.,

[1] A critical realism framework applied to leadership, and intermediary versions of this framework, were presented at the following international workshops and conferences: British Academy of Management (BAM) Conference 2018, European Group for Organizational Studies (EGOS) 2018, Paper Development Workshop CESEE 2018, SKEMA KTO PhD Day 2020, European Academy of Management (EURAM) 2019, Association Internationale de Management Stratégique AIMS 2020 (finalist for the AIMS Best Communication Award)

2018; Kudesia et al., 2020). The organizational context is an observable aspect of the organization; it includes practices (flows of events) and observable structural elements such as the organizational chart, which depicts the distribution of roles and functions.

Practices. Leadership practices refer to leaders' interventions aimed at influencing followers, and fall into the four categories discussed previously: meaning-making, demonstrating, relational monitoring and learning development. These practices are characterized by three aspects. First, they are intertwined with goal-oriented management practices, which influence rules, procedures and processes (Figure 2.4, arrow 1). Second, leadership practices can influence cultural systems, but only indirectly (arrow 2); to achieve change to cultural systems requires regular application of practices over long periods of time. The shortcut 'leadership practices–culture–performance' reflect a lack of understanding of organizational dynamics and the recursive relationships between action and structure. Third, leadership practices activate influence mechanisms (arrow 3); the influence is indirect and mediated by organizational structure. However, the leader position in the hierarchy, enables access to resources and power in the sense of Giddens (1984), and determines the leader's capacity to influence the structure (arrows 1 and 2) and activate mechanisms (arrow 3).

Organizational structure. Some elements of the structure (e.g., allocation of resources, roles, functions) are partly observable, because they are embodied in organizational charts, rules, procedures and processes. Other elements of the structure (e.g., cultural systems) are difficult to observe. The structure and, more particularly, the rules, procedures and processes influence day-to-day practices (arrow 5). However, the individual can interpret and apply these rules and procedures in ways that serve his/her needs. The social structure can include contradictory elements, such as different and partially conflicting cultural subsystems or rules. For example, in high-reliability organizations, safety and performance cultures may be in tension with and activate different mechanisms.

Underlying mechanisms. These mechanisms are not directly observable and constitute the deepest level of reality. They are generic and exist independently of any organization. When activated, underlying mechanisms have causal powers that support the achievement of expected outcomes (Figure 2.4, arrow 4). The activation of leadership mechanisms (sensemaking, mutual trust, motivating, learning) influences followers to implement goal-oriented rules, procedures and processes (arrow 5) more efficiently. For example, activation of awareness (safety mechanism) improves the reliability of operational practices. The interplay among the causal powers activated by practices and mediated by the structure, generates flows of observable events, composed of more or less efficient day-to-day operational practices. Analysis of these events (arrow 6) facilitates readjustments to management and leadership practices (arrow 7).

Temporality. Figure 2.4 depicts different temporalities. The activation of mechanisms (arrow 3) takes place in action and generates immediate – not necessarily expected - results (arrows 4 and 5). A more or less deliberate learning process takes place (arrow 6), leading to progressive adjustments to leadership practices (arrow 7) and elaboration of rules, procedures and processes (arrow 1). These processes of learning and adjustment occur over time and through repeated 'practice–activation of the mechanism–result' cycles. The repetition of practices, over longer time period, can lead to evolution in cultural systems (arrow 2).

The integrative multilevel framework in Figure 2.4 combines and reorders the existing fragmented literature on leadership. Analysis of the interactions among different concepts, such as context, practices, mechanisms and structure, supports the definition of a leadership process as comprising leadership practices, in interaction with structures and contexts, which activate mechanisms of influence to enhance implementation of operational practices related to a particular goal-oriented activity. The efficiency of these operational practices depends on the activation (or not) of the mechanisms underlying the related activity.

2.3.3. Application of the integrative framework of leadership process for safety

Kempster and Parry (2011, p. 107) suggest that a critical realism perspective would contribute to "*our understanding of how context and process shape the manifestation of leadership*". We developed an integrative, multilevel framework which captures leadership as an influence process (Day, 2000; Fischer et al., 2017; Kempster & Parry, 2011; Uhl-Bien et al., 2007). This framework highlights the relationships among observable (context and practices), partly observable (social structure) and unobservable (mechanisms) elements (Gordon & Yukl, 2004; Kempster & Parry, 2011; Parry, 1998). To increase the effectiveness of leadership interventions requires an understanding of their generative mechanisms and activation modes in specific contexts. However, leadership as an influence process is embedded in the organizational context and is related to a particular organizational goal (Antonakis & Day, 2017; Kan & Parry, 2004; Yukl, 2013) – in our case safety management. To allow continuous adjustment to their leadership safety practices requires leaders to understand the complex organizational dynamics affecting safety. The literature shows that, in complex environments, leaders have to guide the emerging dynamics by developing team members' cognitive capacities and designing flexible organizational structures. The findings from previous research need to be adapted to the specificity of high-risk organizations, which require leaders to simultaneously maintain regulated and managed safety. It is therefore necessary to explore the interplay between the mechanisms of leadership influence and those of the safety management.

Chapter 1 highlighted an important safety management tension that needs to be resolved: the need for jointly developed regulated safety (to handle predictable events) and managed safety (to handle unpredictable events). This is not straightforward and requires tomaintain a balance between stability and change, at both the structural and the cognitive levels. The literature review in Chapter 1 identified some safety management mechanisms to manage these challenges and achieve balance between managed and regulated safety and their mutual reinforcement (Figure 2.5).

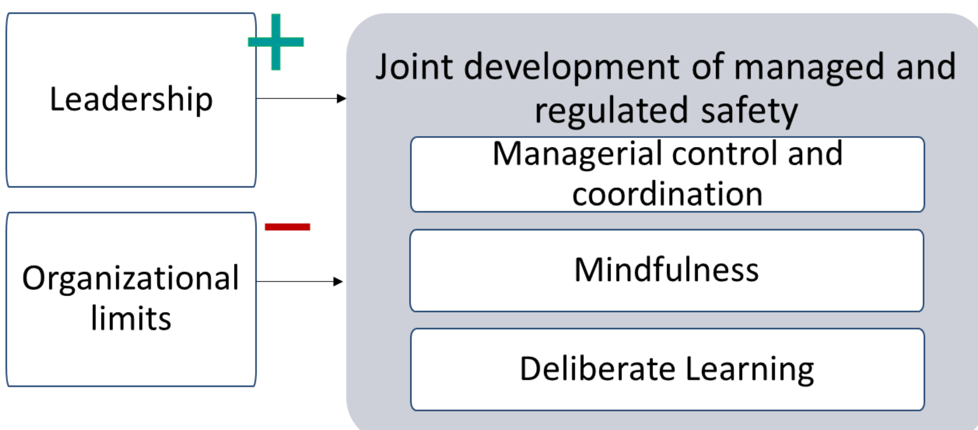

Figure 2.5. Mechanisms of joint development of managed and regulated safety (a reminder)

Managerial control and coordination, mindfulness and deliberate learning aim allow high-risk organizations not to trade-off, but rather to intertwine and jointly develop managed and regulated safety. The activation of these mechanisms can be mitigated or even prevented by organizational limits and negative consequences of exceeding such limits. At the same time, the literature increasingly emphasizes the need to better understand the role of leadership to enable and support the activation of these mechanisms. This role is especially crucial because of the existence of the organizational limits.

In Chapter 2, we developed a framework to elucidate the leadership influence mechanisms. In this doctoral research, we propose to apply this framework to explore how leadership can influence safety management. We are particularly interested in understanding how leadership can favour the activation of the mechanisms that allow to jointly develop managed and regulated safety.

At the end of the two first chapters, we conclude that all leadership mechanisms – sensegiving, motivating, trust and learning – are important to resolve safety management challenges. First, leadership aims to influence followers to comply with systems of managerial control and coordination. This compliance relies on an understanding of rules and routines and on trust. The more complete the understanding of rules and routines, the more positive will be the engagement with them (Grote, 2007; Grote et al., 2009; Hale & Borys, 2013b). The literature also refers to the importance of leader-follower trust for safety compliance (Vogus & Sutcliffe, 2011), but does not clearly explore the ways to activate this mechanism.

Second, the literature emphasizes the part played by leadership in the development of individual and collective mindfulness (e.g., Atkins, 2008; Burton & Vu, 2020; Fiol & O'Connor, 2003; Weick & Roberts, 1993; Williams et al., 2017), but calls for more research to achieve a better understanding of how mindfulness can be developed in high-risk organizations (Atkins, 2008; Kudesia et al., 2020; Williams et al., 2017). Previous work describes the role played by sensegiving: leadership sensegiving accompanies interpretation of the situation, based on noticing and understanding weak signals and deviations from planned situations (Barton et al., 2015; Barton & Sutcliffe, 2009; Katz-Navon et al., 2020; Weick & Sutcliffe, 2015). In this perspective, leadership sensegiving enables followers to embrace uncertainty to enrich their interpretations (Kudesia & Lang, 2020; Levinthal & Rerup, 2021) and develop mindfulness to improve safety. Some studies also refer to the impact of motivation on safety consciousness (Barling et al., 2002).

Third, the literature suggests that the construction of meanings about the focal situation relies on the actors' knowledge (Levinthal & Rerup, 2021; Maslach et al., 2018). Thus, learning is essential to develop and enrich models. In high risk sectors that make limited use of trial-and-error learning (La Porte & Consolini, 1991; Weick et al., 1999), learning must be deliberate (Zollo & Winter, 2002). In this context, leadership learning empowers followers to reach, develop and share knowledge (Sosik et al., 2004) on safety and develop interpretations of unusual events (T. E. Beck

& Plowman, 2009). Thus, leadership learning is important for the development of *mindful sensemaking*. Facing the unpredictable events, sensemaking disruption occurs when the whole system becomes irrational and disordered, and the structure is lost (Weick, 1993). Erroneous sensemaking processes, under pressure, can amplify crises (Hannah et al., 2009; Weick, 1988). Leaders perceive, make sense of and proactively address ambiguities by influencing meanings (Grote, 2019; Hannah et al., 2009; Jansen et al., 2016; W. K. Smith & Lewis, 2011; Vogus et al., 2010). In contexts of uncertainty, leaders provide support, role clarity and coordination, and set priorities (Hannah et al., 2009, p. 912) that reflect the priority of safety (Epitropaki & Turner, 2020; Zohar & Luria, 2003). Thus, learning and sensegiving are two mechanisms, which interact to develop mindfulness (Carroll et al., 2006; Levinthal & Rerup, 2006, 2021).

Our literature review shows that, while all leadership influence mechanisms are important for the activation of safety management mechanisms, sensegiving seems to be crucial in terms of how it interacts with the three mechanisms of joint development of regulated and managed safety. Sensegiving mechanisms emerge as preeminent in the resolution of the key safety management challenges.

In response to calls for more research on causal explanations of leadership and its impact on safety (Barton & Sutcliffe, 2009; Clarke, 2013; Epitropaki & Turner, 2020; Katz-Navon et al., 2020; Pilbeam, Doherty, et al., 2016; Zohar, 2010) and the impact of leadership on mindfulness (Atkins, 2008; Fiol & O'Connor, 2003; Kudesia & Lang, 2020; Ray et al., 2011; Weick et al., 1999; Williams et al., 2017) to develop resilience (Grote, 2019; Williams et al., 2017), we suggest interesting to start by exploring the mechanisms of sensegiving (Barton et al., 2015, 2020; Barton & Sutcliffe, 2009). The interactions between safety management and leadership mechanisms, including sensegiving, are complex and depend on the organizational and situational contexts. The activation of each of leadership mechanisms can affect their interaction and have different impacts, to different extents, on each safety management mechanism. We believe that this complex interplay requires further investigation.

2.4.Conclusion of Chapter 2

In Chapter 2, we demonstrated that the concept of leadership is used in a range of contexts (Bedeian & Hunt, 2006). However, in this research, we consider leadership **as a process of influence** (Day, 2000; Fischer et al., 2017; Parry, 1998; Yukl, 2013). Research on leadership as a process tends to focus on practices related to organizational dynamics, rather than traits or individual behaviours and that, "*rather than looking for leadership in people, we need to look for leadership in organizational practice*" (Denyer & Turnbull, 2016, p. 264). We add to this line of research and highlight the need to examine **leadership as an organizationally embedded influence process, rather than a set of personal traits or behaviours of leaders**.

A processual approach to leadership highlights that the direct effect of the leader on the organization can be overestimated (Dinh & Lord, 2012) and points to the need **to explore and to explain the underlying mechanisms related to leadership practices and organizational outcomes** (Batistič et al., 2017; Dinh & Lord, 2012; Hannah et al., 2009; Hazy & Uhl-Bien, 2015; Hernandez et al., 2011; Oc, 2018; Osborn et al., 2002). In this chapter, we highlight the lack of conceptual clarity concerning the mechanisms of leadership. For example, even some of the most recent research, confuses observable leadership practices (M. A. Griffin & Hu, 2013) with invisible mechanisms explaining the effects of these practices.

Leadership, defined as a process of influence, requires an understanding of how leaders influence, what they influence and why. In this thesis, we study leadership in complex and uncertain environments, where safety is a crucial organizational goal. Leadership is highlighted as essential to improve safety in high-risk organization (Christianson et al., 2009; Clarke, 2013; Inness Michelle et al., 2010; Katz-Navon et al., 2020). We have underlined that the stream of work on leadership for safety, follows the same evolution from leader-centric to more processual perspectives as the research on leadership in general. Therefore, **leadership for safety should be considered as a process of influence offering a way to meet the safety management expectations.**

The processual perspective on leadership for safety involves exploration of the underlying mechanisms explaining the relation between the leader's actions and organizational safety performance. To understand the impact of **leadership for safety, we need to better understand**

the interplay among the generative mechanisms of leadership influence, and its effect on safety management success.

The search for leadership mechanisms in general and, leadership for safety mechanisms in particular, is challenging due to lack of conceptual clarity about the underlying mechanisms. **Therefore, we chose a critical realism approach which allows to explore these underlying mechanisms.** This exploration involves an interpretation of the literature with a focus on the causal relations that explain observable practices. This in turn requires causal mechanisms to be distinguished from contexts and structure, to enable a fuller understanding of leadership in a specific context (Dinh et al., 2014; Hannah et al., 2009; Hofmann et al., 2017; Oc, 2018; Osborn et al., 2002). A critical realist approach conceptualizes the **interrelations among** non-observable mechanisms and **other observable elements (such as contexts, practices and structures).** It also allows for their integration in a coherent multi-level framework, which **will guide our empirical investigation of leadership and safety, and the role of leadership in the joint development of managed and regulated safety** (see Figure 2.6).

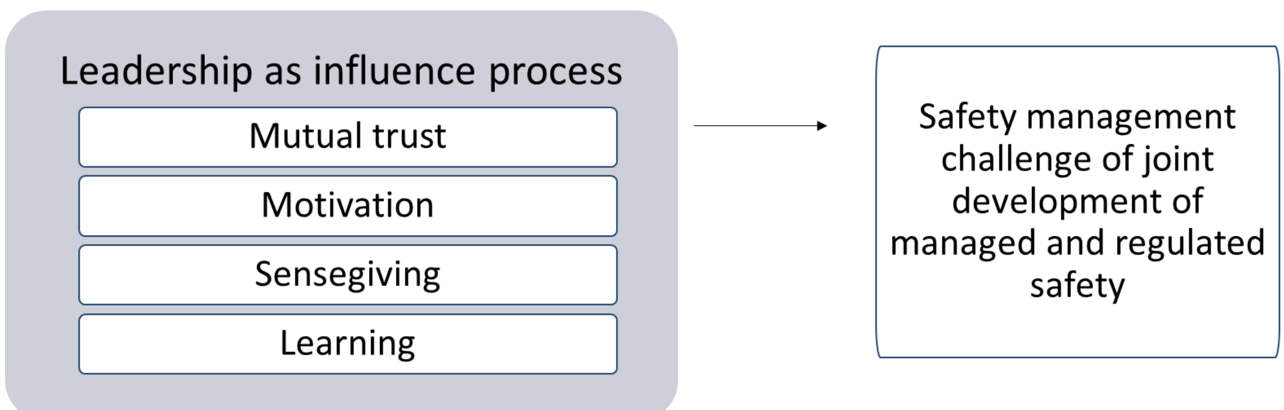

Figure 2.6. Mechanisms of leadership influence to study leadership for safety

Chapter 1 highlights the elements identified in the academic literature that might be interpreted as mechanisms of safety management to face the key challenge of the joint development of managed and regulated safety. We ask then how leadership enables the activation of these mechanisms in day-to-day activities in high-risk environments?

The concept of leadership for safety requires further theoretical development and investigation of the mechanisms that allow leadership influence to achieve safety management objectives in high-risk operations (Clarke, 2013; Pilbeam, Davidson, et al., 2016; Zohar, 2010). Following the view on mechanisms, developed in Chapters 1 and 2, we can specify the research question as following:

> **How, in daily activities, are leadership mechanisms activated and combined with safety management mechanisms to respond to the challenge of a joint development of managed and regulated safety without exceeding organizational limits?**

Figure 2.7 depicts this research question. Chapter 2 Section 2.3.3 discusses the important role of sensegiving.

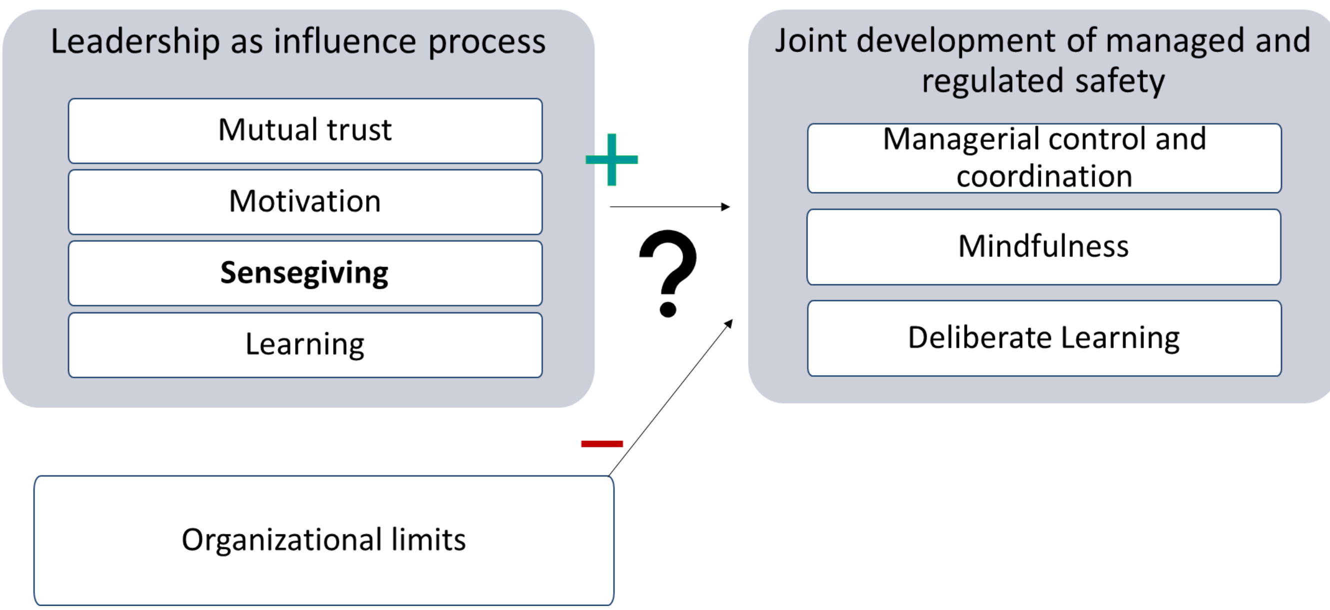

Figure 2.7. Research question on leadership for safety role for joint development of regulated and managed safety

Following chapter present our empirical study addressing the research question.

3. Epistemological framework and methodology

Before starting this doctoral research, we first considered an epistemological framework in which it will be carried out. We chose critical realism; this choice guided both our literature analysis and empirical investigation for our case study.

Chapter 1 reviewed the literature on safety management and identified the main problems related to the joint development of regulated and managed safety. The literature review also identified the elements that could be interpreted as generative mechanisms favouring this joint development. Since leadership is considered to be the most important enabling factor in the context of this challenge (Clarke, 2013; Pilbeam, Davidson, et al., 2016; Zohar, 2010), in Chapter 2 we reviewed the leadership literature, exploring both leadership practices and the underlying leadership mechanisms that allow to influence people. Chapters 1 and 2 adopt a critical realist lens, aimed at differentiating among events, structure and mechanisms (stratified reality) and focusing on mechanisms capable, under specific contextual conditions, of explaining the observed events. Our literature analysis led to the following research question: **How, in daily activities, are leadership mechanisms activated and combined with safety management mechanisms to respond to the challenge of a joint development of managed and regulated safety without exceeding organizational limits?**

To address this question, we conducted a critical realism-informed explanatory case study (Avenier & Thomas, 2015; Tsoukas, 1989). We studied a European nuclear energy operating company, which for reasons of confidentiality, we call ATOM. The context of ATOM, which operates in a high-risk environment, is particularly suited to our research question. We selected a unit within ATOM, which expressed a need for safety improvements.

The case study is conducted within a critical realist epistemology (Bhaskar, 1978), particularly adapted to the exploration of complex phenomena and recognizing the existence of non-deterministic causality, reflected by generative mechanisms. These generative mechanisms, which are activated or not, depending on the context, explain observable events (Fleetwood, 2014; Mingers, 2004; Mingers & Standing, 2017). Even if abduction is the preferred mode of reasoning of critical realist research (Bhaskar, 1978; Kempster & Parry, 2011; Mingers et al., 2013; Mingers

& Standing, 2017; Wynn & Williams, 2012), in our research we used a combination of induction and abduction.

In the remaining part of Chapter 3 we first provide an overview of the research setting, the context of the nuclear energy sector and the organization studied (Section 3.1). Second, we explain our epistemological and methodological choices and describe the methodology including data collection and analysis (Section 3.2).

3.1.Research setting

In this section we describe the research setting of our empirical study. First, we present the nuclear energy sector context in general (3.1.1), including the evolution of its preoccupations and a growing focus on leadership for safety. Second, we present a project of leadership for safety education, funded by the European Union, and discuss its implications for the present research (3.1.2). Third, we present ATOM and justify our choice of this empirical case (3.1.3).

3.1.1. Nuclear sector: a salient an example of a high-risk industry

3.1.1.1. Context of the nuclear sector

Nuclear power is one of the sources of electricity. It involves nuclear reactors, which produce heat (thanks to chain reaction of nuclear fission) that heats the water to produce steam, which powers the turbines and generates electricity. While nuclear fission has a range of applications including in research, medicine, agriculture, the arts, etc., and requires a complex industrial infrastructure related to the mining of uranium, production and transport of nuclear fuel and management of radioactive waste, in this doctoral research we focus on its application in light water-cooled reactors for the production of electricity. The World Nuclear Association (2021e) estimates that, in 2021, nuclear power accounted for around 10.3% of world electricity production. The European nuclear industry is particularly well-developed and accounts for around half of Europe’s low-carbon electricity (FORATOM, 2021); 14 of the 27 European Union member states produce electricity from the nuclear source, which represents 25% of Europe’s electricity supply (FORATOM, 2021). For example, in January 2021, France derived about 70% of its electricity from the nuclear energy and, despite a government policy to reduce this amount to 50% by 2035, had a total of 56 operable reactors (World Nuclear Association, 2021c). Belgium generates about half of its electricity from seven reactors (World Nuclear Association, 2021b) and Hungary, Slovakia, Sweden and Switzerland produce around half of their electricity from nuclear. In Bulgaria, Finland, Slovenia and the Czech Republic nuclear energy production represents about third of their supply (World Nuclear Association, 2021a).

The nuclear industry ecosystem of relations is extremely complex and includes a diversity of stakeholders at different levels. Production of energy from nuclear source requires a large institutional, human and physical infrastructure to license, construct, operate and regulate the construction and operation of the Nuclear Power Plants (NPP). In turn, this requires government commitment to maintain these infrastructures, to ensure effective, sustainable and safe performance. The overall complex infrastructure establishes the nuclear power programme processes and capabilities including nuclear safety, management, the legal and regulatory framework, human resources development, radioactive waste management, etc.

Figure 3.1 depicts the main stakeholders in the nuclear power industry and their interactions. Each actor plays a specific role and each actor's responsibilities evolve as the programme develops.

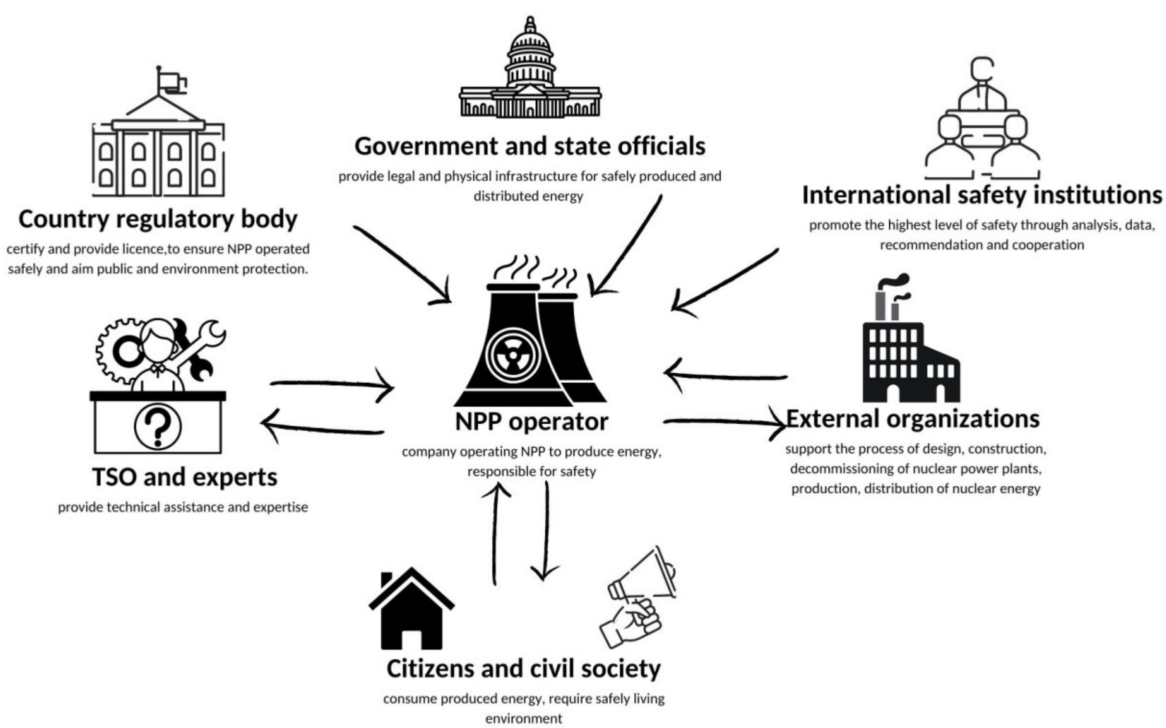

Figure 3.1. The organization of the nuclear sector

The following actors are usually involved in supporting the sustainable development and implementation of nuclear programmes:

- the **NPP operator** operates nuclear reactors to produce nuclear energy using turbines and generators. The NPP operator is primarily responsible for safety;
- countries with NPPs have one or several **regulatory bodies** that certify and licence the NPPs to ensure safe operation and protection of the public and the environment (World Nuclear Association, 2021d). European regulatory bodies include the Nuclear Safety Authority (ASN) in France, the Federal Agency for Nuclear Control (FANC) in Belgium, the Nature Conservation and Nuclear Safety (BMU) in Germany, among others;
- **government and state officials** (such as specific ministries, agencies, councils, commissions, etc.) are responsible for nuclear policy and provision of the necessary legal and physical infrastructure required for the safe production and distribution of nuclear energy;
- **international safety institutions** (such as International Atomic Energy Agency (IAEA), Nuclear Energy Agency (NEA), World Association of Nuclear Operators (WANO), Institute of Nuclear Power Operations (INPO), etc.) promote the highest levels of safety by conducting data analysis and providing recommendations and encouraging cooperation;
- **Technical Support Organizations (TSO) and experts** provide technical assistance, evaluation and harmonization, expertise, research on safety and radiation protection and scientific cooperation and services. Some examples of TSOs are Radioprotection and Nuclear Safety Institute (IRSN) in France, Bel V in Belgium and Gesellschaft fuer Anlagen- und Reaktorsicherhe (GRS) in Germany;
- multiple **external organizations** are involved in the design, construction and decommissioning and of NPP, the production and distribution of nuclear energy, and management of nuclear waste;
- **citizens** consume the energy produced and demand a safe living environment.

A Nuclear Energy Programme Implementing Organization (NEPIO) ensures that efforts are coordinated and emphasizes the importance of sharing information and knowledge among the actors (IAEA International Atomic Energy Agency, 2019). The nuclear sector involves intense international exchanges among the members of the international nuclear energy community, in order to share best practice and, on this basis, establish high standards for safety, security, non-proliferation and environmental conservation. Table 3.1 lists some of the many international institutions, associations and agencies that work to control, promote and support safe nuclear power operations.

Table 3.1. Main international safety institution organizations of the nuclear sector

Name	Mission	Site
Public institutions		
International Atomic Energy Agency (IAEA)	IAEA is the world's central intergovernmental forum for scientific and technical co-operation in the nuclear field. It works for the safe, secure and peaceful uses of nuclear science and technology, contributing to international peace and security and the United Nations Sustainable Development Goals.	http://www.iaea.org/
OECD Nuclear Energy Agency (NEA)	NEA is a specialized agency within the Organisation for Economic Co-operation and Development (OECD), an intergovernmental organization of industrialized countries, based in Paris, France	https://www.oecd-nea.org/
International Energy Agency (IEA)	The IEA is at the heart of global dialogue on energy, providing authoritative analysis, data, policy recommendations, and real-world solutions to help countries provide secure and sustainable energy for all. The IEA's four main areas of focus are: energy security, economic development, environmental awareness, and engagement worldwide.	https://www.iea.org/
Non-governmental organisations		
World Nuclear Association (WNA)	WNA promotes a wider understanding of nuclear energy among key international influencers by producing authoritative information, developing common industry positions, and contributing to the energy debate.	https://www.world-nuclear.org/
FORATOM	FORATOM acts as the voice of the European nuclear industry in energy policy discussions with EU Institutions and other key stakeholders.	http://www.foratom.org/
Institute of Nuclear Power Operations (INPO)	A not-for-profit organization headquartered in Atlanta (USA). Mission: to promote the highest levels of safety and reliability – to promote excellence – in the operation of commercial nuclear power plants.	http://www.inpo.info/
World Association of Nuclear Operators (WANO)	WANO unites every company and country in the world with an operating commercial nuclear power plant to achieve the highest possible standards of nuclear safety.	http://www.wano.info/
World Energy Council (WEC)	WEC is the principal impartial network of leaders and practitioners promoting an affordable, stable and environmentally sensitive energy system for the greatest benefit of all.	http://www.worldenergy.org/

Due to its high-risk activity and its potential for major effects on public health and the environment, the nuclear sector is heavily regulated and controlled. Thus, nuclear safety is a core concern: “*The main goal is that the radiological impact on people and the environment from nuclear installations remains as small as possible for both normal operation and potential accidents*” (Nuclear Energy Agency, 2020). Therefore, all actors at all stages in a nuclear facility’s lifetime (from design to decommissioning) put in place technical and organizational safety measures. Continuous safety improvements allow the nuclear energy industry to be considered reliable – the World Nuclear Association report mentions that an “*independent analysis of the fatality rate of the full lifecycle of various energy sources (including renewables) has confirmed that nuclear power is the safest form of energy ever used when measured such as deaths per TWh [terawatt-hour, a measure of electrical energy] generated*” (World Nuclear Association, 2020, p. 11). The nuclear sector continuously monitors and enhances safety by integrating research advances and by developing internationally shared industry practices such as peer reviews, auditing and control (Hamer et al., 2021). International safety institutions aim to establish and control the implementation of sets of safety standards covering all activities related to the operation of nuclear reactors.

3.1.1.2. Evolution of standards: towards leadership for safety

Standards are the result of international consensus providing a common, generally accepted, framework of norms. This consensus is required to ensure the representativeness and applicability of standards in all settings and for all related activities worldwide.

One of the most important international regulators is the International Atomic Energy Agency (IAEA), which acts as the auditor of the world nuclear safety. It prescribes safety procedures and follows up incident and accident reporting. IAEA safety standards serve as a basis for legal instruments and countries apply and adopt their national regulations accordingly.

IAEA safety standards reflect an international consensus on what constitutes a high level of safety to protect people and the environment from the harmful effects of ionizing radiation. The IAEA Safety Standards Series, which is based on practical experience, provides information on regulatory and operational aspects of nuclear radiation, transport, and waste, in the context of safety for protection of health and the environment and minimization of danger. There are three levels of safety standards, which have different value or weight in relation to safety and protection from radiation: safety fundamentals (strategic objective and principles), safety requirements and safety guides. The first safety standard ("Safety Handling of Radiosotopes") was published in 1958; since then, more than 400 standards have been created and regularly updated (IAEA, 2010). Since the Fukushima accident in 2011, around 89 new standards have been issued (IAEA, 2022).

Nuclear standards are created and updated constantly as nuclear sector knowledge and practices evolve. Interestingly, this evolution is accompanied by the change in how accident risks are treated over time by the actors in the sector (Goumri, 2021).

During the 1950s and the 1960s, safe design of the nuclear facilities was the main focus (Tanguy, 1988). The defence-in-depth approach, requiring safety systems to supplement the natural features of the reactor's core, were introduced. This highlights the initial perception of accident risk as a "hypothetical accident", imagined by the reactor's designers and prevented by multiple means to make it non-credible, if not physically impossible (Goumri, 2021).

In the late 1960s and the 1970s, the focus shifted to safe construction of nuclear facilities and quality assurance. The benefits of the probabilistic approach to safety were underlined in reports and standards issued during this period. After the 1970s, perceptions of accident risk evolved towards "contained accidents" or the idea that should a core meltdown disaster occur, it could be contained using technical means that would contain dispersion of toxic radionuclides in the environment and avoid catastrophic consequences (Goumri, 2021).

The 1980s were marked by an emphasis on safety in operations. The Three Mile Island (TMI) and Chernobyl accidents highlighted the importance of operating procedures, reporting, learning and improvements to human-machine interfaces, and use of Probabilistic Safety Assessment (PSA) tools. New operator training and licensing requirements were introduced. The efforts during this period were focused on accident prevention and operational safety, based on accident mitigation and monitoring networks.

The contemporary perception of accident risk in the nuclear industry is one of "major accident" (such as Chernobyl or Fukushima Daiichi). It assumes that a catastrophic accident is plausible, and the focus is on means to "limit the consequences of the accident, despite the radical uncertainty, which (paradoxically) is reinforced by the progress of knowledge" (Goumri, 2021, p. 4). In more recent decades, there is evidence that major accidents are caused mostly by human and organizational issues. Thus, the current emphasis in the international nuclear community is on the acknowledgment of the limitations of technical barriers to face the inherent uncertainty and the importance of organizational factors such safety culture (INSAG International Atomic Energy Agency, 1991), administrative and management requirements (IAEA, 1996). International safety standards reflect this evolution. The Fukushima Daiichi accident shifted the focus to the importance of demonstrating a safety culture, commitment and leadership for safety.

Leadership for safety has progressively entered safety standards. Starting in 2000, although the importance of leadership and management for safety was highlighted in some standards, these aspects remained defined mainly by the development, implementation and maintenance of a strong safety culture (IAEA 2009). The IAEA and its member states recognized the importance of safety leadership and included it in the frame of its fundamental safety principles. General Safety Requirement GSR Part 2 "Leadership and Management for Safety" was published in 2016 and is in line with the fundamental safety principle that "*effective leadership and management for safety must be established and sustained in organizations concerned with, and facilities and activities that give rise to, radiation risks*" (International Atomic Energy Agency, 2016, p. 2). According to the IAEA, leadership for safety, management for safety, an effective management system and a systemic approach are essential to develop a strong safety culture and relevant safety measures (International Atomic Energy Agency, 2016). In particular, leadership for safety is understood as individual capabilities and competences to influence followers and their commitment to safety principles and achievement of safety objectives. The document emphasizes three complementary concepts upon which demonstration of safety leadership is based: ability to define and attain safety objectives; the values and attitudes underlying leader-manager actions (safety culture); and leader-manager commitment to safety.

However, the foreword to the safety requirement on leadership for safety states that "*standards are only effective if they are properly applied in practice*" (International Atomic Energy Agency, 2016, p. v). Therefore, in 2016, the IAEA General Conference adopted a resolution calling for the development of specific training on the topic of safety leadership. This responded to pressing needs in several countries including those in the process of developing their nuclear sector and those wishing to reinforce safety approaches related to other applications of ionizing radiation, particularly in the medical sector. The first training course, Pilot International School of Nuclear and Radiological Leadership for Safety, was mainly aimed at executives in organizations that conducted nuclear or radiological activities, and was held at the Université Côte d'Azur, Nice, in November 2017. It was organized jointly by the IAEA and the European Nuclear Safety Training and Training Institute (ENSTTI), with financial support and sponsorship from the European Union. The Université Côte d'Azur was chosen by the team of experts advising the IAEA on this project, due to the interest and expertise in its management school component in cooperation with the French institute for nuclear safety and radiation protection (IRSN). The expertise of the Université Côte d'Azur was in issues related to management in the nuclear sector, particularly in the field of knowledge management in nuclear safety. Later, this pilot training was complemented with a new European Leadership for Safety Education (ELSE) project. The pedagogical objectives of the ELSE project were coupled with a present PhD research project on leadership for safety.

3.1.2. European Leadership for Safety Education (ELSE) project

3.1.2.1. Project objectives and implementation

On this basis of the Pilot School of Nuclear and Radiological Leadership for Safety and considering the high level of interest expressed by many countries for such training, the European Union, within the framework of its Instrument for Nuclear Safety Cooperation (INSC), has decided to further develop actions in this field, for example, by financing the ELSE project. The project is managed by the University Nice Côte d'Azur with the support of two partners: the European Nuclear safety training and Tutoring Institute (ENSTTI) and the European Nuclear Education Network (ENEN).

The ELSE project aims to develop an innovative science-based approach to advanced education in the domain of leadership for safety. In order to be able to respond in a sustainable manner, the project brings together management schools and technical universities specialized in education for the nuclear sector in order to provide an innovative professional training. The originality of the ELSE project is that it offers the first in the world Master-level diploma related to leadership skills in a heavily regulated industry such as nuclear sector. No such diploma exists so far in Europe or elsewhere.

The ELSE project started on the 1st of September, 2019 and runs to the summer of 2023. Its objectives were defined as follows: 1) to develop a certified university diploma in the field of safety leadership based on up-to-date scientific knowledge and best practices; 2) to conduct a first training session with a promotion of up to 25 nuclear sector professionals from INSC and European countries (September 2022-June 2023); 3) to establish the basis for a sustainable development of leadership for safety education by developing dedicated Master module for a network of "implementing European Universities". This last point involves designing a free MOOC for a worldwide reach and creating an international and multidisciplinary network of academics and experts in the field of leadership for safety (ELSE Project, 2021).

3.1.2.2. Scientific Workshop

The ELSE project's first objective is the development of a training program based on state-of-the-art knowledge of academic researchers and nuclear industry experts. The design of this innovative ELSE training curriculum began with a scientific workshop, which was held in January 2020 in Nice (France) and included a total of 35 participants (22 researchers from 15 universities and management schools and 13 experts from 11 international institutions - 21 men and 14 women) with expertise in leadership, organizational dynamics, knowledge management, psychology, sociology, risk management and engineering. Appendix 1 summarizes details of the expertise, institutions and countries of workshop participants.

The workshop was held over three days with an agenda developed based on the responses to a pre-workshop survey competed by all the participants. It asked about the characteristics of leadership for safety, the main problems, efficient ways of dealing with risk, important future research, etc. (ELSE Workshop Scientific Report, 2020), to identify the three most relevant themes (safety culture and climate, risk assessment and resilience, and uncertainty and mindfulness) and subthemes, related to the notion of leadership for safety (see Table 3.2).

Table 3.2. Structuring ELSE workshop's themes and subthemes

Themes	Subthemes
1 - Safety culture and climate	1A - Importance of safety culture and climate 1B - Safety culture in the nuclear sector 1C - Safety as a social construction
2 - Risk assessment and resilience	2A - Ethics and management of contradictions 2B - Resilience and organizational limits 2C - Reporting and knowledge management
3 - Uncertainty (dealing with) and mindfulness	3A - Rules and uncertainty 3B - Psychology to deal with uncertainty 3C - Safety mindfulness and meta-cognition

The workshop took the form of a structured conversational process of knowledge creation within a safe communicative space, in which groups of participants discussed specific topics (Tanner, 2019). The workshop was designed as a two-stage co-construction process. The participants were split into three working groups, each moderated by two members of the ELSE team (1 academic and 1 practitioner). Each of the groups worked in parallel, on the same theme, but from a different perspective, in line with the participants' domain of expertise. After a short presentation of the state-of-the-art subthemes, over a period of two hours, the groups addressed two main issues: the potential tensions and relationships between the discussed topic/concept and the implications for safety practice and research. In the debriefing session, the participants met together to share their results. This process is depicted in

Figure 3.2 and was repeated for each theme.

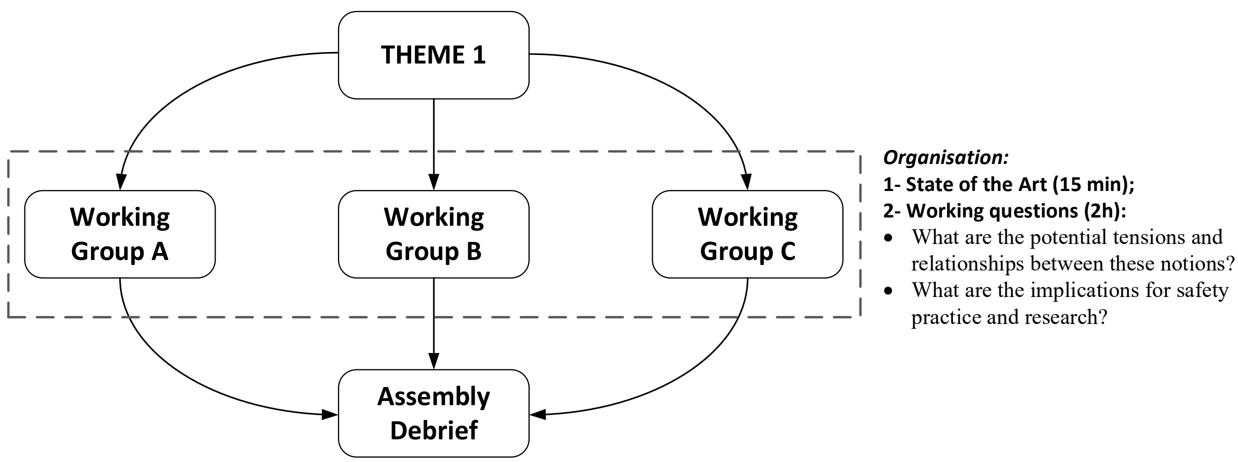

Figure 3.2. Illustration of the co-creation process for Theme 1 during ELSE workshop

This workshop served a dual purpose: it helped identify the state-of-the-art knowledge on the topic of leadership for safety, and it brought together scientists from a range of disciplines with nuclear sector actors.

3.1.2.3. Interaction between ELSE project and the doctoral research

This doctoral thesis and the ELSE project are closely interrelated. The doctoral research started in October 2017 and followed the preparation and launch of the ELSE project in September 2019 and its progressive implementation. The Université Côte d'Azur is the lead applicant of the project. Research team of this doctoral research (PhD candidate and PhD supervisors) are members of the

ELSE project team. The two PhD supervisors are involved in the management of the ELSE project: Professor Catherine Thomas is Project leader and Professor Renata Kaminska is the project's Key-expert. The PhD candidate is also actively involved in all project implementation steps and, since October 2020, as the ELSE project Research and Training assistant. This direct involvment was very valuable for the doctoral research.

First, our involvement in the ELSE project provided access to a specific nuclear sector safety community. The doctoral candidate's involvement began at the yearly design stage and included interacting with ELSE partners from well-known nuclear sector institutions. The interactions with nuclear safety experts continued throughout the organization of and participation in the ELSE scientific workshop. Moreover, the inclusion in the ELSE recruitment committee reinforced our understanding of and our presence within the nuclear safety sector community.

Second, sustainable relationships with nuclear sectors actors, established during the project, allowed an understanding of and access to the field for empirical research. Notably, some of the nuclear sector experts involved provided the researcher with access to representatives of the NPP company ATOM, which is the context of the case study. This recognition from the practitioner community was essential to build confidence in the doctoral project and allow the PhD candidate's access to a traditionally confidential and closed field.

Third, commitment of the PhD candidate and the PhD supervisors to the ELSE project allowed access to the academic community working on leadership for safety and related subjects. More specifically, the ELSE scientific workshop allowed the forging of sustainable partnerships with renowned scholars. The numerous academic workshop participants agreed to be members of the ELSE pedagogical team. This collaboration continued through development of the ELSE MOOC and the ELSE training sessions.

Fourth, since the ELSE project is aimed at developing an innovative science-based approach to advanced education in leadership for safety, our participation allowed us to be aware about the interplay between research and training. In particular, our involvement in the project allowed us to experience innovative pedagogical methodology, which integrated the MOOC, face-to-face training, and individually tutored projects.

The downside to this significant involvement in the ELSE project was that finalization of this doctoral research was delayed. However, this was compensated by access to a complementary funding to continue research. In addition to a three-year doctoral contract with the French Ministry of Higher Education, Research and Innovation, the PhD candidate was employed as a Training and Research assistant of the ELSE project.

The doctoral research and the ELSE project development have been mutually enhancing. First, this doctoral research relies on the most up-to-date and relevant academic work, which is valuable for a scientific base for the ELSE training programme. The existing training for leadership often fails to reach its goal because of a number of managerial and organizational barriers that make it difficult to apply acquired knowledge in daily practices (Beer et al., 2016). This doctoral research tries to tackle this problem thanks to the findings from the ELSE scientific workshop. Specifically, this doctoral research inspires an innovative approach: it considers leadership as a process rather than a set of personal traits and acknowledges leadership as embedded in the broader organizational dynamics. We propose a processual approach to leadership for safety that emphasizes generative mechanisms, their activation and interactions. This reconceptualization of leadership is crucial to design an effective training in leadership for safety (K. Nielsen et al., 2010; Schwatka et al., 2020; Tafvelin et al., 2019). Our approach was approved by the community of the nuclear safety professionals and the European Nuclear Society (ENS) invited us to organize and animate a seminar on “Aligning leadership with organizational dynamics”, which was held online on 28 April 2022.

In addition, some of the results of this doctoral research have been implemented in the ELSE training programme. The in-depth literature review on safety management and leadership for safety, conducted in the frame of this doctoral research, allowed to conceptualize a definition of leadership for safety, structure the training curriculum and enrich some parts of the training modules. This is part of the managerial contribution of this study, outlined in Chapter 4.

3.1.3. The ATOM organization

3.1.3.1. Choice of ATOM and access to the field study

Our research focuses on the nuclear sector. The empirical analysis focuses on a European organization operating in the nuclear industry, we call ATOM for confidentiality reasons. ATOM operates multiple NPPs across Europe. Our choice of ATOM for the case study is based on several reasons. First, ATOM is a company operating nuclear power reactors and as such, functions in high-risk, complex and dynamic environments in daily manner. ATOM is an example of a high-risk organization seeking high reliability, that constitutes the focal interest of our research. Despite their considerable technological and regulatory efforts to control risk and cope with uncertainty, high-risk organizations, such as NPPs, are required to make additional efforts to develop the ability to jointly develop regulated and managed safety (Besnard et al., 2017; Morel et al., 2008).

Second, ATOM invests continuously in safety activities, based on technical progress, but also by enabling safety culture and organizational factors. In recent years, a particular attention is given to the leadership for safety development in relation with the recent standards (IAEA, 2016; WANO, 2019). ATOM is one of the world's largest producers of electricity and the leading nuclear operating company in Europe. Reliance on the best international standards and close collaboration to engage with best world practice, has allowed ATOM to develop nuclear safety. Its integration of the latestworld and European standards and regulations, has allowed several safety improvements and aims to enable the implementation of the best world practices in terms of safety.

Third, despite considerable advances in the development of nuclear safety during the last decades, ATOM continues to experience difficulties and acknowledges that there is 'room for improvement'. Despite all efforts, ATOM is preoccupated that some of its units – nuclear power plants (NPP) – show a deterioration of safety results.

Although the ELSE project facilitated access to the field, accessing nuclear operations was not straightforward and required multiple steps. We began by forging sustainable partnership relations with ATOM representatives, both at the corporate and unit levels. The research was presented at several meetings attended by ATOM corporate-level managers working on the safety culture issues. In June 2018, we were involved in conducting a safety culture evaluation (Alpha NPP) as a part of team of safety culture experts. The researcher was also a keynote speaker at an Operating Experience Seminar for top management in ATOM units, that was held in September 2018. The subject of the presentation was "Leadership for safety in a complex environment" and provided an opportunity to negotiate access to the field. Several unit directors were interested in a deeper investigation of the causes of the fall in safety results levels and the researcher was invited to conduct her study at the NPP unit Beta, during March and June 2019. At the end to the study, in October 2021, we were invited by Beta to present the preliminary results of this study at an internal seminar on safety culture and leadership for safety for Beta managers.

Overall, this doctoral project involved two of ATOM's units – NPPs (for confidentiality reasons named Alpha and Beta). Despite extensive and continuous efforts to improve safety, both units had been recently experiencing temporarily difficulty in maintaining their safety performance and this had been recognized and analysed by top-level management. The head of department admitted: "*we have difficulties, we are not at the expected level. This means that the organization does not allow everyone to be in the best dispositions to act safely" (Int06, head of Safety and Quality department).*

We approached the two cases in different ways. The Alpha case study provided a general view of ATOM's leadership for safety; the Beta case was analysed in more depth. Due to the complexity and specificity of the sector, which tends not to be accessible to non-professionals in nuclear power energy, the empirical study was conducted in two stages: 1) immersion and 2) in-depth case study. These stages are described in Sub-Section 3.2.2. explaining the data collection.

3.1.3.2. ATOM organization

At the international level, ATOM is part of the ATOM Group. The company is specialized in production and distribution of electricity, which involves international partners and affiliates. In addition to nuclear energy, which accounts for the majority of its power production, the ATOM Group produces energy from other renewable and fossil sources. The range of ATOM's activities is large, but the focus in this doctoral research is on nuclear energy production, managed by ATOM's Production and Engineering Division. ATOM has multiple NPPs, each of which operates several nuclear reactors.

The governance of ATOM's nuclear energy activities is depicted in Figure 3.3.

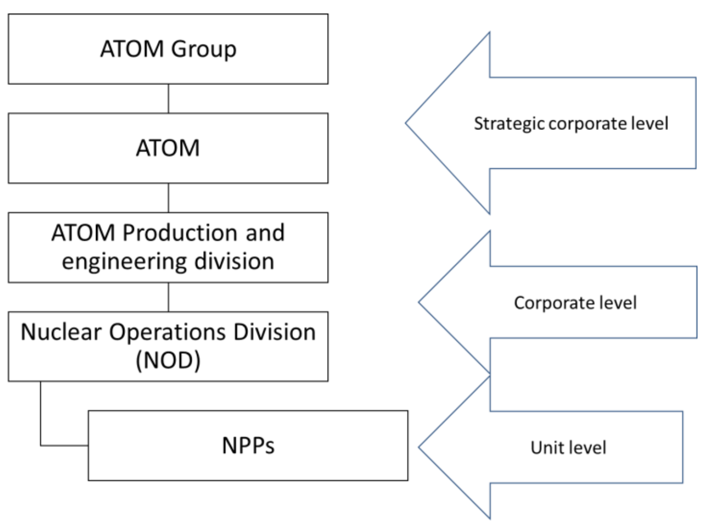

Figure 3.3. ATOM nuclear energy production management levels

At the corporate level, a division, which we call the Nuclear Operations Division (NOD), ensures the safe operation of fleet of nuclear production facilities. NOD has a specific role for safety, this division has responsibilities of strategic and operational management, monitoring and supporting fleet performance, standards compliance, elaboration of operational rules and procedures, support for the NPPs and steering of performances and management of operational feedback. For example, this division produces several corporate documents, such as, for example, a safety culture guide or a safety management guide.

At the unit level, the top management in each NPP ensures the operation and management of electricity production. NPP's management has operational and functional responsibilities related to safety. Operations are the responsibility of dedicated departments (such as operations department, electro-mechanical department, maintenance department, boiler and valve department, etc.). They are supported by the functional departments such as quality and safety services, human and organizational factors leads, an independent nuclear authority body, among others. The unit management has complex hybrid structure, with a vertical specialized hierarchy, projects (e.g., operating unit and shutdown unit's projects) and missions (such as technical and environment, safety quality, risk prevention, etc.).

3.1.3.3. ATOM organizational initiatives for safety

ATOM "*as a nuclear operator takes responsibility for nuclear safety and, in a rapidly-changing context (market competition, environmental issues, European connection, etc.), reaffirms as its absolute priority the protection of the human and environmental health, among other things, through the prevention of accidents and the limiting of their consequences as regards nuclear safety*" (ATOM universal registration documents 2021, p. 25). Drawing on the cumulative experience of its units, ATOM is committed to considering risks, complying with operational rules, establishing a good safety culture, encouraging and implementing continuous improvements and developing people's skills. In addition, ATOM nuclear safety is subject to internal and external monitoring at both the country (e.g., by the relevant regulatory body and TSO experts) and the international level (e.g., through the IAEA Operational Safety Review Team OSART, peer review by WANO, etc.).

To ensure that ATOM NPPs operate under optimal safety conditions, multiple measures are implemented at all levels. In addition to technological and regulatory advancement to achieve enhanced safety, for 30 years, ATOM has invested actively in the development of human and organizational factors. ATOM aims to develop managed safety and recognizes that *"compliance with the rule is necessary, but it alone does not guarantee performance*" (Doc 04, ATOM human performance document). Thanks to all the efforts in promoting safety, ATOM is recognized internationally as one of European leaders in terms of safety.

For this doctoral research, we focus more particularly on several organizational changes to enhance safety, introduced recently by ATOM at the corporate level. These include reliability enhancing practices (REPs), the weak-signal management system for operating experience (OPEX) and an integrated management system (IMS). REPs were introduced in the context of a human performance project conducted in 2006. REPs are a set of concrete practices designed to secure human intervention actions in real-time situations and to keep the actors' attention focused on what matters. The importance of analysing operations experience (OPEX) is also highlighted in the Human Performance project. In addition to the Human Performance project initiatives, ATOM introduced an integrated management system (IMS), a popular quality management concept that was implemented in nuclear industry legislation in 2012, "*to ensure that the requirements relating to the protection of the referred interests are systematically taken into account in all decisions concerning the plant"* (Legislation document). A more detailed description of these initiatives will be presented in section 4.1 of the Chapter 4. At the unit level, each NPP commits to implementing and complying with these initiatives.

All these initiatives were introduced to increase organizational capabilities for the development of better managed and regulated safety. These three organizational changes are focused on the development of individual and collective mindfulness. As discussed in Chapter 1, mindfulness allows to deal with unpredictable events by treating weak signals, but also to deal with predictable events by applying procedural barriers with intelligence. Despite the initiative implemented, the organizational units faced difficulties that intrigued us and motivated our research.

3.2.Research design

To address the research question, we employed a critical realism-informed explanatory case study method (Avenier & Thomas, 2015; Tsoukas, 1989). Thanks to rich and in-depth data, qualitative research allows to capture processual and contextual dimension of the phenomenon studied (Gehman et al., 2018; B. G. Glaser & Strauss, 1967, 2009; Strauss & Corbin, 1990, 1998). A Case study is a valuable method to explore our research question, allowing to explore in the depth a homogeneous case (Eisenhardt & Graebner, 2007; Siggelkow, 2007; Stake, 1995; Yin, 2018), "*especially when the boundaries between phenomenon and context are not clearly evident*" (Yin, 2018, p. 45).

The aim of an **explanatory** case study is to explore general, not case-specific explanations for what is observed, that is, to identify the mechanisms explaining the cause-and-effect relationship in the observed phenomenon. A c**ritical realism-informed approach** enriches the case methodology by enabling a particular focus on of causal powers – generative mechanisms – through the abductive approach (Kempster & Parry, 2011; Rowland & Parry, 2009). A critical realist lens allows to explore and reach a higher level of abstraction, which has a greater explanatory potential for the generated theory. In this perspective a potential, rare, contribution is to find new generative mechanism or more frequently to explain how these mechanisms are activated and interact each with others, but also with other elements of stratified reality (structure, practices, contexts) (Avenier & Thomas, 2015).

In what follows, we describe the critical realist epistemological framework and its methodological implications (Section 3.2.1), discuss the different stages in our data collection (Section 3.2.2) and present our data analysis process (Section 3.2.3).

3.2.1. Epistemological framework and methodological principles

3.2.1.1. Choice of critical realism

Management is a multi-paradigmatic science. The variety of epistemological approaches represent the richness of the implicit philosophy of knowledge (Van de Ven, 2007). Following Avenier and Thomas's (2015) categorization, we can identify four main paradigms: 1) positivism and post-positivism; 2) critical realism; 3) pragmatic constructivism; 4) interpretivism. Each paradigm is based on a set of coherent ontological and epistemological assumptions: ontological assumptions describe the nature of the reality, epistemological assumptions describe the nature of knowledge and means of its elaboration (Avenier & Thomas, 2015; Piaget, 1967).

In this doctoral research, we follow the epistemological paradigm of critical realism. A growing number of researchers argue that critical realism can provide a coherent and robust underpinning philosophy (Carlsson, 2007; De Vaujany, 2008; Fleetwood, 2014; Mingers, 2004;

Mingers et al., 2013). It was first developed by Roy Bhaskar (1978) as a philosophical and meta-theoretical approach (Fleetwood, 2014). It assumes the relativism of knowledge (epistemic relativism, including a transitive dimension), recognizing that knowledge is socially and historically constructed (Avenier & Thomas, 2015; Kempster & Parry, 2011). At the same time, this epistemological framework relies on a strong realist ontological assumption of the existence of a world, independent of knowledge (intransitive dimension). The main ontological principles of the critical realism approach (stratified reality, recursive causality, generative mechanisms) were discussed in Chapter 2 Section 2.3.1.

Several studies point to the suitability of the critical realist approach for management studies (Avenier & Thomas, 2015; Eriksson & Engström, 2021; Kempster & Parry, 2011; McAvoy & Butler, 2018). Our choice of the critical realism lens is based on 1) its recognition of the complexity of the social world; and 2) its bridging position between positivism and interpretivism.

Recognition of the complexity of the social world. First, as researchers, we are aware of the complexity of organizational life. In contrast with the positivist and post-positivist paradigms, aiming to construct and test hypotheses about the linear relationships, critical realism recognizes the non-linear and non-determinist causality. This focuses the research on discovering how generative mechanisms work and perform their causal powers. Chapter 2 Section 2.3 points out that through the identification of the solution to a persisting confusion in the literature between observable practices and non-observable, non-measurable, mechanisms, critical realism allows the discovery of generative mechanisms.

Critical realism suggests that the emergent causal power of mechanisms and structures should be explored, but in a non-deterministic way since the manifestation of this power depends on the contextual conditions (Tsoukas, 1989). Sayer (2002, p. 107) refers to *"the relationship between causal powers or mechanisms and their effects [that] is therefore not fixed, but contingent"*. The focus of study underpinned within critical realism is primary explanatory. Therefore, the aim of the research in critical realist perspective is to uncover mechanisms, structures and contextual conditions and their interactions, that are independent of, but cause the observed event patterns (Avenier & Thomas, 2015).

Bridging between positivism and interpretivism. Second, critical realism provides a strong theoretical framing. On the one hand, it acknowledges the existence of an independent reality that is stratified, and presents some regularities (Bhaskar, 1978). However, these regularities are not observable, but they exist in the deep real and take the form of generative mechanisms. Thus, similar to traditional positivist approach, a critical realist research searches for regularities. A critical realist conception of the world acknowledges the existence of more or less obvious causal powers, mechanisms and structures, capable of producing events that can be observed (Avenier & Thomas, 2015; Mingers, 2004; Mingers & Standing, 2017). On the other hand, critical realism accepts the relativism of constructed knowledge that is similar to interpretivism (Avenier & Thomas, 2015; Kempster & Parry, 2011). Critical realism admits that theoretical productions are socially and historically constructed. However, although it recognizes an epistemic relativism, it does not recognize a judgmental relativism. Once expressed, theoretical productions become available for investigation, and it is possible to eliminate alternative explanations by empirically testing their potential effects (Mingers, 2004). By occupying the intellectual space between positivism/post-positivism, on the one side, and interpretivism/constructivism on the other side (O'Mahoney, 2016), the critical realist paradigm resolves some long-standing theory-practice inconsistencies between positivism and interpretivism (M. L. Smith, 2006), especially inconsistencies about the nature of the causality in the social world.

3.2.1.2. Methodological implications of a critical realist approach

Research objectives. Our research aims to discover and understand how the generative mechanisms related to the studied phenomenon express their causal powers. **In the context of the existing knowledge, the aim is not necessary to discover new mechanisms, but rather to explore how the existing mechanisms are activated or blocked in different concrete contexts. This requires a fine-grained analysis of the empirical context to discover the interplay between non-observable mechanisms and observable practices and contexts.** In line with Kempster and Parry (2011), we believe that critical realism provides an epistemological framework able to capture the complexity of the studied phenomenon, in our case, leadership for safety embedded in complex organizational dynamics. In the context of this doctoral research, our objective is to understand how leadership mechanisms enable a joint development of managed and regulated safety. Therefore, following critical realist perspective, the objective is to explore how leadership practices activate or not leadership influence mechanisms and how these mechanisms interact with safety management mechanisms to generate observable results in terms of safety. In other words, the objective is to explore the relationships between causal mechanisms (unobservable), social structures (partially observable), context (observable) and leadership practices (observable) that explain how the organization performs more or less safe practices (observable).

Understanding the underlying mechanisms is particularly important in social sciences. It guarantees the production of actionable managerial knowledge. A critical realist representation of stratified reality underlines that generative mechanisms and structure exist independently and cannot be changed directly by leaders and managers. However, by acting (managerial and leadership practices) and by modifying the context (processes, organizational design, procedures, etc.), leaders and managers can activate mechanisms, which can produce the desired observable events. In the case of leadership mechanisms, leaders cannot modify, add or delete the existing mechanisms, such as trust or sensegiving, but through their practice, they can initiate or block the activation of these mechanisms. For example, an open conversation about a risky activity may enable activation of a trust mechanism that allows influence while recurrent blaming of a follower's errors might block the activation of the trust mechanism and impede influence.

Abduction and the DREI process. Critical realism suggests a coherent methodological approach, based on abduction. The role of abductive reasoning in organizational and management theorizing has been highlighted (Behfar & Okhuysen, 2018; Folger & Stein, 2017). Abductive reasoning allows to apply rigorous reasoning by considering competing explanations and alternative frames, on the basis of the empirical findings. This reasoning is aimed at increasing explanatory power and developing the 'best' explanation for the observed phenomenon (Behfar & Okhuysen, 2018; Harley & Cornelissen, 2022). Kempster and Parry (2011) suggest that a critical realist lens enriches grounded theory by searching for how mechanisms are activated to explain the observed events. The study should start with an accurate observation of events followed by abductive reasoning to identify the most convincing explanation, the one that is able to explain all the observed events (Bhaskar, 1978; Mingers et al., 2013; Mingers & Standing, 2017; Wynn & Williams, 2012).

Following the critical realist approach, the theoretical explanation follows the DREI process: **D**escribing the significant features of the events, **R**etroducing possible causes (i.e., generative mechanisms), **E**liminating possible alternative explanations (by comparing their capacities to explain observed events) and **I**dentifying the generative mechanisms at work (Avenier & Thomas, 2015; Bhaskar, 2008; Mingers et al., 2013; Wynn & Williams, 2012). Data on practices, social structures, contextual conditions and actors' accounts of why the practices under investigation took place, are collected (Avenier & Thomas, 2015; Tsoukas, 1989) in order to retroduce and then confirm, eliminate or add possible mechanisms.

The present study includes the following critical realist informed research stages:

- description of safety practices, difficulties related to their implementation and results obtained;
- description of leadership practices, difficulties related to their implementation and results obtained;
- description of structure (formal rules and processes, role and resource repartition, safety culture);
- retroduction (identification of the generative mechanisms that explain observed events, i.e., how safety management and leadership mechanisms interact with structures and contexts to explain implementation of safety practices. This involved interaction between the field analysis and the literature to consider whether the mechanisms emerging from the field have been identified previously in the literature or are new mechanisms;
- Empirical corroboration (ensuring the identified generative mechanisms provide a plausible and argued explanation of observed practices): ensuring that the findings explain all the observed events (leadership practices, safety practices, contextual elements, practice results).

Although we pay particular attention to the results emerging from the data, a critical realist approach is not just inductive. Critical realism retroduction implies a "*mode of inference in which events are explained by postulating (and identifying) mechanisms which are capable of producing them*" (Sayer, 2002, p. 107), based on an abductive process. This refers to identification of plausible explanations to account for the observed facts. Retroduced mechanisms may be present in existing scientific knowledge. Based on an iteration between the data analysis and the literature, critical realism seeks theories to support the empirical data analysis to find the abstraction of suitable mechanisms and the search for contextual effects (Kempster & Parry, 2011).

Integrative approach. Critical realism is integrative in character. More specifically, every proposition is considered as a possible explanation that could be eliminated thanks to the contribution of empirical studies (Mingers, 2004). Some academics outline the role of the literature review in a critical realist abduction process and consider existing theories in terms of a retroduction process that may offer guidelines to build hypothetical explanations of the investigated phenomenon (McAvoy & Butler, 2018): "*we use what we do know to explain what we do not know*" (Brannan et al., 2017, p. 24). To achieve abstraction, researchers may redescribe the components of the structural entities and their interactions from existing theories in order to propose potential explanations (Wynn & Williams, 2012). A wide-ranging literature review of studies done within any epistemological paradigm will be required to allow exploration of all possible explanations of similar mechanisms in different disciplines (Brannan et al., 2017). The underlying mechanisms might occur at different levels in different fields of human and social studies: for example, cooperation and control at the social level (Tsoukas, 1989), opportunism at the individual level (Miller & Tsang, 2010). In addition, critical realism offers a stratified view of reality, and selected elements of the existing literature should be reordered according to the level of analysis (practices and context, structure, mechanisms). The application of abductive reasoning in a critical realism approach invites the researcher to integrate diverse theories into a coherent theoretical framework and avoids dispersion by encouraging cumulative science (Brannan et al., 2017; M. L. Smith, 2006; Wynn & Williams, 2012).

For example, drawing on work on safety management, HROs and resilience, Chapter 1 identified the elements that could be interpreted as safety management mechanisms enabling the joint development of managed and regulated safety. In Chapter 2 we studied leadership and distinguished leadership mechanisms from leadership practices (see Figure 2.4).

3.2.2. Data collection

Collecting data about the nuclear sector is problematic for at least two reasons. First, access to the NPPs it is difficult. Despite professing transparency and a long history of research partnerships, NPP top management usually prefers not to disclose details about internal organizational processes to external researchers. In our case, the ELSE project experts allowed us to scale these barriers and helped us get access to ATOM's managers. Moreover, in the frame of our in-depth case study, the confidentiality agreement has been signed between Beta and the PhD candidate. Second, the nuclear sector is highly regulated and has specific characteristics and references. A particular effort should be made by a non-specialist to understand not only technological, but also regulatory and organizational factors involved. In our case, the study began with deep immersion in the research setting. Figure 3.4 depicts the study timeline and its integration in the context of leadership for safety developments at the levels of the international community and the ATOM organization. The in-depth understanding of the nuclear sector specificity was made possible thanks to a two-stage process: 1) immersion in the context (2017-2018); and 2) in-depth case study (2019-2021).

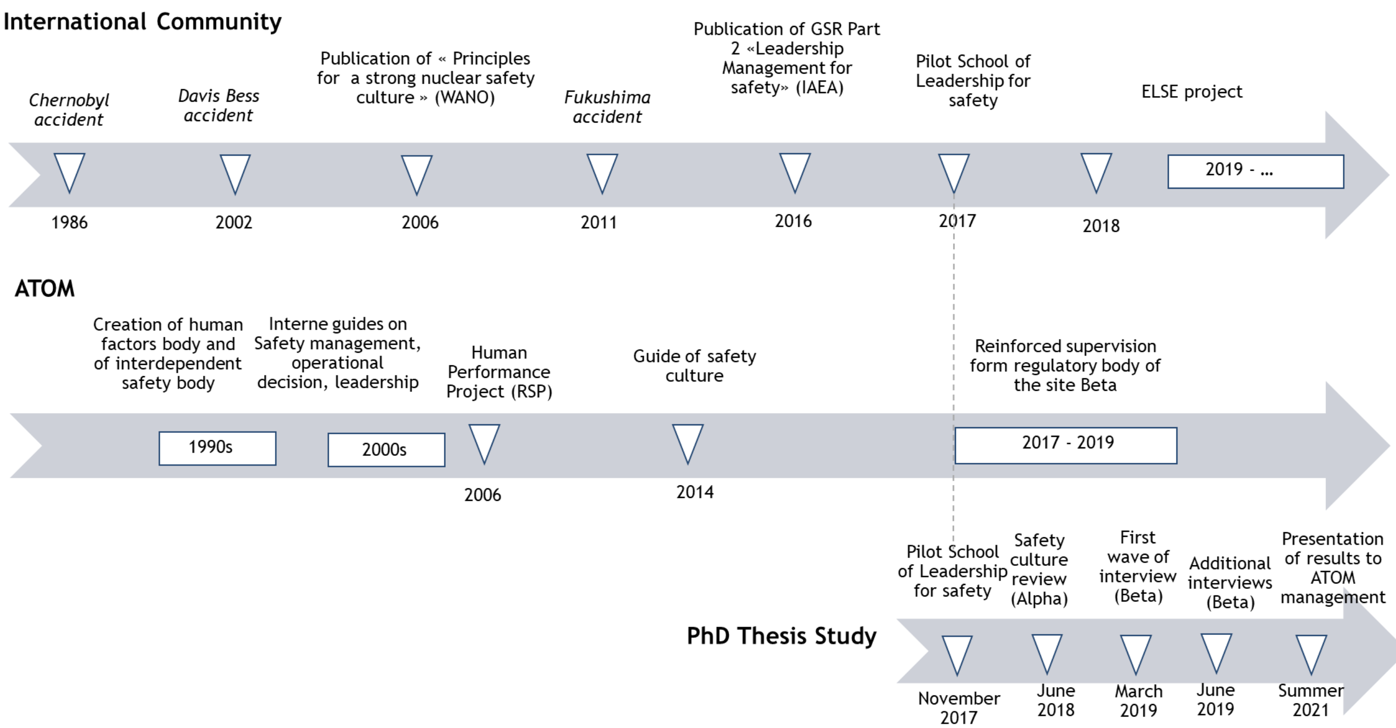

Figure 3.4. Timeline of the study

3.2.2.1. First stage: immersion in the context

Our immersion in the context began with the participation on the Pilot International School of Nuclear and Radiological Leadership for Safety. The focus was on a better understanding of the role of leadership in enabling safety. Then, the immersion continued within the context of the ATOM organization, with a focus on safety culture.

Immersion during the Pilot International School of Nuclear and Radiological Leadership for Safety. The first training implemented by the Pilot International School of Nuclear and Radiological Leadership for Safety (Pilot School), was mainly aimed at executives in organizations involved in nuclear or radiological activities and was held in November 2017 at the University

Côte d'Azur in Nice. This Pilot School was organized to support the IAEA General Safety Requirement 'Leadership and Management for Safety' (International Atomic Energy Agency, 2016) and to develop reliable practices. It was sponsored by the IAEA and ENSTTI. It conducted four School Case Studies (SCSs) based on real events, to study the following components of safety leadership: goal setting; developing values and attitudes; and engagement in continuous improvement. These SCSs were analysed in groups and discussed during plenary sessions, followed by open discussions. Twenty mid-career professionals from 16 countries, from nuclear operator companies and regulatory bodies, attended this school. Former experienced professionals and consultants led the SCS and discussions. During this five-day course and we started to collect empirical data for our exploratory analysis.

Data were collected via participant observation, semi-structured interviews and informal conversations. We observed the participants over the five-day course, noting their reactions, the terminology they used and their preoccupations with safety leadership. The observation notes were transcribed. We conducted six semi-structured interviews: four with mid-career leaders from European nuclear operator companies (Pilot School participants) and two with management and safety consultants (Pilot School facilitators). We focused on their perceptions and safety leadership in the work environment practices. Interviews were recorded and transcribed. These one-to-one interviews based on open-ended questions to learn about informants' understandings of leadership and leadership for safety and safety culture, as well as their observations and beliefs about the role of safety leadership in their own organizations. We asked the interviewees, for example, about the successes and failures experienced in relation to safety leadership. Our observations and the interview guide are presented in Appendix 2.

The objective of this immersion stage was to gain familiarity with the nuclear energy sector and to capture how the notion of leadership for safety was understood and apprehended by a variety of nuclear sector actors (international institutions representatives, regulators, operating companies).

The findings from these exploratory interviews and observations guided our empirical study and more specifically our research protocol. First, Pilot School participants and facilitators highlighted the importance of management and leadership for safety, which pointed to some degree of confusion between these two notions. Second, interviewees highlighted multiple tensions among the different hierarchical levels and visions (e.g., prioritizing production over safety).

Third, informants considered that providing solutions to these tensions was the primary function of leadership; however how leaders do it in practice remained unclear. This immersion in the context highlighted a real need to uncover and better understand the role of leadership for safety and how it should be exercised.

Immersion within ATOM: safety culture perception review. Immersion in the ATOM organisation enabled the collection of data from multiple sources and facilitated data triangulation. Careful analysis of company internal documents and archival data, in addition to interviews with knowledgeable informants, provided a good understanding of nuclear energy production.

At this stage, we held exploratory interviews and meetings with the personnel from ATOM's Nuclear Operations Division. These contacts led to our being invited to participate in the review of the Alpha NPP safety culture perceptions. The review team consisted of two experts from the institute of industrial safety, a representative of ATOM Nuclear Operations Division and the PhD candidate. The safety culture perceptions review included:

- Analysis of the questionnaire responses
- Analysis of internal documentation on managerial process and on safety culture development
- 14 non-participant observations (3 conducted by the PhD candidate)
- 4 semi-structured group interviews conducted by members of the review team and the PhD candidate
- 16 semi-structured individual interviews (3 conducted by the PhD candidate).

The safety culture perception review process involved two stages. First, the questionnaire was administered by ATOM to the Alpha NPP. The questionnaire was aimed at evaluating respondents' perceptions about the main themes and the requirements in ATOM's safety culture guide. Second, following an analysis of the questionnaire responses, the review team conducted interviews with members of Alpha to explore and to complete the information obtained from the questionnaire. The group interviews animated by the review team were focused on the explanation of questionnaire results. In addition, separately, three individual interviews, which were based on our interview protocol, provided the opportunity to experiment with the interview guide, which is provided in Appendix 3. During this safety culture review process, for confidentiality reasons, we were unable to record the interviews during the internal evaluation. However, we were able to take field notes and, also, were given access to the field notes taken by other review team members.

This immersion stage helped us to familiarize with the research context (ATOM's history, structure, terminology, main challenges, etc.) and provided us with a clearer picture of the safety culture vision at ATOM. It also provided an understanding of the organizational processes related to safety developments. We obtained knowledge about how the different ATOM units, specifically, Alpha NPPs, understood safety and safety culture issues. We also learned about their implementation and monitoring across ATOM units. For example, the analysis of the safety culture review highlighted the existence of different perceptions at different hierarchical levels. However, the quantitative review involved mainly auto-declarative compliance and, therefore, it does not guarantee that declared practices are in line with standards or are implemented effectively. Although the questionnaire captured different perceptions of safety culture and safety practices (across time, hierarchical levels and different NPPs), it did not allow to explain these differences or difficulties related to the implementation of different practices. Notwithstanding its value and interest for the company, the review had some limitations, for example, it did not provide insights about how underlying mechanisms act on behaviours and how they are activated. Hence, we concluded that there was a pressing need for further exploration of these issues through an in-depth case study.

During our immersion at ATOM we were invited to present a key-note speech at an Operating Experience Seminar for all ATOM units' managers (around 20 NPP top managers and their managerial teams). We presented the highlights of theory on leadership for safety and expressed our interest in continuing the study. Our participation (presentation and informal exchanges) at this event allowed us to identify a case for our in-depth study. The director of Beta NPP expressed his willingness to further explore the causes of the difficulties experienced by his unit to respond to a high level of safety requirements and, more specifically, the role played by organizational factors.

3.2.2.2. Second stage: in-depth case study of ATOM Beta NPP

The second stage involved an in-depth case study of ATOM's one unit, Beta NPP. We selected this particular unit because of the expressed concerns about the degradation of safety level despite considerable efforts made by Beta managers. The unit has been placed under reinforced supervision of the regulatory body. Interviewees expressed their concern about the safety levels and safety improvements. The head of Safety and Quality department told us: "*we have difficulties, we are not at the expected level - this means that the organization does not allow everyone to be in the best position to act safely… we had the difficulty of losing our bearings in 2016 - 2017. That's why we implemented a Rigor Safety Plan, and in this plan, we clearly identified that we needed to work on the safety culture, because we have lost the sense of priority that we must give to safety.*" *(Int06, head of Safety and Quality department).*

Data were collected in two stages - first in June 2018 and second in June 2019 – and included document analysis, non-participant observations (8) and semi-structured face-to-face interviews (14 individual and 4 collective).

Interviews. The interviewees represented several hierarchical and functional levels. More specifically, in the frame of this doctoral research, we suggest differentiating four organizational levels according to the position in relation to operational activities 1) corporate top management; 2) unit top and middle managers (operational and functional leads, heads of departments); 3) proximity management (operations shift manager) and 4) front-line actors (control room supervisor, reactor operators, field agents). Table 3.3 presents the interviews, according to their organizational level.

Table 3.3. Organizational level and positions of the interviewees (Beta NPP)

Organizational level and positions	Number of interviews
Top Unit management	**6**
Human and Organizational factors /Leadership leads	5
Managers- Heads of missions	1
Middle management	**2**
Heads of departments	2
Proximity management	**4**
Operations shift managers	2
Assistant shift manager	1
Engineer	1
Front-line actors	**5**
Field agent	1
Reactor operators	2
Control room supervisors	2
Functional responsibilities	**1**
Instructor	1
Total	**18**

Our participation was supported by a member of Beta NPP (Leadership lead), who arranged the venues and timings of the interviews, according to our requirements expressed during a preparatory online meeting with Beta's top managers. The interviews were held on the Beta site and lasted between 60 and 90 minutes. We were able to record all the interviews, which were later transcribed using NVivo Transcription. The automated transcriptions of collected audio data were reviewed and supplemented by our notes.

Each interview began with a presentation of the research project and the "entry message" (Appendix 4). The interviews were semi-structured and followed the interview protocol that is presented in Appendix 5.

During the interviews we asked interviewees about their perception of risk, uncertainty and safety as well as organizational values. We also asked them for their evaluation of the effectiveness of organizational practices currently in place. We had three main focuses on interest: 1) focus on day-to-day activities; 2) focus on operational and safety activities; and 3) focus on leadership for safety.

First, our interviews focused on normal day-to-day activities in this high-risk organization, rather than accident analysis, and this for multiple reasons. Our case, ATOM, did not experience any major accidents; however, some ATOM NPP were finding it difficult to maintain high level of safety in their daily operations. This day-to-day focus is relevant because origins and rooted causes of accident situations can be explained by the general conditions of normal activity (Lorino, 2009; Starbuck & Farjoun, 2005). Also, as discussed in the subpart 1.3.2 of Chapter 1, since accidents are rare events, they are a source of limited empirical information, whereas dangerous situations can occur daily.

Second, we were interested in safety processes and practices related to operational activities. In line with a critical realist perspective, we paid a particular attention to such observable elements and, especially, the difficulties encountered by the actors when trying to implement safety processes, in other words, their practices. This constitutes the observable elements that the theory-building should explain. We were also interested in individuals' perceptions (safety values and explanations of difficulties) behind practices. This constitutes empirical elements that guide explanation-building. Guided by our interest in daily operational and safety practices, we chose to pay a particular attention to operational teams, involved in daily control of nuclear reactors' operations. Most of the interviews included individuals from the operations department, where work is divided among shift teams and few members of the support team. The individuals involved are responsible for the daily operation and assessment of the safety status of the NPP installations mainly through 1) monitoring (control room operating parameters, direct controls on installations carried out by operating technicians, etc.), 2) evaluation of the appropriateness of adaptations to the production of electricity based on an assessment of the safety status of the units, and 3) checking the status and availability of equipment and installations and their compliance with technical operating specifications and safety rules. We also studied other daily safety practices of operations department such as pre-job briefings (as part of the REP). Pre-job briefings are conducted by line managers immediately before any intervention and are used to discuss potential risks and countermeasures (scenario of actions in case of risk occurrence) to respond to these risks. Similar to other REP practices, pre-job briefings aim to "*enable the actor to manage his mental resources more effectively, by training him to enter and/or leave a "professional routine"" (Doc 04, ATOM human performance document).*

Third, in our interviews, we also focused on leadership for safety. Following the same interview protocol, we asked respondents not only to describe leadership practices but also their perceptions of the notion of leadership and the difficulties involved in implementing leadership for safety. We interviewed a range of different actors: operational managers (top, middle and proximity managers), functional managers and actors not in managerial positions (front-line actors and people with functional responsibilities). This is coherent with the definition of leadership proposed in Chapter 2, defined as the influence process that could be exercised by different types of actors. Moreover, to preserve clarity and avoid the confusion, we remained attentive to interview managers about their leadership, rather than their managerial role and activities.

Observations. Interviews have been conducted across multiple hierarchical and functional levels and Table 3.4 presents the details of observations.

Table 3.4. Organizational level and positions of the observed actors (Beta NPP)

Organizational level and positions	Number of observations
Proximity management	**4**
Operations shift managers	2
Mixed positions	2
Functional responsibilities	**3**
Safety engineers	3
Mixed levels	**1**
Mixed positions	1
Total	**8**

During the observations we took manual notes, which were later transcribed. Our observation of organizational practices included meetings, audio-conferences, briefings and evaluations. During the observations, we paid particular attention to capture operational practices (e.g., daily installation safety reviews), leadership practices (e.g., ways to organize daily meetings or to formalize discussed decisions) and concerns expressed about safety and leadership for safety (e.g., during shift handover meetings).

Document analysis. We collected a rich retrospective data from external and internal documentation on safety management, safety culture and leadership for safety. Some of this added to our immersion in the context; others were useful for the in-depth case study. First, we collected a large number of documents related to the recommendations of international safety institutions, which provided useful contextual information. These included, for example, IAEA safety standards and accident investigation reports, WANO safety culture guides, TSO safety culture reports, etc. We also collected several ATOM corporate documents, such as the ATOM safety culture guide and its safety management guide, REP presentation booklets, human performance project reporting, etc. Finally, we analysed documents related to Beta NPP more specifically, such as Beta NPP management note of the operations department.

This multi-stage research design provided rich data from a range of different sources. These are presented in Table 3.5, which lists different sources of data and their repartition by level.

Table 3.5. Data sources

	Pilot school	**Alpha NPP**	**Beta NPP**	**General ATOM**	**Int. safety institutions**	**Total (number)**	**Total (number of pages)**
Immersion stage	13	42	0	13	9	77	2395
Documents	5	8		13	9	35	2215
Observation	1	14				15	86
Collective interviews		4				4	20
Individual interviews	7	16				23	74
Sub-total interviews	*7*	*20*				*27*	*94*
In depth case study	0	0	33	11	4	48	621
Documents			7	11	4	22	382
Observation			8			8	23
Collective interviews			4			4	48
Individual interviews			14			14	168
Sub-total interviews			*18*			*18*	*216*
TOTAL	**13**	**42**	**33**	**24**	**13**	**125**	**3016**

In summary, the in-depth case study produced rich and multi-faceted data, providing strong empirical evidence for theorizing. This theorizing has been achieved through data analysis.

3.2.3. Data analysis

In the critical realist perspective, Bhaskar (2008a) suggests that it is up to the researcher to find the generative mechanisms. This can be done in two interacting ways: 1) directly from the field (e.g., Tsoukas (1989, p. 558) suggests that data should be collected on "*actors' accounts as to why the actions under investigation have taken place*"), or 2) from the existing literature. Informants' descriptions of implementation problems and why they occurred can provide possible explanation, helping to uncover the activation of underling mechanisms (Tsoukas, 1989). At the same time, explaining different situations in different contexts, the literature contributes to the identification of generative mechanisms by providing evidence of these mechanisms and their activation modes. We combined both ways: we applied an inductive approach (by asking the informants about implementation problems and their explanations) and an abductive approach (by mobilizing existing literature to explain observed events). Our methodology **mixes induction and abduction** to generate knowledge about generative mechanisms and their activation modes. This logic is reflected in the different coding stages.

3.2.3.1. Coding process

Data analysis followed the conventional coding process to capture human organizational experience and involved continuous comparison techniques, which helped to delineate key concepts and aggregate dimensions (Charmaz, 2006, 2009, 2014; Gehman et al., 2018; Gioia et al., 2012; B. G. Glaser, 2004; B. G. Glaser & Strauss, 1967, 2009; Strauss & Corbin, 1990, 1998). Data were coded using the qualitative data analysis software N'Vivo 12. The transcription of the interviews and observations notes were in French; selected quotes were translated into English during the data analysis process. To maintain confidentiality, no proper names have been disclosed, all results are present in an anonymised way. In line with Gioia et al.'s (2012) methodology, the coding process followed three stages: open, selective and axial coding. Open coding was used to identify initial relevant codes, which were grouped into increasingly abstract and conceptual categories, through successive levels of abstraction (Clark et al., 2010; Gioia et al., 2010).

First stage: open coding. We systematically compared informant quotes and regrouped them into first-order codes, which were as close as possible to the field. This coding process was open, the continuous comparison was guided by the main themes of the data collection: safety management and leadership.

First, we identified different first-order codes describing practices: operational and safety (safety management) and leadership (leadership) practices.

Example of the first order code	Example of associated quotes
"Leadership practices to remind about safety culture and safety fundamentals" *Leadership practice*	*"It's also the notices that are posters everywhere, the logo "nuclear safety is our top priority".* *"It's also said over and over again"*

Second, we identified first-order codes that characterized diverse elements of the structure: procedures, responsibilities, but also informants' representations of organizational effectiveness and leadership roles, and safety culture values.

Example of the first order code	Example of associated quotes
"Importance of clear roles and their understanding" *Organizational effectiveness*	*"This is important because each actor must know exactly what he or she has to do; and above all to whom he or she obliged to do something: whether it is his or her manager or even other departments, because we are all ultimately linked by interdepartmental networks. Everyone must know exactly what they are expected to do to others and what others are expected to do them"*

Third, we identified first-order codes that revealed problems related to practice and process implementation. These codes provide empirical elements to help identification of generative mechanisms and their activation modes.

Example of the first order code	Example of associated quotes
Difficulty to implement learning	"*Training of the changes to our standards is always a bit difficult because we had the training, for example, in February - the change of standards will take place in September. We've had time to forget everything because we're dealing with a lot of other things, but we're nevertheless, we know what's expected of us*"
"Problem of developing followers' trust in leaders"	*"In order for the person to accept that you are beside them, that you are piloting and setting up things - they need to have confidence in you. And for them to have confidence in you, they have to know that you know their job, you know the constraints, you know the person. As a manager - you have to know the person. The main difficulty is to create this relationship of trust in order to have leadership. This is my conviction, but a few years ago with the different generations, it was not like that"*

At this stage, we had a total of 3,082 quotes which were regrouped into 180 first-order codes. For practical reasons, these codes were regrouped into specific themes, such as leadership practices, problems related to leadership implementation, representation of leadership or competences and learning and safety management practices. The code book resulting from this open coding is presented in the Appendix 6. With available interviews we consider achieve theoretical saturation, because coding of additional data did not make emerge any new codes (Gioia et al., 2012; B. G. Glaser & Strauss, 1967, 2009).

At this stage, we mainly identified **informants'** interpretations of difficulties related to the implementation of safety or leadership practices and their plausible explanations. In the next stage, we considered the **researcher's** interpretation of the data collected, to identify patterns of coherent events related to leadership and safety practices, and the explanation of these patterns (i.e. identification of generative mechanisms). To achieve this, we selected codes relevant to our research question, and then, we began the abstraction process.

Second stage: selective coding and abstraction process. The analysis for selective coding requires the implication of the researcher for creation of researcher-centric, rather than informant-centric codes, themes and dimensions (Gioia et al., 2012).

The selection of codes was guided by our research question on how leadership enables a joint development of managed and regulated safety in high-risk environments, in day-to-day activities. The field work revealed three salient and interrelated issues related to our research question. The first concerns ATOM's implementation of safety practices aimed at a joint development of managed and regulated safety. The second concerns the difficulties encountered by ATOM in implementing these safety practices. The third is linked to the role of leadership in overcoming these difficulties and promoting efficient implementation of safety practices.

For each issue, we selected the relevant codes; we reworked the first-order codes to achieve more precision and then analysed them through an abstraction process. The reworking involved 1) creation of new categories and 2) elimination of codes based on only one quote. The abstraction process consisted of grouping the first-order codes into more abstract categories, second-order codes and aggerated dimensions (Gehman et al., 2018; Gioia et al., 2012). Second-order codes regroup lower-level codes though a constant comparison. In line with a critical realist approach and also as suggested by Gioa et al. (2012), to elaborate the second-order codes, we iterated between the categories that emerged from the field and the explanations suggested by the literature. Finally, we regrouped the second-order codes into aggregate dimensions. The creations of first-order terms, second-order themes and aggregate dimensions allowed to build a data structure (Gioia et al., 2012).

First issue: ATOM safety management practices. This issue refers to how ATOM plans to improve safety, thus, the codes explore safety management practices and representations of safety, capturing the elements of structure. Informants highlighted the introduction by ATOM's management of organizational practices to enable safety.

Our coding process was iterative and involved several rounds (attempts) of abstraction for higher-order codes and dimensions. At each round, we verified whether our propositions made sense and remained representative. NVivo-12 software provided a useful tool to monitor and compare the relative weights of lower-order elements in the second-order and aggregate dimensions, to control for whether the abstraction proposition was relevant. For example, Figure 3.5 is a visual representation of the quotes (coding references) and repartitions among codes in the aggregate dimension "*Ensuring safety via formalization*". It depicts the weights of the second-order codes "*Formalization to managed anticipated events*" and "*Formalization to manage unanticipated events*" and, for each second-order code, the weights of each first-order code. Figure 3.5 shows that all the codes are well represented, but that the most represented code is "*Anticipation*".

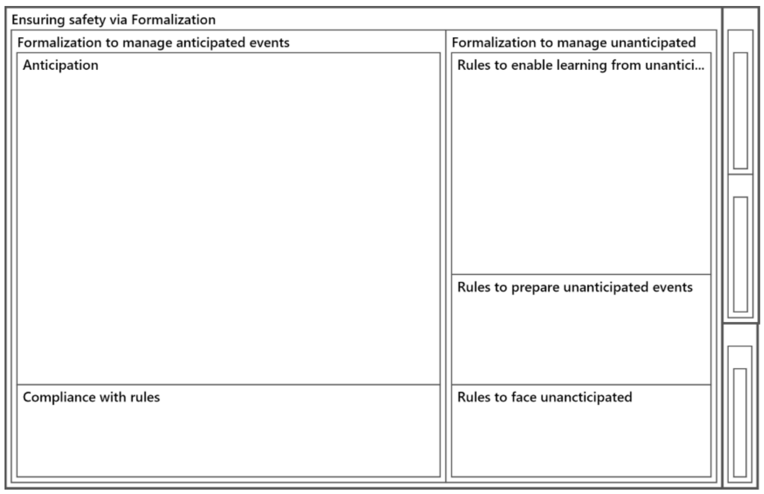

Figure 3.5 Example of visual coding references repartition within code (NVivo extraction)

The analysis of the related codes allowed to build a data structure of organizational safety practices, as illustrated in Figure 3.6.

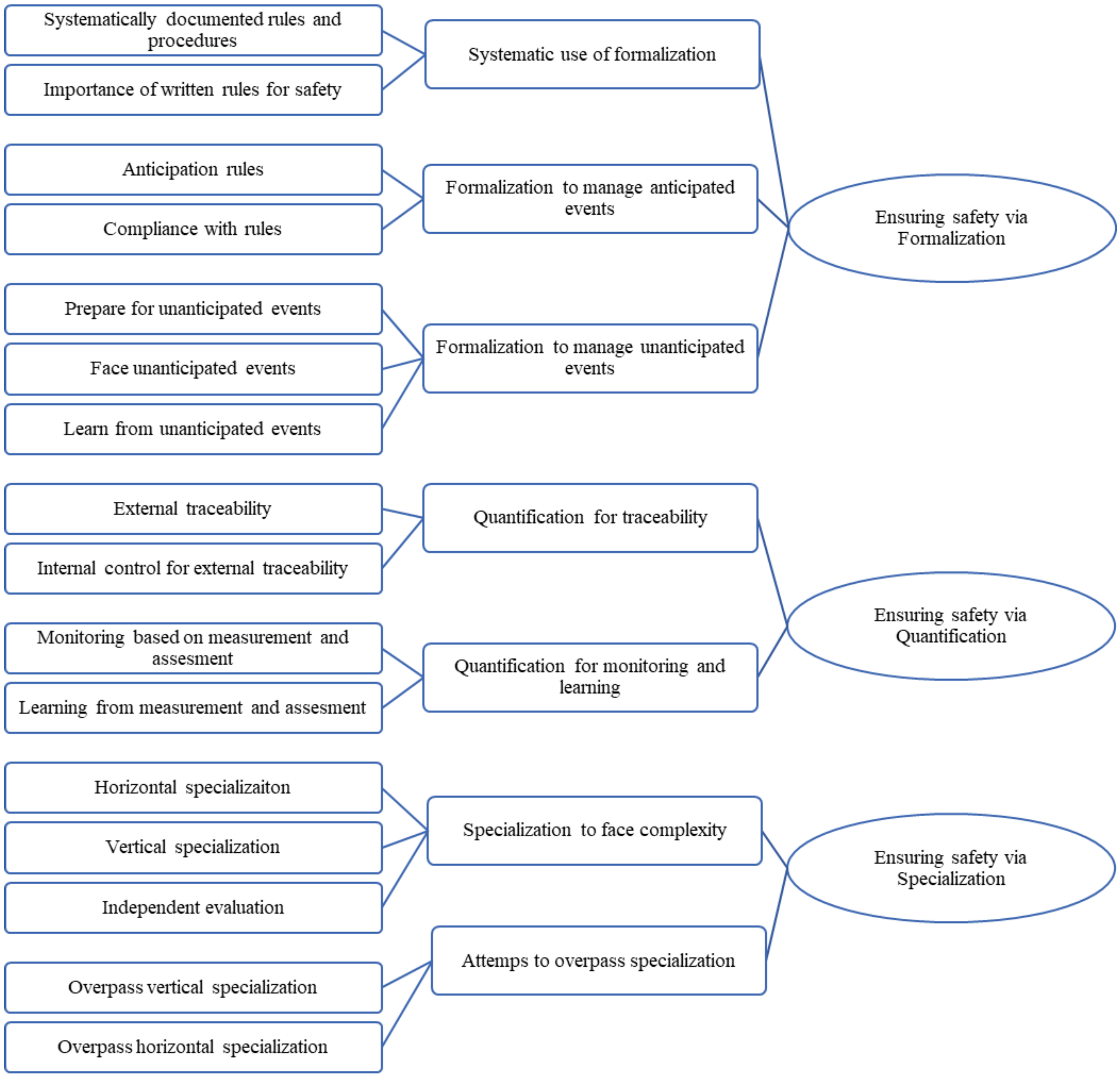

Figure 3.6. Data structure: organizational practices for safety

Second issue: difficulties encountered by ATOM when implementing safety management practices. The analysis of the field data revealed that the implementation of safety management practices was challenging and, paradoxically, sometimes impeded safety. The search for second-order codes and aggregate dimensions shows the iterative process between data and literature analysis. For example, the field data pointed to second-order codes, which resonated with problems related to mindfulness (e.g., Sutcliffe et al., 2016; Weick et al., 1999), and the danger of organizational limits (Farjoun & Starbuck, 2007; Oliver et al., 2017).

Figure 3.7 depicts the data structure for organizational challenges related to safety management practices.

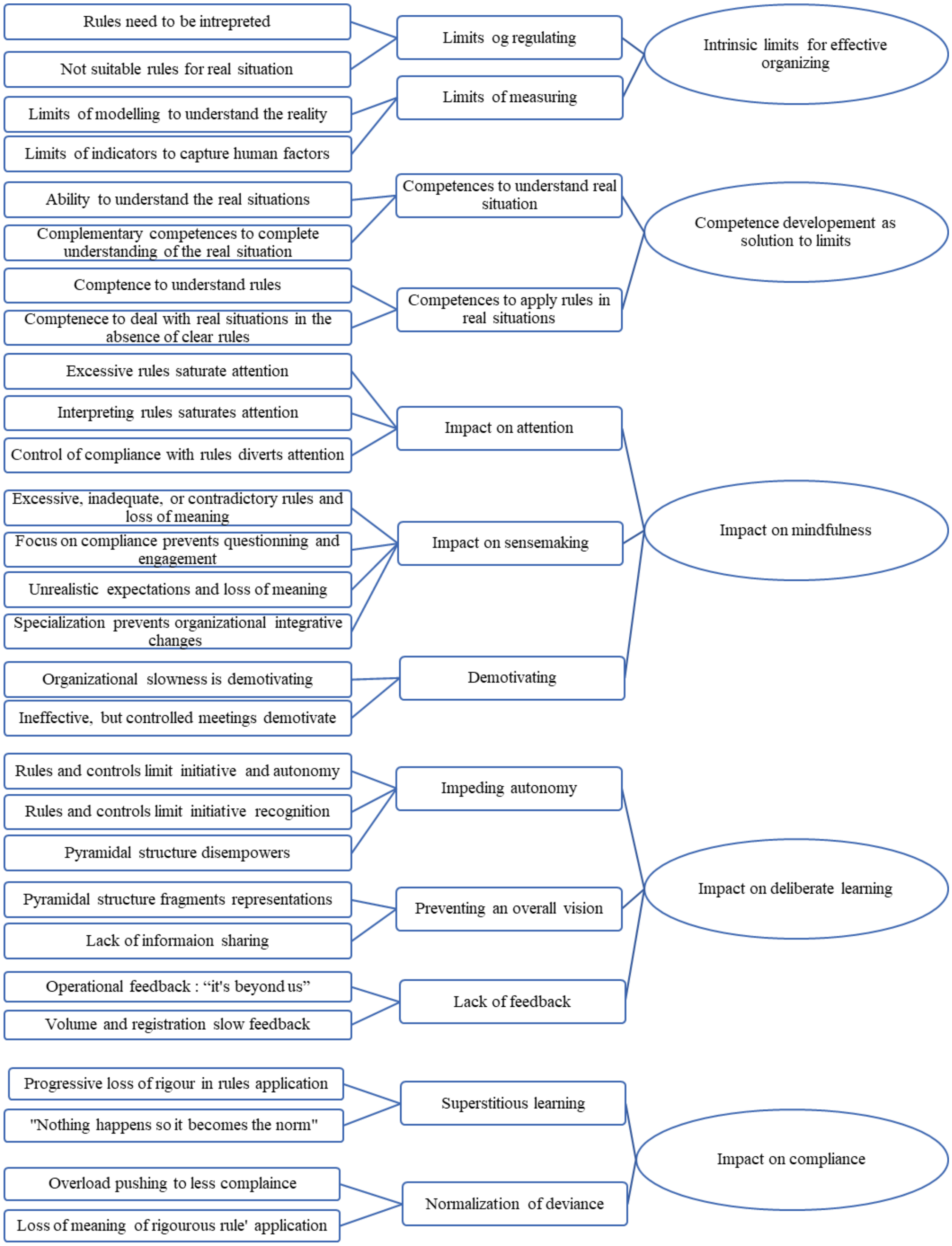

Figure 3.7. Data structure: organizational challenges in developing safety

Third issue: the role of leadership in overcoming the difficulties and favouring an efficient implementation of safety practices. Since leadership could help resolve challenges of the implementation of safety management practices, we selected first-order codes about leadership (representation of leadership, leadership practices, problems with implementing leadership practices). Again, we reworked the first-order codes to achieve precision. Specifically, we conducted an in-depth analysis, which revealed disparities across organizational levels. This had been already highlighted in the analysis of Alpha NPP. Thus, we reworked the first-order codes and regrouped them by organizational level. By specifying a level attribute for each interview, NVivo-12 software allowed a more fine-grained data analysis. For example, Table 3.6 presents the quote repartition by organizational level of the first-order code "*Fuzzy representation of safety*".

Table 3.6. Example of matrix query with quotes number repartition by organizational level (extraction NVivo)

	A : Fuzzy representation of safety
Organizational level = International Institution	0
Organizational level = National Institution	0
Organizational level = TOP	3
Organizational level = MIDDLE	0
Organizational level = PROXIMITY	2
Organizational level = FIELD	4
Organizational level = MIX	0
Organizational level = FUNCTIONAL	0

Generally, the field data underlined leadership efforts as the solution to develop managed safety in the context of regulated safety. In particular, two issues requiring leadership attention came up in the interviews: understanding or making sense (of rules, procedures, working processes, etc.) and learning. Our empirical investigation generated more quotes and codes about sensemaking than about learning. This is in line with the literature on leadership for safety, which highlights the importance of sensemaking (Barton et al., 2015; Barton & Sutcliffe, 2009; Hannah et al., 2009; Katz-Navon et al., 2020; Weick & Sutcliffe, 2015). Consequently, in the present research we chose to focus on the role of leadership for safety in sensemaking and sensegiving. Figure 3.8 illustrates data structure about sensemaking-sensegiving process of leadership for safety.

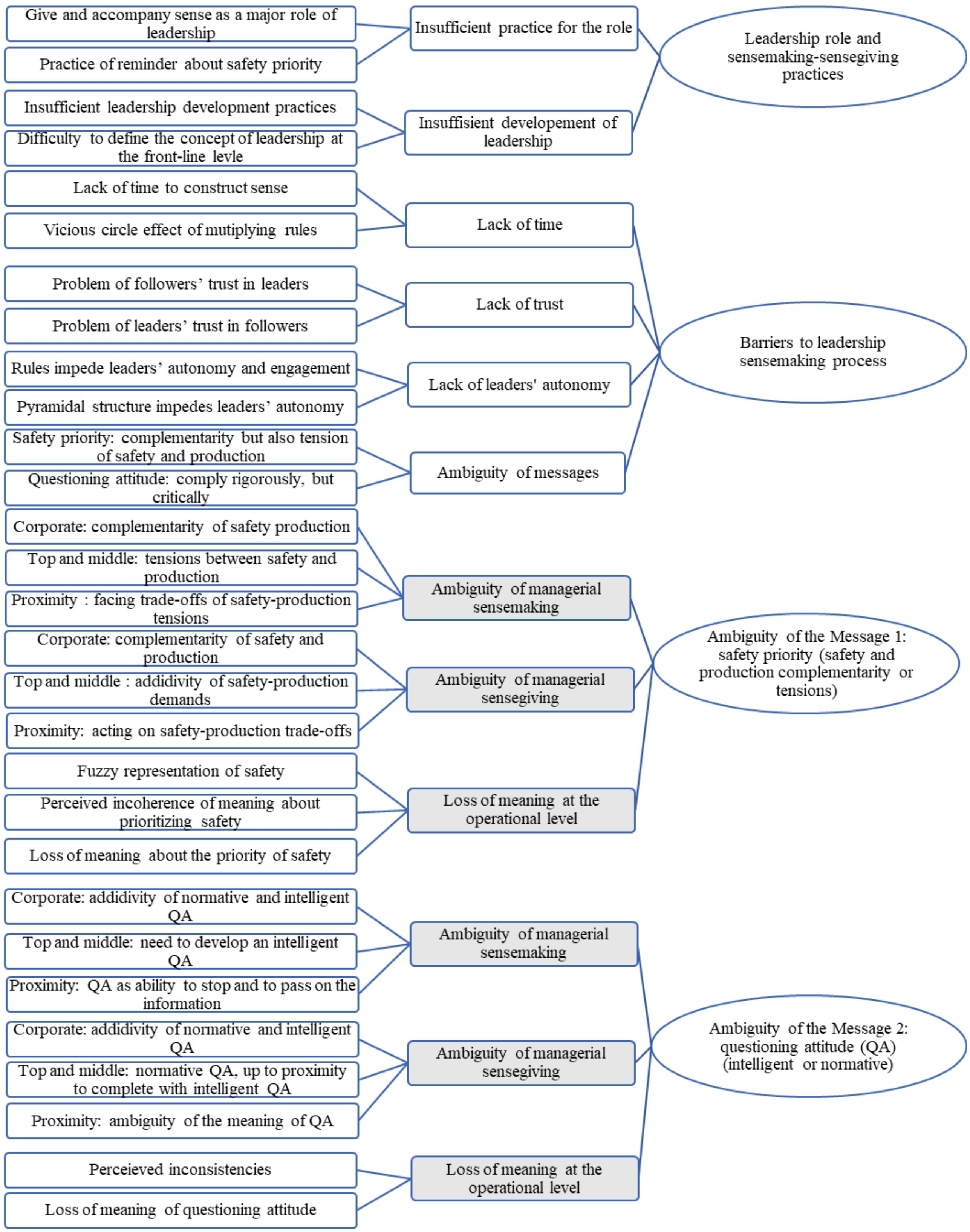

Figure 3.8. Data structure: sensemaking-sensegiving process of leadership for safety

Third stage: axial coding. Oscillating between induction and abduction helped the code structure emerge. The fine-grained understanding of the mechanisms and their activation modes required a particular attention to the relationships between abstract codes (second-order codes and aggregate dimensions). These relationships allowed us to build theoretical blocs. Thus, in addition of emerged data structure, we conducted axial coding.

Some of relationships were recognized by our informants themselves. We coded them through an axial coding. For example, the code "*Lack of autonomy demotivates"* formalized a link between two aggregate dimensions: *"Impact on deliberate learning"* influences *"Impact on mindfulness"*. Moreover, different codes allowed us to formalize the relationship between two second-order codes in the same aggregate dimension. For example, the code *"Saturated attention leads to the loss of sense"* formalizes the influence of attention on the sense within the aggregate dimensions *"Impact on mindfulness"*.

However, not all relationships have been explicitly expressed by our informants. Therefore, through abductive reasoning, we engaged in the process of linking concepts. The aim was to find a plausible explanation that would allow us to build an emergent theoretical model. On the basis of observable elements, we retroduced possible explanations of activated mechanisms and their modes of activation. This process involved several analytical loops to construct an explanation based on the second-order codes and aggregate dimension. For each explanation pattern, we first verified the analytical coherence of the explanation and second, its ability to explain more of the observed elements to eliminate alternative explanations (Bhaskar, 2008). In the case of two possible theories to explain the observed patterns of events, we retained the one that allow to explain the most of events. We progressively extended the retroduced explanations to identify those that best fitted the data and had the best explanatory power. The results, which are discussed in Chapter 4, refer only to the relationships that were retained. We paid particular attention to internal validity to guarantee the relevance of our choice of the underlying causalities.

3.2.3.2. Internal and external validity

Internal validity. Internal validity aims to guarantee the strong interrelations between the empirical evidence and the theoretical explanations (Ayerbe & Missonier, 2007; Gibbert et al., 2008; Miles et al., 2014). This process of verification and questioning of the quality of inferences made by the researcher was adopted to build the emerging model.

First of all, our data analysis followed the protocol provided by Gioia et al. (2012) – building the data structure and making explicit all the inferences made from the raw data to the conceptual categories. Indeed, internal validity is guaranteed by the coherence and meaningfulness of the researcher's cognitive progression in abstraction. The construction of these data structures was the subject of frequent interactions between the PhD candidate and the PhD supervisors. In addition, we regularly performed some double coding sessions with the PhD supervisors to ensure that the emerging codes made sense.

However, we did not perform systematic double coding for two reasons. The first reason comes from critical realist positioning. In a critical realist approach the quality of inferences is related to the production of plausible explanations for similarities and differences observed, rather than to double-coding with an external researcher as suggested in post-positivist approach (Avenier & Thomas, 2015). An additional reason comes from limited data accessibility due to the particularity of the context. The raw data from interviews and observations were protected by a confidentiality agreement between the ATOM unit and the PhD researcher and could not be communicated to a third-party without written agreement from ATOM.

Moreover, we continuously shared our emerging results with informants to ensure accuracy of conclusions, as suggested by empirical corroboration (Ayerbe & Missonier, 2007; Yin, 2018). To ensure the best among plausible explanation (Behfar & Okhuysen, 2018; Mingers et al., 2013; Mingers & Standing, 2017; Wynn & Williams, 2012), we discussed our emergent results with different types of actors.

First, multiple sessions were organized with ATOM managers. Halfway through the analysis (June 2019), we presented preliminary results to Beta NPP director and top managers. This meeting with Beta NPP top management helped confirm general directions of the analysis and engage second data collection wave (more focused interviews). Once the data analysis was completed, we presented the results to two Beta NPP directors and other top senior managers. The explanations proposed for the explanation about underlying mechanisms and their activation modes were considered meaningful and we received positive feedback.

Second, to ensure that the explanations were valid and sensible (made sense), but also to overcome the limits related to idiographic representation of a single unit, we presented our results, to an extended audience from ATOM NPPs. During an online meeting we presented our results in front of a representative of more than a dozen different ATOM NPPs, not under our scrutiny in the present research project. Thus, our explanatory results were aligned with evidence coming from different human and organizational factors leads across ATOM NPPs not involved in the case study.

Third, we obtained feedback from nuclear industry experts outside of ATOM. The use of specialists with expertise and in-depth knowledge of the field helped build confidence in the transferability of results (Koenig, 2005). We presented our results (in an anonymized manner without disclosing proper names, compony or country) online and we discussed them with two nuclear energy sector experts. Two additional recognized experts with a long experience of working in a TSO also confirmed the validity of our reasoning and our results. Table 3.7 lists the results presentations sessions and received feedbacks.

Table 3.7. Summary and feedback of results presentations

Audience	Date	Example of feedback from the audience
ATOM (Beta NPP) top management (new NPP director, Leadership Consultant, Head of operations, Human and Organizational factors Consultant)	June and July 2021	• *"this is what we experience every day"* • *"it seems obvious"* • *"how to turn it into concrete action?"*
ATOM (Beta NPP) top management (previous NPP director)	August 2021	• *"the focus is the sense of the rules, its understanding and sharing"*
ATOM (around 15 NPP): Safety management & Human Factor Expert at the Corporate level; network of Human and Organizational factors consultants	April 2021	• *"highly relevant",* • *"I find myself in these analyses",* • *"it really echoes situations that we can live!",* • *"Thank you for the presentation, the material was fascinating and very rich, I think it will feed my next reflections"* • *"I found the elements of restitution representative of my experience after 3 different nuclear sites and 17 years in the plant. I did not perceive any gap between your elements and what I perceive on a daily basis."*
Nuclear sector experts from regulatory bodies	May 2021	• *"thank you for your interesting presentation, it highlights that all excesses are dangerous and the question is whether organizations are capable of realizing this before disaster strikes"* • *"it's very interesting, it reflects the reality that we suspect"* • *"this is a reality not only of ATOM, but we could also observe this in our regulatory organization"*

All these presentations and discussions of our results reinforced the internal validity of the findings and pointed to the possibility that the findings could be generalized to other firms with similar characteristics.

External validity. The primary objective of our case study was explanatory. In line with a critical realist perspective of stratified reality, we were interested in the underlying causal powers, rather than in surface empirical regularities. Our case study methodology was aimed at explaining the interaction among contexts, structures and events and their underlying mechanisms (Avenier & Thomas, 2015; Tsoukas, 1989; Wynn & Williams, 2012). In other words, we aimed to uncover the patterns of interactions among causal powers of mechanisms, structure and contextual contingencies that produce the observable events (Tsoukas, 1989). This focus on generative mechanisms, independent of the event they generate, and their activation modes maintained the emphasis on generalizable and transferable knowledge. This **generalization is analytical, rather than statistical** (Avenier & Thomas, 2015; Ayerbe & Missonier, 2007; Gibbert et al., 2008; Yin, 2018). Thus, generalization from a critical realist perspective is achieved via abstraction. By moving from surface evidence to the depth of causal powers, we were able to capture not only abstract theoretical elements and their interactions, but also explanations for these interactions.

Tsoukas (1989, p. 559) considers that "*causal powers are externally valid, but their activation is, and thus their effects are, contingently determined*". In this case study, we explored leadership for safety in the context of a representative nuclear power operating company, (Gobo, 2004) to address our research question. Our case study results could potentially be generalizable to other organizations, but with the specificity of the context has to be considered. Thus, knowledge generated by the present study may be easily generalizable within the nuclear sector and probably to other organizations operating in **high risk** and **highly regulated** environments. Such organizations are often concerned with the role of leadership for safety in overcoming the challenge of the joint development of managed and regulated safety.

4. Results: safety management and leadership for safety challenges

Leadership for safety, as an influence process to fulfil safety management expectations, is essential for safety improvements in high-risk organizations. In our research, we investigate the way that **leadership mechanisms are activated and are combined with safety management mechanisms in daily activities, to enable a joint development of managed and regulated safety.**

Our study of the ATOM NPP case uncovers how ATOM uses organizational levers to develop safety capabilities with a particular emphasis on managed safety in a highly regulated environment. In particular, this involves the implementation of safety practices aiming to facilitate the development of mindfulness and organizational learning. ATOM relies on control and coordination rules and practices based on the three design principles of formalization, quantification, and specialization. These three principles constitute levers for safety, particularly for regulated safety. Nevertheless, they may become barriers to safety if applied excessively, echoing the notion of organizational limits. Our results highlight challenges to implementing these principles in terms of whether they are facilitators of or barriers to safety. We found that although ATOM introduces open and flexible rules, these are managed using excessive formalization and quantification, which in turn has a negative effect on mindfulness and deliberate learning. Moreover, this negative effect is amplified by the way that ATOM elaborates and applies indicators that divert attention away from and to distort the meaning of organizational artefacts such as formalized rules and indicators. In Chapter 4 we explore these findings and their implications in more detail.

Our research highlighted that the main challenge in assuring high levels of safety stemmed from the difficulty employees experienced in making sense of the rules and indicators used at ATOM. While the role of leadership for safety is to help employees overcome these sensemaking challenges (make sense of the rules and apply them in real-life situations), our case study revealed that the sensemaking-sensegiving-sensemaking process across organizational levels is not straightforward.

In section 4.1 we analyse organizational processes and safety practices. In section 4.2 we explore the organizational challenges related to the joint development of managed and regulated safety and their organizational limits[2]. Finally, in section 4.3 we highlight problems related to implementing a leadership process to enable collective sensemaking for safety[3].

4.1.Organizational processes and practices for safety

We start by describing the organizational changes introduced at ATOM to jointly develop regulated and managed safety (4.1.1). We then show how ATOM enables safety through formalization (4.1.2), quantification (4.1.3), and specialization (4.1.4). These results refer to the data structure depicted in Figure 3.6 "Organizational practices for safety".

4.1.1. Organizational changes to enhance both regulated and managed safety

Safety development in the nuclear sector relies primarily on rules and principles developed by international safety institutions (AIEA, WANO, etc.) including: 1) priority of safety; 2) need for an interrogative attitude; and 3) safety fundamentals of guiding the daily operations (monitoring, observation of configuration changes, prudent and rigorous approach, collective work, development of competences). These rules are adopted at the corporate level at ATOM and applied at the unit level. In line with international safety institutions, ATOM makes an ongoing effort to improve safety through the introduction of organizational processes, procedures and practices aimed at enabling safety.

In chapter 3 section 3.1.3 we showed how ATOM continuously introduces new organizational processes, procedures and practices to enhance its safety capabilities. These include reliability enhancing practices (REPs), weak signals management system for operating experience (OPEX)

[2] Early results on organizational limits "Unintended Cascading Effects of Exceeding Organizational Limits While Trying to Improve Resilience: Lessons from the Nuclear Industry" were presented at the following international workshops and conferences: European Group of Organizational Studies (EGOS) Conference 2021, XXX Conférence Internationale de Management Stratégique (AIMS) 2021, European Safety and Reliability (ESREL) Conference 2021

[3] Early results on leadership sensemaking-sensegiving-sensemaking process "The role of leadership for resilience: challenges of sensegiving and sensemaking across organizational levels" were presented at the following international workshops and conferences: British Academy of Management (BAM) Conference 2021, European Academy of Management (EURAM) 2021, SKEMA KTO Paper-Development Workshop 2021.

and the integrated management system (IMS). **The recently introduced processes, practices and procedures are increasingly oriented toward the development of managed safety**. **While the regulated safety tools allow to deal with the risks of technical systems, managers at ATOM admitted that higher safety levels could be achieved only through better managed safety.**

Reliability enhancing practices (REPs) to improve human and organizational factors. The top management insisted on the need to develop practices to cover all possible risks, to "*reduce the gap between planned and real experience*" *(Doc 04, ATOM human performance document)*. The rules guiding REPs were aimed at enhancing alertness to expected and unexpected risks. This underlines the need to rely on both regulated (planned experience) and managed (real experience) safety.

Concretely, ATOM introduced rules guiding behaviour-focused practices, such as pre-job briefings (analysing risk and procedures, and declaring readiness to act), debriefings (capturing and formalizing the experience) and self-checking (pointing with a finger to the installations and reading aloud the relevant reference from the procedure). These rules are based on findings in cognitive psychology, which describe how actors work and preserve their mental resources, especially through repetitive actions. For example, the self-checking rule is aimed at maintaining attention and awareness by mobilizing multiple senses (voice, vision, touch). Also, the pre-job briefing is conducted immediately before embarking on a risky task (or immediately following a major disruption to a task), to enable memorization of and vigilance related to complex issues. These rules were designed to help people maintain vigilance towards weak signals, to increase their ability to select a panel of relevant signals in the environment, to allow the construction of meaning and the development of appropriate responses. The introduction of these REP rules was accompanied by the publication of detailed guidelines on their systematic implementation. REPs are part of a bigger ATOM project on human performance development and were developed from the perspective of preventing risk of non-vigilance and enhancing ability to react to unplanned situations, echoing managed safety development. According to an internal document, such practices aim to "*implement the appropriate response to an unforeseen, complex situation, or compensate for the failure of equipment or an organization*"; *"to create the conditions that allow nuclear professionals to 'do it right, the first time, by making it everyone's primary concern" (Doc 04, ATOM human performance document).*

These rules aim to increase individual and small team mindfulness by simultaneously enhancing focus and vividness of operators' attention. ATOM highlights that such rules *"mean ensuring strong safety management implemented as close to the ground as possible…; it also means, particularly today, providing teams with guidance; it means giving meaning to this "cultural" step to be taken on a daily basis" (Doc 04, ATOM human performance document).*

Operating experience (OPEX) and weak signal management system for learning. Another part of ATOM's project on human performance development involves the implementation of weak signal management system, which allows to collect feedback on operating experience. It involves registration, classification and quantification of anomalies and gaps, aimed at identifying and analysing incidents. These gaps spanned from simple field observations to significant safety events. The OPEX initiative includes gap diagnostics and action plans to ensure continuous safety improvements – *"such feedback is the driver of progress, internal knowledge of the facts and of the needs and expectations of stakeholders is at the basis" (Doc 16, ATOM Safety management guide).* ATOM's official stance is that *"mistakes are inevitable, the challenge is to use them to allow progress" (Doc 04, ATOM human performance document).* Rules on operating experience or OPEX were aimed at developing collective learning. As discussed in Chapter 1, learning is crucial for the development of mindfulness and shared sensemaking, which constitute the foundation of managed safety. Focus on learning clearly points to ATOM's aim of developing managed safety.

Integrated management system (IMS). The third initiative involved the implementation of a processual approach to organizing, in line with an IAEA safety requirement: "*The management system shall integrate its elements, including safety, health, environmental, security, quality, human-and-organizational-factor, societal and economic elements, so that safety is not compromised"* (IAEA, 2016, p. 10), in order to "*ensure that the management system...is designed and applied to enhance protection and safety while maintaining coherence between measures for protection and safety and other measures, such as those addressing operational performance and security" (IAEA International Atomic Energy Agency, 2018, p. 11).* The IMS involves the implementation, based on a processual approach, of a more coherent and global view of all activities, better communication and coordination through a transversal management process. This allows to coordinate attention to enhance shared sensemaking and, as a result, develop mindfulness thanks to the construction of global view. Again, the aim is to develop managed safety.

In a framework predominated by regulated safety (technical and procedural barriers), ATOM recognized the need for additional levers to enhance managed safety. The organizational changes introduced aim at increasing operators' vigilance toward weak signals, enhancing coordination of individual and collective attention, favouring of learning and increasing of operators' preparedness to deal with unexpected events. **In other world, the aim of all three organizational changes was to enhance mindfulness, sensemaking and learning, which are key to the development of managed safety.** In section 4.1.2, we discuss the use by ATOM of levers such as formalization, quantification and specialization to implement these organizational changes, and the use of a range of tools and organizational artefacts (e.g., procedures, reports or indicators) employed to implement these organizational changes.

4.1.2. Ensuring safety via formalization

4.1.2.1. Systematic use of formalization

Systematically documented rules and procedures. The fieldwork revealed that ATOM continuously formalizes and adds new procedures in line with international safety requirements, such as IAEA requirements to provide a "*description of how the management system complies with regulatory requirements that apply to the organization" (IAEA, 2016, pp. 11–12)*. For example, IAEA requires that, in addition to the formalization of technical activities, *"the management system shall be documented… The documentation of the management system shall be controlled, usable, readable, clearly identified and readily available at the point of use" (IAEA GSR Part 2, 2016).* In addition to the general operating rules and technical operating specifications, more formalization is used to solve organizational and technical problems. Respondents acknowledged: "*we want to respond to technical faults or any significant safety event systematically by the paper [written rules]" (Int11, reactor operator)*.

Importance of written rules for safety. Formalization is encouraged by international safety institutions and should refer to the safety priority. Management systems need to be formalized through, for example, policy statements on values and behavioural expectations, fundamental safety objective, descriptions of the organization and its structure, responsibilities and accountabilities, description of compliance with regulatory requirements, etc. ATOM recognizes the importance of formalization for safety: "*write down what you plan to do, do what you have* *written you will do, record [write] what you have done" (Doc 16, ATOM Safety management guide).* More specifically, formalization is aimed at highlighting the value of safety. Several interview respondents talked about safety fundamentals, which are formalized general principles of safety work and of a safety culture, such as prudent and rigorous approach and the need for effective communication:

> *"Typically, we have the five fundamentals that help us operate and produce safely. They represent values that help us operate and produce safely". (Int05, trainee reactor operator)*

> *"Safety culture is based on the professions' and rigour fundamentals. It has a strong base and I adhere to it". (Int 26, Alpha team leader)*

Interviewees highlighted that formalization was crucial for ensuring safety. At ATOM, documented procedures are used as a way to help employees face both anticipated and unanticipated events.

4.1.2.2. Formalization to manage anticipated events

Anticipation rules. Interviewees stressed that formalization of rules to anticipate undesired events is vital for safety. Despite the recognition of the inherent uncertainty and risk in the nuclear sector, interviewees continuously stressed the importance of anticipation: "*there is no such thing as zero risk, but we can reduce the risks, to reduce the probability of further risk" (Int07, functional top manager).* The most effective responses to most frequently occurring risk situations are formalized in rules and procedures to regulate interventions in day-to-day activities: "*to act in a professional manner by all those involved in the nuclear industry requires anticipation and very precise preparation" (Doc 04, ATOM human performance document).* One ATOM manager from Alpha NPP told us: *"it is a system that more than ever pushes you to be prepared. Well planned, well performed" (Int 25, delegated head of department).*

Compliance with rules. Written rules are important at ATOM. However, employees highlighted that formalized rules must be applied. The following quote illustrates ATOM employees' belief in the role of strict compliance with written rules: "*if we respect the rules then, normally, we do not experience [safety] gaps*" *(Int10, control room supervisor).* The application of rules is also reassuring: "*Following instructions reduces the burden for us and the fear that we might do something stupid, which will lead to a mistake or degradation of safety'. Except in the* *case of a technical failure, if we adhere to the rules, we can operate the plant in complete safety" (Int05, trainee reactor operator).*

As expected, ATOM insists on the formalization of rules to deal with predictable events. This focus on anticipation echoes the underlying hypothesis of regulated safety that compliance with written rules guarantees safety. However, interestingly, ATOM's formalization extends beyond anticipation. In section 4.1.2.3., we discuss ATOM's reliance on formalization to deal with unanticipated events, highlighting the need for managed safety.

4.1.2.3. Formalization to manage unanticipated events

While rules allow known situations to be anticipated, formalization allows better management of unanticipated events and, particularly, preparation for, handling of and learning from unexpected events.

Rules to prepare for unanticipated events. IAEA suggests that novel tasks require deliberate thought processes. However, it also mentions that these processes should be formalized: "*In the case of relatively routine tasks, for which the individual has been fully trained, question and answer will be automatic to a large extent. For tasks with a novel content, the thought process becomes more deliberate. New and unusual tasks, which have an important safety content will be the subject of written procedures clarifying these matters" (INSAG International Atomic Energy Agency, 1994).* This IAEA recommendation highlights the ambiguity between unusual and unpredictable versus unusual, but still anticipatable events. In the same line, the rules for REPs were introduced at ATOM to support agents' understanding of the interventions to prepare to deal with the unexpected situations. More specifically, the REPs include formalized pre-job briefings to prepare agents not only for interventions (anticipated), but also for unplanned disruptions (unanticipated): "*it is essential that any risky activity is preceded by a briefing to allow the actors to familiarise themselves with the risks and countermeasures; similarly, any unforeseen event must lead to an interruption in the activity in order to re-examine it"* (*Doc 04, ATOM human performance document).* REPs and, in particular, pre-job briefings, guide operators in their appropriation of tasks and intervention-related documents: "*in terms of safety, the REPs help us* ***think more clearly about what we are doing****" (Int02, control room supervisor),* pointing to the development of mindfulness.

Rules to face unanticipated events. ATOM recognizes the possibility of the occurrence of unanticipated events and the need to prepare the employees to face them through the implementation of formalized rules. Our informants recounted, for example, that REP rules constitute step-by-step guidelines to cope with unexpected events, including the rule to immediately stop the activity:

> *"When the intervention does not go as planned, the operator must: stop the activity as soon as possible (stopping conditions foreseen during the Pre-Job Briefing) and analyse the new situation and the associated risks by going back to the Risk Analysis, asking for advice from a more senior and/or more experienced colleague and restarting the activity only when all the problems have been resolved and everyone agrees that it is safe to restart."(Doc, Operator's book)*

The above citation constitutes a salient example of an open rules. However, the condition: "*if the intervention does not go as planned*", leaves room for interpretation. How does the operator assess the gap between real and planned experience to qualify an event as unexpected? These interpretation margins are not always understood in the same way at the different hierarchical levels. An interesting illustration is provided by an example of rules for accidental situations in case of unpredictable events, that operational teams follow rigorously: "***we ignore the brain, and we follow the procedure.*** *The procedure has been thoroughly tested for application in accident situations" (Int01, operations engineer).* When faced with an unpredictable event, operational employees recounted that following step-by-step accident rules "replaced" their own thinking:

> *"In the end, if [there is] a doubt [about how to proceed in accidental or incidental situations], what brings relief is the appearance of an alarm named "Guidance and Stabilisation", and consulting the [specific] Accidental Operational Procedures instructions,* ***and adhering to them to manage the event... We refer to these instructions and apply them to the rigorously****." (Int09, operations shift manager)*

Interestingly, top management interviewees also referred to these accidental rules, but considered them to be rules in comprehension (objective-rules in Grote's term), rather than rules in extension (action-rules):

> *"The Accidental Operational Procedures are intelligent because the idea that is not possible to know how to respond to every type of event is integrated into their design...***however, we must assess the situation and respect the objective. That doesn't mean that we do not have to apply [the instructions]– [but] it's not a strict application [of instructions].*** If their application is appropriate to the strategy, then the terms have real meaning. The instructions say that it might be necessary to adapt to the situation." (Int04, ex-head of Safety and Quality department)*

Therefore, although ATOM formalizes rules to face unanticipated events, these open rules (defined in comprehension) are interpreted differently on the different organizational levels, pointing to the importance of sensemaking. Sensemaking is obstructed by extensive formalization and quantification (see section 4.2). The role of leadership for sensemaking is discussed in section 4.3.

Rules to enable learning from unanticipated events. The behaviours required to face unanticipated events evolve through learning, which relies on formalized rules aiming to apply lessons learned from previous experience of incidents and accidents. Learning from incidents is achieved via debriefings (a REP), which must be formalized: "*the debriefing remarks must be recorded, so that they can be consulted immediately or at a later date … they contribute to a weak signals database." (Doc Operator's Book).* In particular, OPEX feedback allows for a continuous improvement of rules and procedures. One field agent recounted that *"in the case of either good or bad events, it is important to trace [to record]good practices in order to help others involved in the activity" (Int05, trainee reactor operator).*

Learning from accidents is invaluable and results in modifications to existing rules: "*we are obliged to develop our policies so that this does not happen again, so that we do not ask the same questions". (Int02, control room supervisor). "Fukushima, Chernobyl, Three Mile Island: as a result of these incidents, the constraints and requirements progressed a lot, they became more restrictive" (Int10, control room supervisor).* For example, the Fukushima accident resulted in the evolution of the following rules:

> *"Our requirements have evolved. They are updated following incidents. After Fukushima, we integrated more requirements, a lot of monitoring, especially monitoring of the cold source, whether it's in summer or winter. This did not happen before [Fukushima]." (Int10, control room supervisor)*

This example is interesting, because the incidents or Fukushima accident resulted in learning and in the modification of rules. However, not all interviewees were equally open to accept these new rules: *"afterwards, it's hard to imagine a Fukushima here. When you see the geographical position of our town - it's hard to imagine a wave more than 10 metres high here, however, we have taken measures of this kind" (Int11, reactor operator).*

Learning from unanticipated events is formalized in additional rules, which extend the already significant portfolio of rules. However, not everyone understands the new rules and their introduction does not guarantee efficient sensemaking.

4.1.3. Ensuring safety via quantification

ATOM introduces rules to guide the development of safety practices and monitors adherence to these rules through quantified indicators. Every additional or modified rule requires additional indicators to measure rule compliance. In this section, quantification refers to the control of the adherence to rules rather than to safety results, such as number of injuries or accidents.

Quantification of rule adherence allows control through traceability and monitoring. First, traceability allows tracing of adherence to rules and ownership of consequences in case of failure (accountability). Second, monitoring and the resulting learning are focused on engagement in continuous improvement (responsibility).

4.1.3.1. Quantification for traceability

External traceability. ATOM is part of a highly regulated sector where external traceability is used by the operating company to demonstrate and by the regulator (e.g., IAEA or national regulatory body) to monitor the implementation of organizational processes and practices to meet safety requirements. For example, ATOM is part of an international network of nuclear power plants, which assess, benchmark and improve their performance through peer reviews and sharing of best practice. In this context, international organizations can make recommendations about safety and develop safety capabilities. These recommendations require adherence to rules through additional quantified indicators: ATOM "*is committed to meeting a certain percentage of WANO (World Associate of Nuclear Operators) recommendations each year. I think it's 80% this year" (Int01, operations engineer).* The link with formalization is clear. For example, IAEA requires that management system be documented and that these "*documents shall be controlled*" (IAEA GSR Part 2, 2016). For ATOM, **quantification is a means of control.** International safety institutions also stress independent assessment of aspects such as leadership, management and culture, which can be difficult to evaluate: "*senior management shall regularly commission assessments of leadership for safety and of safety culture in its own organization; and "responsibility shall be assigned for conducting independent assessments of the management system"* (IAEA GSR Part 2, 2016). Thus, quantified indicators allow assessments to easily demonstrate that international recommendations are known and respected*: "inspections frequently require an* ***element of visibility*** *[traceability] with the associated* ***mode of proof****" (Int01, operations engineer).*

Internal control for external traceability. To meet external traceability expectations, ATOM put in place an internal traceability system with multiple levels of control. ATOM's safety management guide states that "*the responsibility of a nuclear operator is to ensure that safety results and progress are measurable" (Doc 16, ATOM Safety management guide)*.

Hence, traceability is not only a means of control, but it also shows that safety settings are in place and operational. The **objective is to show the existence of safety practices and artefacts and that they are used, rather than to measure their effectiveness.** Traceability allows to assess the existence of and compliance with formalized rules. It provides an evidence base in case of a problem, to facilitate accountability. Rule compliance to guarantee safety refers to the regulated safety principle. In contrast to traceability, monitoring measures the effectiveness of the safety setting in order to allow improvements.

4.1.3.2. Quantification for monitoring and learning

Monitoring based on measurement and assessment. ATOM aims to "*improve the safety performance of the organization, through planning, control and supervision of activities" (Doc 16, ATOM Safety management guide).* International safety institutions emphasize the importance of measurement and assessment to allow continuous improvement: "*the effectiveness of the management system shall be monitored and measured to confirm the ability of the organization to achieve the results intended and to identify opportunities for improvement of the management system… The status and effectiveness of all corrective actions and preventive actions taken shall be monitored and shall be reported to the management at an appropriate level in the organization"* (IAEA GSR Part 2, 2016).

Our results show that, at ATOM, the method of monitoring based on (quantitative) measurement and assessment affect a wide range of activities. The following extract refers to quantification applied to an activity of the control room monitoring:

> *"We have really reinforced the control room monitoring. So, you'll see that the person in charge of control room monitoring has a badge attached to his belt.... Every 30 minutes, something rings and he has to check, at least, the flashing parameters. Now they take the alarm forms*

> *more regularly at least. I'm not going to say it's perfect. Thanks to this, we have evolved considerably." (Int 13, head of the operational department)*

However, the above citation uncovers an ambiguity relative to the purpose of the indicator. It is unclear if it was used to verify the existence of the control room monitoring practices (external traceability) or to control the effectiveness of this practice (monitoring for improvement).

Learning from measurement and assessment. Monitoring indicators enable continuous improvement and organizational learning. This refers to one of a basic principles of quality management. IAEA requirements state that: *"the management system shall include evaluation and timely use of …lessons from experience gained and from events that have occurred…results of research and development; lessons from identifying good practices"* (IAEA GSR Part 2, 2016). ATOM recognized that in order to manage significant deviations quickly: *"various means are used: periodic reviews, risk analyses, controls and assessments" (Doc 16, ATOM Safety management guide).* A respondent explained why an integrated management system (IMS), implying a process-based approach to management, required indicators for each process: "*the idea is to make these processes move forward and be sure that there are always people to make them move forward. Hence, the interest of these indicators" (Int01, operations engineer).*

Therefore, quantification-based monitoring, followed by learning, leads to better control (regulated safety) and a better understanding of the operating system (managed safety). More specifically, learning enriches sensemaking and adds to improvement of safety rules, but also of real safety practices.

Practices are controlled by quantified indicators, which are the traditional means used to develop regulated safety. However, this needs to be augmented by monitoring and learning in order to improve safety practices. While monitoring and learning for continuous improvement are present in ATOM, quantification is used mainly as a form for traceability.

4.1.4. Ensuring safety via specialization

Our findings show that the complexity of nuclear power plant activities requires highly qualified and specialized managers and operators. However, ATOM recognizes that specialization can lead to the formation of multiple silos (for example, between the different departments, executive managers and operational agents, functional and operational activities) and makes efforts to remedy the disadvantages of specialization. One means used is its new integrated management system (IMS), which was introduced to enable a better overview of activities through the implementation of the process-based management.

4.1.4.1. Specialization to face complexity

Horizontal specialization. Specialization allows for *"clarification of roles so that everyone is aware of their responsibilities and does the right things at the right time" (Int01, operations engineer).* ATOM formal structure is characterized by well-defined roles. A clear definition of roles contributes to ensuring availability of the "*right skills at the right time*" (Int 14, chief of the safety and quality mission). Awareness of these different roles and responsibilities is important to ensure that safety-sensitive information reaches the relevant individuals or departments. This stability of role in ATOM's specialization is considered to be an important element of safety because it helps the employees to understand the complex work environment and the multiple inter-department and inter-professional links:

> *"Stability is important because each actor must know exactly what he has to do and, especially, to whom he is answerable and his responsibilities vis-à-vis colleagues: whether his manager or another department, because we are all ultimately linked by inter-departmental networks. Everyone must know exactly what he owes to others and what are others' responsibilities. In case of a problem, whom should I contact, etc.? That's a solid organization". (Int01, operations engineer)*

However, respecting the limits of each role may be difficult and it may impact safety. For example, external perturbation and re-negotiation of the boundaries of individual roles may disrupt mindful monitoring in the control room ("being here and now"), leading to incidents or even accidents due to missed alarm signals. An operations shift manager admitted*: "I try as hard as I can to make sure people are in their defined place, even if it might be painful for some. An operator has to stay on monitoring, because the control room has to always be monitored" (Int 16, delegated operations shift manager).*

Vertical specialization. Vertical specialization should guarantee the respect and understanding of roles at multiple levels. A delegated operations shift manager acknowledged: "*when I say - I make the decision, but I'm not the only one making the decision, I'm part of a decision-making level" (Int 16, delegated operations shift manager).* The vertical specialization at ATOM is well rooted: *"in our department, we work by vertical action plans" (Int 04, functional top manager).* This "pyramidal" approach of vertical specialization is internalized in the company's values and culture: "*culturally, we only know the pyramidal system" (Int 04, human and organizational factors lead)*.

Independent evaluation. Our informants highlighted that specialization guarantees necessary independence of safety evaluation: "*one of the key elements is...the fact that we have an operations shift manager and an independent safety authority that make independent safety assessments - this allows us to guarantee good safety" (Int 12, operations shift manager).* The independent safety authority aims to ensure 'safety first' priority (for example, in face of production pressure) and to enrich representations through two parallel and independent analyses.

While specialization ensures stability, vital for regulated safety, it sometimes prevents ATOM from seeing the bigger picture required for mindfulness, which also matters for managed safety. ATOM informants recognized the limitations and potential negative effects of specialization such as, for example, silos and difficult communication. Section 4.2 provides more detail on these challenges. Interviewees acknowledged that specialization is not sufficient to guarantee safety and search to overpass its limitations.

4.1.4.2. Attempts to remedy the disadvantages of specialization

Overpass vertical specialization. Specialization inevitably results in the fragmentation of representation of the operational reality. ATOM has introduced several practices to enable employees gain a more complete view of operations across different hierarchical levels. For example, shift changeover briefings are conducted by specialized groups and followed by a general briefing:

> *"This is done at many different levels. The changeover to the chiefs of operations, the changeover to the delegated chiefs of operations, the changeover to the unit pilots, the changeover to the operators, the changeover to the field agents. Once we have finished all our changeovers, the whole team meets for the overall shift changeover. They look at all the changeovers that have occurred to ensure everyone is in alignment with the activities to come and with what has happened". (Int 12, operations shift manager)*

This citation shows that independent evaluations at the different levels are shared and discussed during the general briefing. It respects stability of specialized roles (for regulated safety), but at the same time allows representations sharing and reinforces sensemaking (for managed safety).

Overpass horizontal specialization. The IMS ensures a transversal approach to activities. A technical support organization (TSO) report mentioned that: "*the IMS requires that all settings* *relating to the environment, safety and security are combined and integrated into a single management system" (Doc TSO's report).* ATOM highlights that this favours inter-professional communication and greater sharing of representations about safety objectives:

> *"We are in the process of recreating a link between the professions. All the professions and all the departments are talking to each other more and more.... In fact, we are putting everyone around the table and trying to find a solution that will satisfy everyone and really find the right pilot for the action (this might involve several professions). I think that we are correcting what happened a few years ago, namely, a breakdown between the professions, we are really working to rebuild this inter-professional connection." (Int01, operations engineer)*

As discussed in Chapter 1, a processual approach allows a transversal view of the organization and construction of a global vision and shared representation of activities. The global vision and presence of effective interfaces enabling interactions leads to a more flexible coordination and adaptation in face of unanticipated situations (managed safety).

All the safety management rules, and corresponding practices used to improve safety described above are interdependent. ATOM relies on formalization in order to cover the maximum number of possible situations using rules and procedures. To control their application, ATOM uses measures and indicators (quantification) and assigns roles and responsibilities (specialization).

Our results show that, despite ATOM's efforts to develop managed safety, the implementation of safety management rules remains problematic. The company relies mainly on levers traditionally used for regulated safety ("the same recipes"), such as formalization, quantification and specialization. However, systematic use of formalization, amplified by control through quantification and organizational silos, limits its effectiveness. Section 4.2 discusses these problems and the effects on safety development.

4.2.Organizational limits to developing safety

Managers implement control-related actions to activate safety levers. However, these managerial actions such as formalization, quantification and specialization, have some limits. Our results suggest that overly intensive formalization, quantification and specialization can be ineffective for or produce unintended negative effects on safety, highlighting the limits of managerial control. In line with Starbuck and Farjoun (2007), we provide empirical evidence of these limits. Our result point to the intrinsic limits of regulating and measuring for effective organizing (4.2.1) and competence development to overcome these problems (4.2.2). We show that ATOM's extensive use of formalization, quantification and specialization had unintended negative effects on mindfulness (4.2.3), deliberate learning (4.2.4) and compliance (4.2.5). These results refer to the data structure presented in the Figure 3.7"Organizational limits in developing safety".

4.2.1. Intrinsic limits of regulating and measuring

Our results reveal intrinsic limits of regulating and measuring to enhance safety. The identification of these limits implies the necessity to look for alternative means for the joint development of regulated and managed safety.

4.2.1.1. Limits to regulating

In Chapter 1 we put forth the idea that organizations create rules, which take the form of different processes and procedures. Rules guide, but do not completely determine practices. IAEA highlights that: "*there is a great difference between having excellent procedures on paper and having procedures that are understood and applied consistently and conscientiously by all staff*" (IAEA, INSAG 15). A top-manager at ATOM said that it was difficult to act upon safety directly; it is only possible to "*act on the levers of safety practices*":

> *"Safety is always difficult to define - it is the result of good work. The installation is safe, if we have done our job well. It is difficult to measure the level of safety. There is nothing that can increase safety, we only have the levers that act on practices." (Int 14, chief of the safety and quality mission)*

The above citation show that rules and practices are different, but interconnected notions. Our results show that rules do not fully determine practices for at least two reasons described below.

Rules need to be interpreted. During an immersion stage at the Alpha unit, a proximity manager highlighted that*: "Procedures are our bible, but they sometimes do not describe everything or are not easy to understand" (Int 27, Alpha unit).* First, not all rules are easy to apply and require interpretation. Our results show how compilation of different types of rules can lead to contradictions. A proximity manager confirmed that even technical procedures are interpretable and emphasized the importance of a decision-making system:

> *"There are always different ways to interpret the rules. One would think that it is as clear as 'starting the initiating the retreat in steam generator under one hour'. Yes, that is very clear. But even in this document, which is our operating reference, there are things that can be interpreted differently, that are not as clear-cut as one might think." (Int09, operations shift manager)*

No rules are suitable for all real-life situations. Even the strictest and extensive formalization cannot guarantee that a rule or set of rules are appropriate for all possible events: *"we have frames of black and white rules, but we can find ourselves in a grey situation, where we are not sure what to do. There is a problem of interpretation" (Int09, operations shift manager).* The proximity manager highlighted a recurring problem of reality differing from planned and formalized situations: "*We regularly have to change the procedure, because the procedure is not adapted [to the situation]" (Int12, operations shift manager).* For example, due to the complexity and uncertainty involved, rules thought to be relevant in some simulations might require adaptation when applied in real life situations:

> *"A simulation on a reactor simulator will tell you exactly what you want to hear. In the reactor unit things might be different, reactor reacts differently. For example, I had a simple shutdown, I had an isolation of the discharge that I should never have had, so... by mutual agreement we asked for an automatic discharge isolation system. In the end we adapted the instructions." (Int11, reactor operator)*

The limits of interpretability and suitability of rules in real-life situations illustrate why the development of regulated safety should be complemented by the development of managed safety.

4.2.1.2. Limits of measuring

Limits of modelling to understand the reality. Similarly to the formalisation of rules, quantification has intrinsic limits for effective organization. The introduction of quantifiable indicators relies on modelling, which can reduce sensemaking ability.

> *"We are modelling everything. I think that there are things that cannot be modelled, which is why the counting, transmission and knowledge transmission workshops matter. There are some things that need to be well structured, there are other things - you don't need to structure, it will happen by itself." (Int04, functional top manager)*

In addition, despite all efforts, modelling cannot always capture complex and changing reality, such as, for example: "*change in ventilation configuration to control the generated flow of dust - these are things that are difficult to take into account*" *(Int06, head of Safety and Quality department).*

These limits of modelling reduce measure suitability and effectiveness in real-life situations and highlights the need for jointly developed regulated and managed safety.

Limits of indicators to capture human factors. Our results also show that it is often difficult to quantify human-related factors. As one proximity manager recounted:

> *"It's very difficult to always try to frame people... the human risk is always present. Competence management is a bit soft, it's difficult to manage. In the teams, the human element - we know what it is, we share the mistakes we make, 'yes, it wasn't a good day, you didn't sleep well...' And that can't be understood. Finally, when you take over responsibilities, you don't want to hear - 'he didn't sleep well the night before'." (Int 16, delegated operations shift manager)*

This highlights the problems and even discomfort related to making human errors transparent, thus they remain not sufficiently covered by formalized rules and corresponding indicators.

4.2.2. Competence development to face the limits

Our interviewees recognized the limits of formalization, quantification and specialization. Development of employee competences helps overcome these limits. Developing competences help employees make better sense of the different situations, understand organizational rules and act even in a context not covered by rules. Competencies are considered important to complement and share representations and deal with real-life situations (managed safety).

4.2.2.1. Competencies to understand real-life situations

Ability to understand real-life situations. Professional experience was highlighted as crucial for enriched representations:

> *"The [nuclear] facilities, you see it differently every day as you do activities. With experience, you start to anticipate things or sometimes, maybe, you anticipate too much." (Int05, trainee reactor operator)*

Experience was also seen as increasing mindfulness:

> *"When we intervene in facilities - there is theory and there is practice that will tell us: 'such noise, it is not normal'. So maybe there's a tap you haven't seen, which is closed and needs to be opened. So, it's little anecdotes like that - that's the experience for me". (Int 03, field agent).*

Complementary competences to complete understanding of real-life situations. ATOM admits that competences help overcome problems stemming from the existence of organizational silos. Furthermore, the cognitive diversity and variety of experiences of team members enriches the interpretation of the different situations: "*this mental visualization of actions and their repercussion and the appropriation of the facilities" (Int11, reactor operator). "We added other people to the teams... Other skills, other ways of looking at things were brought in. So, for me, that contributed to the good functioning of safety" (Int05, trainee reactor operator).* For a middle manager, a good mix between knowledge and experience ensures a balance between regulated and managed safety:

> ***"When you have little experience, you end up doing a lot of regulated safety****. That is to say, we cling to procedures, to what we have learned. As a result, we aren't necessarily aware of what could happen, we have much less adaptation.* ***In fact, adaptation is based on experience, on what we know... You have to find the right balance between the two:*** *when you have very, very experienced people who are too sure of themselves – managed safety is too strong and regulated is too weak. What we try to do...is to find the right balance and put the very experienced people with the less experienced ones." (Int 13, head of department)*

4.2.2.2. Competencies to apply rules in real-life situations

Competence to understand rules. ATOM management makes a clear link between experience and understanding the meaning of rules and procedures:

> *"With experience, we tend to add real-life experience and understanding, because we have analysed a certain number of situations that we have seen, the safety studies that have been carried out,* ***we understand better the reason why there is such and such prescription*** *and we are able to say, there, we did not respect the rule, so we have to analyse it, but it is less serious than there, where we did not respect the rule, but safety was reduced." (Int 14, safety and quality top manager)*

Thus, experience leads to the development of mindfulness and sensemaking, which are crucial for managed safety.

Competence to deal with real-life situations in the absence of clear rules. Similarly, competences are crucial for decision-making in face of unexpected situations (managed safety) differing from planned procedures (regulated safety). In face of unexpected situations, the interpretations and actions are based on experience. Furthermore, experience is especially important in the case of "grey areas", where it is difficult to clarify whether a situation is evolving as planned or accidentally:

> *"The problem with the in-between (not normal, but not accidental yet), which means that very quickly we may evolve towards an accidental stage...* ***In the in-between period there are no rules and little organization****. Each defect will bring its own specific organization because we won't have the time to really create everything and put all the competent people around the*

table to find a solution. So, we're really going to base our decisions ***on people's competences****. After that, it's down to the shift team alone". (Int01 operations engineer)*

A top manager linked competences to managed safety and defined them as a set of technical, reflective and situational intelligence allowing flexibility:

"When we talk about proactivity, competence and adaptation, we are talking about competences. Someone who is competent is not only technically competent but also competent in terms of reflection and approach to problems.... It is also this intelligence of action." (Int 04, functional top manager)

Competence development is considered important for the implementation of both effective regulated and managed safety: rich, diverse and shared professional experience allows a better understanding of the situation and a better understanding and application of rules, while allowing adaptation to a real-life situation. Nevertheless, despite this acknowledgement, competence development is seen by some employees as insufficient: "*the transmission of good practices is less common, so, afterwards, we stay more on the academic side; things that we learn from books, but experience is not learned from books" (Int 10, nuclear reactor pilot).* Moreover, the influence of safety levers on competence development (formalization, quantification, specialization) is not well understood and has not yet been explored in ATOM.

Despite the willingness to develop managed safety to complement regulated safety and the acknowledgement of the limits of rules as well as the need for the development of human competence, managerial control and coordination are seen as primary levers of safety management.

According to ATOM's top managers, *"making an intervention more reliable means reducing the gap between what is planned and what is actually done" (Doc 04, ATOM human performance document)*. However, not much is said about how to "reduce the gap between what is planned and what is actually done", which can sometimes lead to paradoxical recommendations. For example, ATOM's management insisted that REP rules, aiming to develop **vigilance and mindfulness**, should be done "*systematically in a* ***reflex-mode***" because "*reflex-mode leads to rigor*" (Operational Manager, non-participant observation). However, a reflex-mode contradicts mindfulness.

Finally, use of formalization, quantification and specialization is aligned to nuclear industry requirements, to demonstrate and prove organizational safety. Moreover, the choice of these levers is aligned with the spirit of production efficiency:

> *"When we talk about the rules, I think what has become central in their representation is the procedure, the planning. Even the planning is a central element in their representation of safety. Why? Because it is at the heart of the representation of common elements with the representation of production" (Int04, functional top manager).*

Our results show that use of formalization, quantification and specialization can have negative effects in the context of organizational limits. We discuss the impact of extensive use of these levers on mindfulness (section 4.2.3), deliberate learning (section 4.2.4), and compliance (4.2.5).

4.2.3. Impact of formalization, quantification, specialization on mindfulness

Effective joint development of managed and regulated safety is based on mindfulness, which allows for noticing and interpretating weak signals and leads to the development of an appropriate response to an ongoing event. Our results suggest that the tendency towards excessive managerial control at ATOM, produces unintended and negative effects on attention, sensemaking and motivation.

4.2.3.1. Impact on attention

Excessive rules saturate attention. As shown above, formalization is considered at ATOM as one of the main levers of safety. Our results show that there are too many rules and procedures and highlight a perceived lassitude with an excessive number of written norms: *"the problem we have, I think we have too much doctrine... which means that people are a bit drowned" (Int10, control room supervisor*). The necessary continuous updating and formulating of rules and procedures leads to an overload of attention. With an intensive formalization, the countless detailed documentation becomes difficult to exploit: "*there's so much paperwork, no one reads them anymore." (Int11, reactor operator).* A proximity manager confirmed that:

> *"This is often a problem, that is to say, we have a huge body of documentation and sometimes the information that would help us takes a long time to find or we are obliged to ask other people." (Int09, operations shift manager).*

Instead of guiding operators' attention, excessive formalization prevents assimilation of information and results in attentional overload. This is also true even for rules intended to overcome the risk of non-vigilance: "*we are not only focused on REPs but on a lot of other things and this makes our brains tired" (Int10, control room supervisor).* This example illustrates the unintended effects of managerial control: ATOM has developed REP rules, aimed at ensuring focused attention and high-quality operations, but their implementation can result in cognitive fatigue and reduced vigilance.

Interpreting rules saturates attention. ATOM agents struggle to identify which rule to apply to what situation. In addition, some rules and procedures do not reflect or are not easily applicable to the operational reality. Having to make the choice of the "right" procedure saturates attention through the interpretation efforts required:

> *"We look at the activity, if the procedure doesn't match, our operating instructions are no good - so we throw it away. So, we think about it and we try to put together a new protocol." (Int 03, field agent)*

Control of compliance with rules diverts attention. To monitor compliance with the rules, ATOM has established control, which insists on rigid application of rules and quantifiable measures. Therefore, operators' attention is focused on rule compliance and managers' attention is focused on monitoring this compliance.

Instead of being focused on problem analysis and resolution, operators are focused on problem formalization. This diverts their attention from a deep understanding to accurate formalization. A respondent gave an example of diversion from alert monitoring:

> *"We get asked to do a lot of small tasks. We don't spend an hour doing one thing, we do more like 10 things at a time, but every time, we have to go to the computer: we'll enter an activity on schedule, as soon as there's a periodic test that ends, we have to go into an application to say, here it is, it's over, I checked it. There are a lot of little things, which means that sometimes, we detach ourselves a little from the heads-up monitoring...****Sometimes, the risk is that we put ourselves in a tunnel, we put blinders on, and then we do our work. And then something happens - we didn't see it.****" (Int10, control room supervisor)*

In particular, extensive use of indictors diverts attention from practices. For example, monitoring of the indicators related to IMS processes had become the objective *per se*, rather than the continuous improvement they were aimed at.

> "IMS today as it is done here, is an objective. It's not the means. It's a constraint, it's a review. The review of sub-processes, the review of elementary processes. These are indicators, but they are not going to help me to manage or improve my objectives or to gain efficiency in the objectives. The IMS is an expected result, whereas from my point of view, it should be a means to an end." (Int04, ex-head of Safety and Quality department)

Formalization and quantification focus agents' attention on box ticking-type rule compliance, rather than the development of a deep understanding of the situation, required to mindfully deal with on-going day-to-day events. For example, risk analysis is limited to the identification of only one or two key risks. Formalization and quantified measures in risk analysis limit the questioning:

"Pilot: Risk analyses should be done for two main risks, there is no need to include seven or eight. Two main risks are more than enough.

Researcher: Do two main risks depend on the activity or is it always the same?

Pilot: We can put one or two." (Int11, reactor operator)

This suggests restricted reporting (usually a number of identified risks) which may not provide a picture of the real-life situations. Our result show how quantification deviates attention and, thus constraints mindfulness by reducing questioning and focus on the reality.

In addition to the challenges of the number and quality of rules and procedures, there is the challenge of controlling their implementation. The attention of actors and managers is saturated by the number of rules and deviated by choice of relevant rules, compliance and quantified control of this compliance with rules. **This saturated and deviated attention impedes the possibility of developing mindfulness.** One interviewee talked about the control room where monitoring, crucial for safety, had deteriorated: "*control room monitoring was less effective overall, because, I think, we were diverted, there were lots of things that diverted us from the monitoring desk" (Int11, reactor operator)*. This is paradoxical and particularly problematic for rules designed with intention to develop mindfulness.

4.2.3.2. Impact on sensemaking

Our results show that formalization, quantification and specialization not only affect attention but also sensemaking.

Excessive, inadequate, or contradictory rules and the loss of meaning. Excessive formalization results in distorted understanding of the rules. Operators are unable to simultaneously understand the rules and monitor the situation, that may exacerbate safety risk. A middle manager said: "*They [front-line actors] are asked to do more and more things... - they don't* *see the point. They don't have the meaning, but in fact they've lost all sense of things" (Int13, operations shift manager department).*

This echoes the limits of extensive formalization and quantification, which interfere with the effectiveness of rule implementation: "*the rules that are least respected are those that clash with obstacles for the agents... there, we have to try to redefine actions, make them understand the meaning" (Int09, operations shift manager).*

If the decision to introduce a new practice is not accompanied by appropriate explanation, this will provoke a loss of sense at the operational level and may even lead to social tensions between front-line actors and top management. Tensions are specifically vivid in case of perceived gap between required rules and required practices. A field agent acknowledged that:

> *"Sometimes they tell us clearly 'no, there is no need for risk analysis, you can do this activity'. But wait, I was trained last week, they come and tell me that I need a risk analysis. No-no, they're talking nonsense... It's very complicated. We're made to do things we shouldn't even be doing, we're told to 'shut up', it's very, very confrontational." (Int03, field agent)*

The proliferation of problem-specific procedures often leads to less coherent rules and operator confusion. An interviewee told us*: "you can find documentation flaws: since documents are made for very specific situations and sometimes, you're in a different situation - and you're a little bit lost" (Int01, operations engineer).* The accumulation of more or less detailed rules and procedures can inhibit their clear understanding, which is crucial, especially for operational activities: "*The clarity of the documents is also to ensure that they are not too fragmented; because in real time activity we need to have the information quickly to understand it quickly" (Int09, operations shift manager).*

Moreover, compiled rules (of different levels, types or temporalities) sometimes suggest to contradictory paths: *"in the end, we write so many things, we end up in situations where we have procedures that are ultimately contradictory…"(Int11, reactor operator).* The extract below illustrates how two different types of documents related to the same activity, were incompatible:

> *"For example, if we have manoeuvre instructions that tell us - you have to turn this valve. Then we have another document, it's a kind of plan, so we have mechanical diagrams... We look at the activity, if it doesn't correspond - there, our manoeuvre instructions are not good - so garbage." (Int03, field agent).*

Continuously produced formalized procedures are compiled without sufficient integration, which makes it difficult for ATOM employees to make sense of them. This challenges sensemaking and has a negative effect on both regulated (applying existing rules for expected events) and managed (dealing with unexpected events) safety.

Focus on compliance prevents questioning and engagement. While questioning is important to develop safety, formalized rules and procedures can impede it – *"by describing everything, it prevents you from thinking" (Int17, human and organizational factor lead).* A top manager confirmed: "*we don't ask ourselves questions anymore, we go along with our procedure, and we are not able to take a step back and say to ourselves: finally, I am doing this, but why am I doing this?" (Int07, functional top manager).* This lack of questioning attitude and overreliance on existing formalized rules may be risky, especially in the context of unexpected events (managed safety). The following citation illustrates how exclusive compliance to rules does not guarantee safety and needs to be complemented by mindful sensemaking:

> *"We ended up with a loss of cooling in the fuel pools. We lost two pumps, because it was a hazard. But we screwed up the maintenance schedule for the second pump. We had a pump that had been failing for some time. There was no impact in the strict sense of our technical operating specifications, I'll call it administrative safety - on the documents, we weren't asked to put it back into operation... except that the second one broke down. And we found ourselves without a pump to supply water to the pool in case of a problem for, it's not much, maybe 6-7 hours. We also made a mistake in prioritizing and safety priorities, if we did administrative safety, as we had done,* ***while respecting the doctrine framework; but in fact, I think we didn't necessarily think through the potential consequences****". (Int07, functional top manager)*

This questioning attitude considering what is happening here and now is essential for safety: *"Ok, I respect the text, but I don't apply intelligence [think for myself], I don't think about the fact that if I lose the other pump, even if it's not written in the papers, I don't have a pump anymore" (Int07, functional top manager).*

The existence of formalized instructions for all activities can reduce actor engagement. This can be exacerbated by a managerial focus on control of compliance with rules rather than control of efficient actions: *"this is not about commitment; this is about applying procedures" (Int04, functional top manager).* For example, ATOM management requires exact application of self-control REP, by pointing the finger to the procedure and while pronouncing aloud installation elements name (to control that the intervention is done on right element as described by the procedure). Thus, actors, subject to this control, are under pressure to reproduce a required gesture with precision, because the self-control rule compliance is assessed and results in a quantifiable measure. One operator criticized this rigidity:

> "*Sometimes you get remarks about the gesture of the REPs method [of self-control practice] you have applied. That the finger was not exactly in the right place. You see, that makes you smile. So, we applied the self-checking, if we take this example, but perhaps we didn't have the perfect gesture.* ***I think it's a pity that it traps people even more in the procedure, even in the gestures, instead of having their attention focused on the action*** *that is being done and not on the gesture to do the action". (Int11, reactor operator)*

Some representatives of the ATOM's top management are conscious of this problem and point to the extensive use of strict managerial control, even to implement REPs normally aiming to develop managed safety capabilities:

> *"REPs – once again, we are dealing with tools,* ***we are not dealing with involvement, we are not dealing with commitment, we are dealing with the application of procedures****…The application of REPs procedures will be effective if the persons are mentally committed to what they are doing. It's not the REPs that will make them committed. Commitment is a personal thing." (Int 04, functional top manager)*

The rigidity of control of written rule (formalization) compliance is closely linked to the measurement systems (quantification). The way to control compliance to rules and the way to measure this control's results (though quantifiable indicators) have effect on sensemaking. During the immersion stage of the case study, an Alpha operator referred to "*indicators that cloud the mind*" (Alpha observation) and said that: *"I do something either according to what I feel, or I do it for the numbers - it's a pie charts contest"*. As described above, this sense deviation is amplified by the pressure to meet quantifiable requirements.

For example, ATOM managers are encouraged to make field visits for monitoring field activities. In their reporting, managers highlight potential gaps between procedures and real activities. The practice of the field visits was introduced to enhance learning, but excessive attention to quantified results (number of visits per year) has led to lack of sensemaking (by both controlled and controller). A quantitative reporting of gaps identified during field visits was perceived by field actors as personal criticism and sanction: *"They don't understand that. It's more about policing them" (Int07, functional top manager).* This results in perceived lack of trust: *"we are over-controlling with all our tools. We could simplify a lot of stuff by doing targeted control, but reworking trust." (Int04, functional top manager)*

As already discussed, the objective of indicators was to control compliance with rules through the existence of practices, rather than the effectiveness of practices. Therefore, this deviation of sense amplifies the sensemaking difficulties related to rule compliance. Again, this affects both regulated and managed safety, but particularly impedes managed safety efforts to develop competences and allow adaptation.

Unrealistic expectations and loss of meaning. Extensive use of quantitative control measures shifts the focus from ‘means to develop efficient practices and resilience’ to becoming an objective ‘*per se*’. All organizational levels acknowledged the existence of sometimes unrealistic objectives. In particular, operational proximity mangers highlighted unrealistic planning that may provoke a danger for safety: “*Typically this morning, the planning was unrealistic on different planned activities, if we did those that were marked in the planning, we would go to a safety gap directly”. (Int 16 delegated operations shift manager)*

An interviewee explained:

> *“We're in a ‘gap ’culture based on the idea that 'the benchmark is there'... And in reality, we have a tremendous number of constraints.* ***In fact, it's just not feasible. In fact, we don't know how to do it.*** *And so, that means that at some point, you have to be reasonable.” (Int04, human and organizational factors lead)*

This approach can arise from regulated safety assumptions that respecting procedural barriers (alongside their corresponding indictors) guarantees safety. However, as discussed in Chapter 1, while regulated safety foresees predictable events, real life is uncertain and particular managed safety practices should be developed to manage unpredictable events. Thus, in real-life situations, planned expectations foreseen by regulated safety, became unrealistic and may not reflect anymore the complex and dynamic reality.

Specialization prevents organizational integrative changes. Excessive specialization prevents integrative changes and impedes sensemaking. Implementation of integration-oriented IMS, superimposes process-based management on ATOM’s existing pyramidal structure, rendering division and coordination of activities opaque. The following citation illustrates how the implementation of this superposition of the two structures meant to improve coordination, produced the opposite effect – a greater fragmentation of activities (with corresponding measurable indicators), amplifying existing ambiguities and tensions. The interviewees told us that:

> *“Culturally, we only know the pyramidal system. This means that every time we finally develop something that should be integrative, whose objective is to be integrative, in fact, we reproduce the patterns we know, we make the pyramidal” (Int04, human and organizational factors lead).*

"In our department, we operate on a vertical action plan. And our macro-processes pilots are not in the right posture, they stay in a vertical posture, they also give the action plans. So, in our power plant, the process-based projects are managed as the departments: 'you do this to us, you do that" (Int 04, functional top manager)

4.2.3.3. Demotivating

Challenges related to developing safety through formalization, quantification and specialization are linked to decreased motivation. Motivation is required for mindfulness as a necessary engagement in this effortful process. Demotivation impedes safety practices and competence development.

Organizational slowness is demotivating. Challenges of rules presented above lead to the perception of slowness of working processes. Several interviewees referred to organizational "slowness", which results from excessive formalization: "*everything is slow - to change things, to do maintenance, to implement software - you have to go through meetings of I don't know how many hours, but it doesn't actually go forward, and people are demotivated" (Int03, field agent).* Field actors perceived activities or initiative such as implying filing of numerous documents, as taking too much time: *"it is long, it is heavy" (Int11, reactor operator), "an activity that should take five minutes can take three days" (Int02, control room supervisor).*

Ineffective, but controlled meetings demotivate Workers and managers are required to attend certain meetings and attendance is measured. Having to attend meetings was considered demotivating. ATOM to value indictors (indicator of meeting attendance) *per se* more than the efficiency of the measured practice (meeting efficiency). This can impede safety. While regular interfaces meetings are set up to enable exchange and information sharing, less motivated participants are less likely to perceive and explore their benefits. Many interviewees believed some meetings were ineffective and time consuming if too frequent and not well prepared neither managed and did not contribute to effective problem solving:

"Everyone in the department *knows about the meetings that are more or less useful: those that are going to be really important, those that are a little less, b**ut that are subject to an attendance indicator. An indicator is still an indicator.** But we still try to respect them, our indicators. And in fact, I may end up having to show my face." (Int01, operators engineer)*

Moreover, rigidity in the control prevents people from making sense out of it and, if necessary, questioning it in the development of a mindful response. Inefficient use of time spent on attending meetings increases the load in already tight schedules. A proximity manager said: *"we get asked* *to do a lot of representation in seminars and meetings. Thus, it's complicated to manage our schedule – we don't have enough time for our core business" (Int09, operations shift manager).*

The results from our axial coding show **interconnection among the negative effects on attention, sensemaking and motivation**. For example, attention, saturated by excessive use of formalized rules, prevents effective sensemaking. A middle manager confirmed:

> *"The problem is that we have a lot of requirements. And people get a bit lost, lost or saturated by all these requirements. And I think that we lose the meaning every time." (Int13, operations shift manager department)*

Attention overload is also linked to demotivation. A top manager said: "*I think we waste a lot of energy on tasks that have little added value" (Int14, chief of mission safety and quality).* In turn, demotivation, resulting from this rigid control of compliance of the rules, relates to the loss of meaning: *"there are things that we could make people accept more quickly if we put a little more sense into them, and a little less rigidity in the way we apply them" (Int11, reactor operator).* Demotivation also blocks learning opportunities. ATOM organizes regular seminars for operations teams, but "*no one goes there; people are no longer motivated - they don't want to attend" (Int 03, field agent).* These examples highlight the mutual -reinforcement of negative effects induced by organizational limits.

4.2.4. Impacts of formalization, quantifications, specialization on deliberate learning

4.2.4.1. Impeding autonomy

Autonomy is crucial for competence development and deliberate learning. However, extensively used formalization, quantification and specialization reduce autonomy development.

Rules and controls limit initiative and autonomy. Formalized rules and corresponding monitoring reduce opportunities for initiative and reduce autonomy– *"what bothers and saddens me is that a lot of new requirements have been put in place to hide the non-respect of what could be considered as the core, the culture of the agents" (Int 04, ex-head of Safety and Quality department)"*

An automated control room monitoring is a good example. Operators wear badges, which beep at regular intervals to remind the operator to check certain alarms. According to the interviewee, this approach leads to loss of safety competence:

"Control room monitoring is the hard core of the job. And yet, we had to instrument it. This means that all this proactivity, all this room for manoeuvre, all this ***initiative, in the end, it no longer exists. All initiative has been taken away****" (Int 04, ex-head of Safety and Quality department)*

Moreover, one interviewee said that automated control room monitoring led to loss of mindfulness, especially important to capture and analyse weak signals:

"To monitor all the parameters of the installation, we have implemented a powerful practice that says, depending on the conditions, every x minutes you have to go and check this parameter, every y minutes this parameter, etc. I think we've lost something fundamental because that's normally an acquired skill." (Int04, ex-head of Safety and Quality department).

Rules and controls limit initiative recognition. While procedural barriers (regulated safety) are undoubtedly useful to maintain safety, they affect workers' autonomy to deal with real, sometimes unexpected situations (managed safety). This is recognized by ATOM informants. A control room operator explained that: *"In fact, what is caricatural to be 'locked' into your rule, without having a tiny bit more hindsight vision [distance to analyse] ...**it robotizes and kills initiative**..." (Int11, reactor operator).* This understanding that rules and procedures prevent autonomy is present at the highest organizational level A top manager told us that:

"Here, we have added layers and layers of paperwork...while they have an expectation of simplifying the procedures. In fact, we keep adding to it. We don't help them; we don't make them ***responsible****. (Int07, functional top manager)*

Moreover, managerial control creates the perception that top management ignores field actors' professionalism and capacity to make relevant decisions when faced with critical events.

Pyramidal structure disempowers. Specialization can also inhibit autonomy. One interviewee told us that: *"there are more and more layers of responsibility. So, it's kind of chopped up, so people, to me, are taking less and less responsibility" (Int16, head of Safety and Quality department).* Another highlighted the tendency of lower-level employees to rely on upper-level decision-making, which leads to loss of efficiency:

"There is a loss of efficiency, because necessarily when you go up - there is the funnel effect, and instead of having, I don't know, five people making the decisions, you're going to have one, so you're going to wait for him to make the decision." (Int14, head of safety and quality mission)

This is caused by the pyramidal structure (vertical and horizontal specialization), in ATOM: "*pyramidal structure is not very empowering - in fact, in the end, the accumulation tends to disempower" (Int 04, human and organizational factors lead).*

4.2.4.2. Preventing an overall vision

Pyramidal structure fragments representations. Our results show that extensively specialized structure prevents rather than facilitates communication degrading communication and inhibiting learning. We recall that deliberate learning is also considered a key element of joint managed and regulated safety development.

Therefore, ATOM agents found it difficult to understand the complex system of fragmented responsibilities in day-to-day activities and to respond to and prioritize multiple simultaneous demands from different operational and functional ATOM entities. A top manager acknowledged:

> *"I organize and as a result, it becomes something 'in addition'. Because the only way that it will not become something in addition, is if the agent himself, who is in the middle of all this, has some perspective, a global understanding, to synthesize the different requests to arrive at something that makes sense. Here, instead of four requested actions – I'm going to do one, which actually answers all that." (Int04, functional top manager)*

The sensemaking required to achieve a general overview of activities, which is crucial for managing real events (managed safety), is compromised by fragmentation due to specialization.

Lack of information sharing. Our results highlight lack of information sharing, both vertically and horizontally. A middle manager expressed concerns about poor information sharing across hierarchical levels: "*a big problem of communication in the department where information does not necessarily go down and does not necessarily go up either" (Int13, operations shift manager department).* ATOM employees recognized the importance to overcome this problem – *"if a decision is made, it should be discussed with the people who will be responsible for executing it and those who will be impacted. Only this way we can improve things. But sometimes it's only in one top-down direction". (Int10, control room supervisor)*

However, horizontal siloes exist, also, present among groups of operational teams. The interviewees referred to different practices among, supposedly interchangeable, shift teams – "*it's internal management... everyone does their own things [habits]" (Int05, trainee reactor operator).* For example, there are differences in compliance with REPs:

> *"The messages about REPs have been heard. Afterwards, on the practical side, I think it depends on the teams. There are some - they will touch [facilities without REPs*

> *implementation]... We, in our team, try to 'blow down' the procedures [engage the adherence to procedures to lower levels] that we are asked to do from above" (Int03, field agent)*

Despite extensive (and even sometimes noxious) control efforts, rule compliance across teams differs, and these disparities may be considered as evidence of poor managerial control. In this context, shifts teams do not share their experience and their best practices, thus, learning and, more particularly, the ability to face unexpected events (managed safety) is constrained.

4.2.4.3. Lack of feedback

Operational feedback: "it's beyond us". Poor feedback – and especially on operations – has a negative impact on learning development. For example, ATOM's system of operating experience feedback (OPEX) is hampered by the existence of silos of individuals responsible for identifying anomalies and those responsible for deciding how to deal with them. Specialization can create these barriers: *"there is a big communication concern in the department where information doesn't necessarily go down and doesn't necessarily go up either" (Int13, operations shift manager department).*

As a result of silos in the formalized and centralized OPEX system, the individual reporting an issue does not receive systematically the information on the follow-up or action taken to resolve it. A field agent explained:

> *"For us, on the side of the field agents, it means detecting anomalies, reporting the anomaly, and then it is up to them to decide… **We notice something abnormal - afterwards, it's beyond us**" (Int03, field agents).*

Operators "*have a lot of alarms in the control room, they don't have feedback on how the alarm is processed or how it was processed" (Int07, functional top manager).* A field actor confirmed that decision-making about reported incidents is not shared nor accompanied*:*

> *"I think the feedback works, but we don't have acknowledgement of its receipt – it doesn't always come back. If we don't question ourselves and say I found this, where is this follow-up? We don't have feedback like: 'OK, I've seen it and we'll change it. I'll let you know when it's changed'. ... So, it's difficult for us to see in real time whether this information is being passed on correctly." (Int10, control room supervisor)*

Volume and registration slow feedback. The described lack of feedback about reported anomalies and incidents, blocks learning: "*OPEX is useful, but the problem is that it is not followed" (Int11, reactor operator).* This might be due to the extensive number of anomalies registered and 'treated'. High-risk industry, and specifically nuclear industry, follows the logic requiring capturing and analysing maximum anomalies and near-misses. The assumption is that by working on weak signal (by covering a maximum of minor incidents) organization will reduce the risk of major accidents. Based on our observations and informal discussions, ATOM search to capture (by registering) and to analyse all anomalies and minor incident.

Moreover, existing OPEX system requires each anomaly to be categorized in one of four categories for further treatment, before discussing during specific OPEX meetings. Registering and categorizing is time consuming and results in blocking relevant and timely feedback:

> *"It doesn't loop back very much. You see, on the operational level…they make work requests, but they don't have any feedback on the work requests they have made. In fact, it is not organized. (Int07, functional top manager)*

> *"When it is traced, for the moment, we don't necessarily know how to use it. Well, we know how to use it, but we don't do it. I say, 'we don't know how to use it', we don't go looking for it" (Int13, operations shift manager department).*

This focus on extensive identifying; reporting and processing all incidents and anomalies (gaps) affects learning. Due to the pressure of the volume of anomalies to treat, their analysis may remain superficial, leading to deviant learning.

> *"We put in a rule... I struggled a bit with the site's OPEX project, where they came in through a tool, neither through the meaning. The idea ... what I mean is: it's not the gap that interests me, but I want us to set up a weak signals approach. If I deal with weak signals, they are based on reported gaps anyway. So, I'm going to have a lot of findings, some of these gaps are not processed - it's not important, but they are weak signals. The gaps that are important - we're going to address those. We built it differently here.* ***We simply built it to treat anomalies. I register the gaps - I processed them, so it a real labyrinth to register the gaps.*** *As a result, people didn't want to do too much". (Int07, functional top manager)*

A proximity manager highlighted that analysis of reported issues (anomalies) depends on the competence of the manager concerned and his/her ability to identify, analyse and act on weak signals, echoing mindfulness:

> *"For the success of the managerial field visit looking for weak signals, all our managers must have the same vision. They need to have a well-honed eye. That means that when I watch someone work, I have to see how I can pick up weak signals and the right information. It's all in the analysis. What analysis am I doing? What is good? What is bad? What could improve the system? Like all our managers, we don't have the same eye set in the same way…" (Int12, operations shift manager)*

In addition, the focus on negative gaps overlooks the feedback positive experience: "*there is no communication about successfully avoided near-misses*" *(Int13, operations shift manager department).*

Again, our results highlight the **links between the negative effects on autonomy, global vision and feedback.** For example, poor feedback is an impediment to the development of a general overall vision of the process and the development of learning. Failure of the effectiveness of OPEX reduces motivation to share information, reinforcing the silo effect and reducing learning:

"We share debriefing information, but it's not organized, it's more word-of-mouth between us.... Not everyone has information and sometimes it stays within the team." (Int09, operations shift manager).

The negative effects on deliberate learning also reinforce and are reinforced by the negative effects on mindfulness. For example, ATOM respondents highlighted the links between lack of autonomy and lack of motivation, which are closely related:

"It's important to be empowered. First of all, it's in terms of recognition - I recognize you, I delegate this responsibility to you, so you have a value. After that, taking responsibility means you go a bit on the motivation and the sources of commitment. If I make you responsible for this, you will, I think, put a lot more of yourself into achieving the objectives" (Int07, functional top manager)

We found that sensemaking difficulties in relation to rules, lead to lack of initiative, which, in turn, affects mindfulness and learning:

"Researcher: What do you expect to ensure safety? Is there anything more to do?

*Pilot: Yes, there must be more to do. But I'm not here to... My job - I do technical work. After that, everything above that, **I listen to what I'm told, I'm a good soldier, I do technical work**". (Int02, control room supervisor)*

"I don't really know; I don't know anymore. I don't know if it's up to me to manage this, or if it's for our superiors? And today we are clearly told that it is no longer up to us to manage this. We have superiors who have a vision and a perspective on certain activities and who will tell us that we need to do this or that, etc." (Int 03, field agent)

In sum, lack of autonomy coupled with fragmentated representations and amplified by lack of feedback, is a barrier to deliberate learning. This also affects mindfulness since, in the absence of effective information sharing and feedback, employees have difficulties to interpret their experience and develop mindful responses.

4.2.5. Impact of formalization, quantification and specialization on compliance

Compliance with rules is at the heart of regulated safety, providing procedural barriers against predictable events. Interestingly, despite the highly regulated character of the nuclear industry, an extensive use of formalization, quantification and specialization can have negative effects on compliance with rules. Obviously, the impact on attention, sensemaking and motivation affects not only mindfulness (described above in section 4.2.3), but also compliance as ability to rigorously apply the rules. Thus, in the context of compliance weaknesses, ATOM was aware of superstitious learning and the potential to lead to normalization of deviations.

4.2.5.1. Superstitious learning

Progressive loss of rigour of rules application. Top managers recognized that there is lack of rigor in applying rules that become systematic "*in operation departments, we have lost a lot of rigour in the way we carry out our requirements" (Int13, chief of operations department).* This affects safety results– "*so there have been a number of incidents because this safety culture has actually started to decline" (Int04, functional top manager).* Following example of the use of the periodic test practice instead of equipment requalification practice illustrates the drift:

> *"After repairing of an equipment, we have to requalify this equipment [requalify the status of this equipment to signal its availability]. In fact, we tended to requalify this equipment using initial periodic test [used to notice repair needs]. We repaired it – we reran a periodic test* ***. So, this was not a permanent practice, but we often did this. And in fact, we're not allowed to do that.*** *It's a drift, it's a drift, and we're currently trying to correct it, to correct our aim, and therefore to improve safety... In fact,* ***the amalgam has developed over time*** *because it's something that we've been seeing for several years. The amalgam was made and as a result, in people's minds, we have a periodic test, a material failure, a repair is behind it, we carry out a periodic test again..." (Int01, operations engineer).*

"Nothing happens so it becomes the norm". Superstitious learning is based on misattribution of the link between lack of compliance and absence of negative safety results. ATOM recognized that the loss of rule meaning combined with superstitious learning can lead to deviations becoming normalized.

> *"Managers are well aware that this is a difficulty, because when they go and observe they realise that the actors implement certain things and do not implement others.* ***Maybe because they were never convinced****, that could be it, or yes, they were convinced, but with time it's tiring and finally they realize the normalization of deviance, there is that too.* ***One day they didn't do it, the next day they didn't do it, finally, nothing happens, it becomes the norm****." (Int14, chief of mission safety and quality)*

4.2.5.2. Normalization of deviance

Overload pushing to less compliance. ATOM sets controls to counterbalance the risk of superstitious learning:

> *"Finally, in our industry,* ***that's why there are so many control loops, it's because we want to check that there is no degradation****, that it doesn't go down, that the level of operations remains in place." (Int14, chief of mission safety and quality)*

A middle manager pointed to the link between demotivation due to control, and lack of compliance: "*because it's so tiring to be on all the accounts, that there are inevitably to be some fields that we drop voluntarily or involuntarily". (Int14, chief of mission safety and quality)*

ATOM's informants recognized that compliance with rules could sometimes be jeopardized by workload pressures: "*people are very overloaded and cannot necessarily produce good quality work all the time" (Int01, operations engineer).* Thus, "crossing the line" in relation to applying the rules frees up time to allow to try solving a problem, with the time leading to the normalization of deviance:

> *"Because in fact, if we analyse why we have lost rigour: I think that everyone wants to do things well and wants to help, but you know very well* ***where the red line is and you say 'I can get close to it, I can get close to it' and at a given moment you say 'if I take a step on the other side, it's just one step, it's not very serious. If I put one foot in, it's not a big deal'****, once you've put one foot in - you say you can take one step and then in the end you forget where the line is. The job is to repaint the red lines and to say now it is strictly forbidden to put your foot on the other side." (Int13, chief of operations department)*

Loss of meaning of rigorous rule application. ATOM managers described lack of appreciation of the importance of rigour while applying procedures: *"this rigour is not transmitted, it is not present, it is not anchored most of the time" (Int 04, top functional manager)*, which is reinforced by loss of rule meaning:

> *"What are the key elements for guaranteeing and maintaining safety in your daily practices in operation or in the plant in general?*
>
> *I think that the first key element is to* ***remind people of the challenges and the meaning of each of our requirements, which we tend to forget too much****. Behind rigour we can put many things..., we are working a lot on our fundamentals, because we have lost a lot of rigour." (Int13, head of operation department)*

To manage both anticipated (regulated safety) and unanticipated events (managed safety), ATOM's managers rely on three levers, rooted in the production efficiency logic - formalization, quantification and specialization. Specifically, formalization and quantification respond to ATOM management's willingness *"to act in the field and to contribute to the performance of each stakeholder...by providing markers for the teams; by giving meaning to the "cultural" steps to be taken on daily basis" (Doc 04, ATOM human performance document)*. ATOM interviewees acknowledged that the company generally controls by quantification: "*we have added meetings, we have added indicators, we have added monitoring of action plans, etc. and we continue. It's never-ending. We're still using the same recipes". (Int 04, human and organisational factor lead)".* However, due to extensive and sometimes irrelevant use, levers of managerial control and coordination can become ends in themselves, rather to stay means to develop safety.

Our results show how an extensive use of traditional levers produces unexpected negative effects on mindfulness and deliberate learning, which points to the dangers of exceeding organizational limits of managerial actions. More specifically, our results reveal the negative effects of extensive formalization and quantification and inappropriate quantification to control practices, aiming at the development of mindfulness, using quantifiable indicators.

Diminishing mindfulness and deliberate learning reduces capabilities not only to deal with unanticipated events (managed safety), but also to efficiently apply procedural barriers of regulated safety (e.g., loss of meaning of rules, indicators, and roles).

Our results reveal the negative effects of formalization, quantification and specialization, which have an impact, mainly, on sensemaking. ATOM's top-management suggested that leaders could compensate for these negative effects by helping people to make sense of their day-to-day activities. In this context, the role of the sensemaking-sensegiving process of leadership for safety is crucial.

4.3. The role of leadership for safety: sensemaking-sensegiving-sensemaking process

"Safety is too important to be left to engineers and economists" (Sagan, 1993)

Our results reveal that sensemaking is a key element to develop managed safety and to avoid or minimize unintended negative effects of levers of control and coordination (formalization, quantification, specialization). Thus, the role of leadership for safety must include sensegiving and accompanying sensemaking. In the succeeding sections, we highlight ATOM perceptions of the key role of leadership in sensemaking (Section 4.3.1) and the barriers to the leadership sensemaking-sensegiving-sensemaking process (Section 4.3.2). Then, we use safety-related messages (about safety priority- Section 4.3.3 and questioning attitude – Section 4.3.4) to exemplify the leadership sensemaking-sensegiving-sensemaking process across organizational levels. The results refer to the data structure depicted in Figure 3.8 "Sensemaking-sensegiving process of leadership for safety".

4.3.1. Sensemaking: the key role of leadership

4.3.1.1. Leadership role and sensemaking-sensegiving practices

To give sense and accompany sense as a major role of leadership. Our analysis reveals four main leadership roles for safety, described by managers in ATOM: 1) giving sense, 2) supporting sensemaking 3) enabling trust and autonomy and 4) controlling. Giving sense and supporting sensemaking were particularly emphasized. Figure 4.1 is based on NVivo extraction of the related quotes repartitioning.

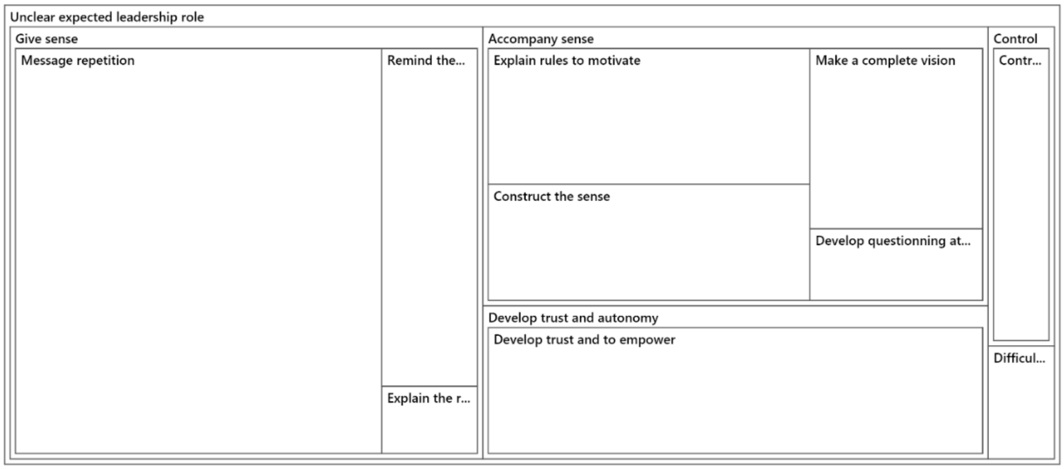

Figure 4.1. Quote repartitioning in the code "Unclear expected leadership role"

Thus, giving meaning to safety is an important leadership role. In answer to the question "*what leadership is beneficial for safety*", ATOM informants referred to*: "being present in the field, knowing what's going on, regulating the workload, prioritizing, communicating on the status of the facility" (Int 17, human and organizational factors lead); "knowing activities, to have a less theoretical vision of things and not take decisions that lack meaning and therefore will not be understood or accepted" (Int04, ex-head of Safety and Quality department).*

Practice of reminder about safety priority as a major leadership practice. While ATOM respondents cite different example such as presence on the field, animation of pre-job briefing, providing feedback, however the practice of reminder of safety messages and compliance with requirements is emerged as a mainly cited practice of leadership:

> *"We have to carry the messages on a daily basis, repeating things." (Int12, operations shift manager)*

> *"The meeting begins with an item called "safety minute". This is a briefing on one safety item per day that starts all meetings for the day and the subject is different each day. The safety minute point of the committee meeting focuses on basic personal protective equipment: short/long sleeves, wearing glasses." (Observation, Macro-Process Safety and Quality Review)*

Thus, leadership in relation to building and sharing meaning is based, almost entirely, on simple reminders about rules.

Insufficient leadership development practices. ATOM top management recognizes the importance of leadership role in sensemaking and the insufficiency of the reminder practices to cover this need. Informants referred to leaders' inability to give meaning to the rules:

"Today, the leader, is not able to, or at least, from the feedback I have currently managed, he does not use the levers to give meaning." (Int04, top functional manager)

This inefficiency would seem to be caused by managers' 'posture', referring to leader-centric theories about leadership traits and points to the inability of leaders to give meaning and accompany sensemaking:

"That's why in our leadership programme, we talk about 'Listen. Empower. Free up initiatives'. Yes, in a normal system, that's what would make it work. But it doesn't. Because from the beginning, the manager's posture is not the right one." (Int04, top functional manager)

ATOM aims to develop leadership and offers monthly internal leadership training seminars for top and middle managers, focused primary on of leaders' traits ('posture') and autonomy development.

"So, if we change the posture of managers, we try to ensure that they give responsibility to the players, that they encourage initiative, that they encourage autonomy" (Int07, functional top manager)

"That's why the idea of the Leadership lunch (a practice of meeting over lunch to discuss a text on leadership) was to force them to speak, to express themselves". (Int07, functional top manager)

Difficulty to define the concept of leadership at the frontline level. However, our results suggest that leadership *per se* and leadership for safety remain difficult to define for ATOM employees at lower organizational levels, including those closer to operations (proximity managers and front-line actors). Some informants referred to these difficulties related to understanding and defining leadership:

"Researcher: What do you think leadership for safety is?

Pilot: I have no idea. It's not complicated. The question. I can't answer, I don't know what it means. What is leadership?" (Int02, control room supervisor)

Researcher: What do you think leadership for safety is?

Pilot: That's not easy to answer... It's something we don't do at present." (Int10, nuclear unit pilot)

Others defined leadership in terms only of a managerial role as, for example, operations shift manager.

"Researcher: What do you think leadership for safety is?

Operator: We already have it. He's our operation shift manager" (Int05, trainee reactor operator)

In sum, at more senior upper levels, there is an understanding about the importance of leadership's role in sensemaking, although used practice mainly consists of reminders. This is not sufficient to give sense: repetition does not contribute to sensemaking. In addition, despite efforts of internal leadership training, the notion of leadership for safety is poorly understood (especially, at the lower organizational levels).

4.3.1.2. Sensemaking-sensegiving-sensegiving across organizational levels

Sensegiving and sensemaking develop simultaneously, at different organizational levels. In ATOM, leadership is not performed at one particular hierarchical level, but rather cascades at multiple organizational levels:

> *"Managers are tired, a little discouraged because they have a hard time finding support from their colleagues, from their leaders. And they themselves are managed, **we are all managers and are managed**. They are managed, they also need to find that support" (Int04, human and organizational factors lead)*

We studied the creation of shared meaning through the sensemaking-sensegiving-sensemaking sequence, across organizational levels: 1) corporate top management, 2) top and middle unit managers (operational and functional leads, heads of departments), 3) proximity managers (heads of operational teams) and 4) front-line actors (nuclear unit pilots, operators, field agents).

As described in the research context description, international safety institutions establish guidelines which must be applied by NPP, therefore, international safety institutions influence sensemaking in ATOM's corporate management. Corporate level managers interpret the standards and recommendations published by international regulatory bodies (sensemaking for themselves) and this corporate meaning cascades to lower management levels, including the sense underlying the standards and recommendations, which is conveyed through messages and organizational artefacts, such as rules, procedures, indicators, etc. (sensegiving). These meanings are formalized in internal documents describing corporate requirements for lower levels (unit top and unit management) – for example, ATOM safety management guide, documents introducing corporate project of 'Human Performance".

We explored the process of the creation of a common meaning through the sensemaking-sensegiving-sensemaking sequence across levels. Corporate management's understanding or sense is supposed to cascade through levels, however, at each different level, there are managers who first make sense of this understanding themselves, and then give sense to and support the sensemaking of lower levels (see Figure 4.2).

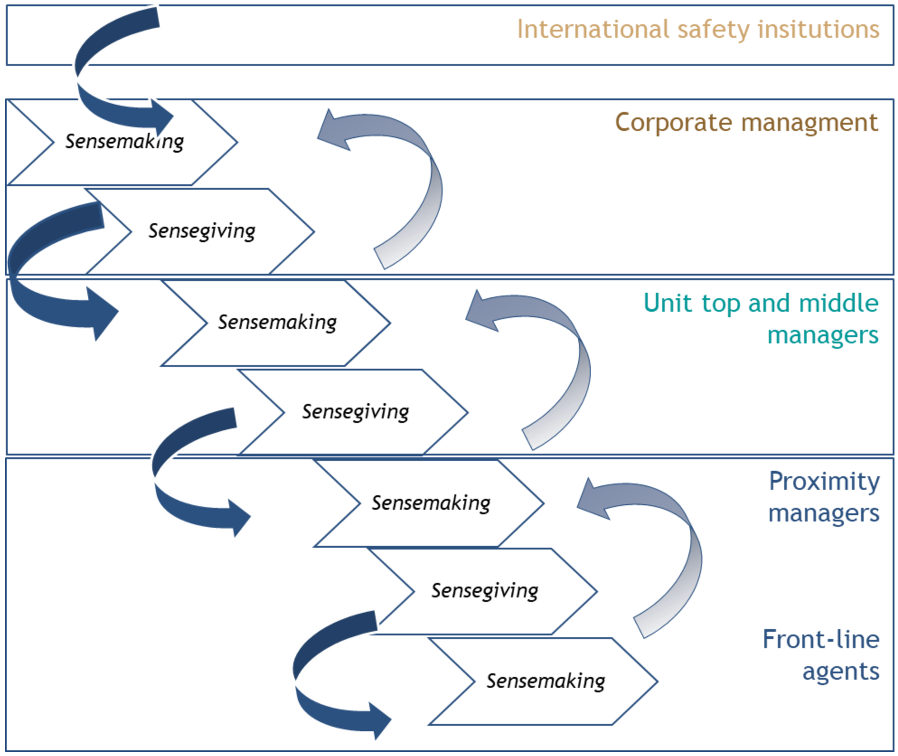

Figure 4.2. Sensemaking-sensegiving process across organizational levels in ATOM

However, our result show that there are organizational barriers, such as lack of time, trust, autonomy and message clarity, that impede effective cascading of the meaning across levels.

4.3.2. Barriers to effective leadership sensemaking-sensegiving-sensemaking

4.3.2.1. Lack of time

First barrier that emerged from our interviews and observations is the lack of time.

Lack of time to construct sense. Our results show that ATOM managers suffer from overload and time constraints. Top management said that this impeded managerial sensemaking and sensegiving:

> *"We don't have time to encode this meaning, we don't have time to share it. I think we don't take the time to build it, **we don't take the time afterwards to maintain it, to make it live, to share it, to question it.**" (Int07, top functional manager)*

> *"Before starting to work out how the manager could share the meaning... The manager needs to be freed up; he needs to have time because all this takes a lot of time". (Int04, ex-head of Safety and Quality department)*

> *"What we need is time to manage, time to go to the field, time to explain things. What we lack is time" (Int12, chief of operations)*

Proximity managers, such operations shift manager who guarantee safety, are *"caught up in a lot of things, such as to make representations in seminars, meetings"* control and *"are not left to core business" (Int09, operations shift manager),* which is operating activities.

> *"The difficulty is trying to reconcile a schedule in which we are often caught up in the handling of major projects and that takes up precious time for managing our teams. It's a workload that's already very full just because of the process, but we have to manage the team, so, it's the time - it's really problematic." (Int09, operations shift manager)*

Understanding the operational field context was seen as important for an effective sensemaking-sensegiving process.

Vicious circle effect of multiplying rules. ATOM informants highlighted the impact of quantification as one of the reasons for lack of managerial time. Managers at different levels found it difficult to integrate and to "*absorb"* the continuous flow of new rules that they had to implement and control their implementation. This harks back to Section 4.2, which described how extensive formalization and corresponding control through indicators, saturates and diverts managerial attention.

> *"It's self-fuelling: today's managers in general don't have time. We have added meetings, we have added indicators, action plan follow-ups, etc. and we continue. It's never-ending. We're still using the same recipes. I think that... it's difficult to see the chicken and the egg [to see what is cause and what is effect], including because they've been 'nursed' on it [used to it]..." (Int04, human and organizational factor lead)*

This extract is particularly interesting, because it highlights the vicious circle effect: ATOM creates rules, which need to be controlled, requiring quantified indicators for a follow-up. To explain the meaning of the rules, ATOM managers need to engage in sensegiving activities and supporting others sensemaking. However, overload of rules and indicators (extensive formalization and quantification) leaves no time for these activities. Thus, rules are poorly understood and are not applied as intended. The answer of this lack of rigour is viewed on the elaborating of new rules and their compliance control through indicators, such as a number of the managerial field visits:

> *"The manager, the leader, no longer has time to go out into the field, so much so that... what have we put in place? We set up the managerial field visits with indicators and which are monitored. You have a certain number of visits to do per year." (Int04, ex-head of Safety and Quality department)*

A middle manager confirmed that the new rules and controls had been created to cover organizational weakness, which amplifies workload.

"The control of the agenda is complicated to allow time to go into the field. It's the management of priorities that is not always there." (Int06, head of Safety and Quality department).

This extract describes how lack of time makes it difficult to build meaning about activities and to prioritize them mindfully.

4.3.2.2. Lack of trust

We also found there was lack of mutual trust between leaders and followers. As discussed in Chapter 2, trust is one of the key leadership mechanisms allowing influence.

Problem of followers' trust in leaders. Our findings reveal a lack of trust between ATOM leaders and followers. For example, field actors sometimes questioned managers' technical expertise. Fields actors talking about their direct manager's recounted:

"My managers, they're supposed to go out into the field. I'm not sure that's...Maybe, but I don't see how it [managerial presence in the field]'s going to improve." (Int02, control room supervisor)

"They are supposed to be our leaders on the field side, but we put people in charge quite often, we call them managers, but managers in terms of technical responsibilities – we shouldn't in fact [call them managers, because they are unable to supervise us]." (Int03, field agent)

However, trust is crucial for supporting sensemaking in the field:

"For the persons to accept that you are next to them, that you are organizing and setting up things - they have to trust you. And in order for them to trust you, they have to know that you know their jobs, you know those constraints. The main difficulty is to create this relationship of trust in order to have leadership" (Int16, assistant operations shift manager)

A proximity manager linked lack of followers' trust and with the control artefact, perceived by field actors as a way to *"police them"* managerial field visit *(Int13, operations shift manager department):*

"I would like to be more in the field with my agents, but without sanctions, without the deliverables [control document of managerial field visit providing information on observed gaps in subordinates behaviors]. I would like not to have to give deliverables. That's my role as a manager. I'm supposed to do it even if I don't have a deliverable to give. Otherwise, we have to explain to him that I'm going to have to give a deliverable that will be an element of visibility for all the hierarchy of the plant. So, there's not the same relationship as if I'm his manager and I see things, just me. Just me." (Int16, assistant operations shift manager)

This lack of trust stems also from fear of blame or sanction if the individual expresses concern about safety– *"we immediately try to see who is responsible" (Int10, unit pilot),* "*we immediately think, like at school, you're going to go see the principal, the director" (Int10, pilot of the unit):*

> *"I put myself in the agent's shoes. My boss asked me to do something that is contrary to the values of the company, what do I do? Do I go to war against [challenge] my boss? Maybe, but I have to be sure that I won't suffer consequences…I think that we have not written enough mechanisms that allow agents to safely raise concerns."(Int14, chief of safety and quality mission)*

In the extract above, a top manager suggested that the solution to lack of trust would be elaboration of new rules, which resonates with systematic use of formalization and quantification. Another manager pointed to the importance of behaving in a way that demonstrated the value of safety and protecting agents:

> *"The manager, in addition to giving meaning to these agents, he must also reassure them, I would not say to protect them, but to* ***preserve*** *them. Agent thinks "I can trust him, he asked me to do be proactive, to be questioning, to be rigorous and careful, he gave me that autonomy, but if I have a problem, I have to know that* ***he's not going to let go****". And today, leaders, managers, if they do that, they put themselves in danger, so they don't do that. That's why for the agents, the notion of trust, is totally absent. Why Is that? Because the trust between the base and the manager is non-existent" (Int04, top functional manager)*

Problem of leaders' trust in followers. Inversely, ATOM leaders also lack trust in their followers. This lack of trust is related to the lack of initiative, described in Section 4.2.

> *"We need to give some leeway to the levels. There are a lot of things that go up. It may be because people lack confidence in themselves and prefer to take the decision upwards. Or it could be because the* ***decision-maker brings everything to him, because he doesn't trust his collaborators****. This is a loss of efficiency, instead of having, five people who make decisions, you're going to have one, so you're going to wait for him to make the decision. So you have to go to him, explain it, etc." (Int14, chief of safety and quality mission).*

In discussing her participation in team meetings, a middle manager expressed doubt about followers' honesty and spoke of their "*destructive*" attitude:

> *"I attend on Tuesday and Thursday morning meetings. They will tell you the opposite, but that's okay… I consider myself to be a very good listener. I don't like to impose my choices. At some point, my role is to decide, but I like to listen before deciding, to get opinions. But, there's nothing that goes. There's never anything that goes. It's a time when they can talk, but it's not constructive at all. It's very destructive...But anyway, as they are not really inclined to say positive things, I should not expect it." (Int 13, chief of operations department)*

This shows failure to establish constructive dialogue to allow development of shared meaning.

4.3.2.3. Lack of leaders' autonomy

Our results reveal that the leadership sensemaking process faces multiple barriers, such as lack of time, lack of trust, lack of initiative and complexity of a multi-layered process. Empowerment of leaders is constrained by structural element as rules, repartitioning of roles and responsibilities.

Rules impede leaders' autonomy and engagement. The extract below shows that formalized artefacts disempower ATOM managers. For example, responsibility (technical or managerial) takes forms of a formal signature on a document, often with no real engagement behind the signature:

> *"I have the impression that people are gradually being cut off from their core business, from their responsibilities. For me, operators are less and less responsible, because they are made responsible in another way...* ***we offload the responsibility onto the person... via sign offs****." (Int16, assistant operations shift manager)*

Personal engagement, which follows from successful sensemaking, is important for successful implementation of safety practices. An interviewee explained:

> *"In the implementation the question of competence always comes back. That is to say, if the person who is leading it, facilitating it, has understood, the meaning, has understood, they know where they want to go - they will do it in a qualitative way, and conversely, if it is done in a mechanical way, in fact, we can completely miss out..." (Int04, human and organizational factor lead).*

Thus, lack of autonomy, due to rigid rules and formal procedures, affects motivation.

Pyramidal structure impedes leader autonomy. ATOM informants underline that a pyramidal top-down organization may be harmful to leadership autonomy:

> *"There are more and more layers of responsibility, so it's a bit of a split, so people, for me, are* ***taking less and less responsibility****" (Int16, assistant operations shift manager)*

> *"IMS as it is applied today, from my point of view, is particularly restrictive. I find that it inhibits and abolishes part of the leadership. Why? Because the leaders, in the end, no longer take initiative and no longer have any responsibility" (Int 04, ex-head of Safety and Quality department)*

The lack of autonomy results in disempowerment and demotivation:

> *"I asked the question: why are we doing safety fundamentals? And you know, the first answer I got was: 'because it's a national demand'. No! I think we missed something. Who cares if it's a national request? Why? There is a sense. Because there are issues. Safety fundamentals are forgotten over time. So, we had to reconstruct for fifteen minutes the why. And then, once you have the why, it's easier to say. Now I know why I have this, how I'm going to take it to the departments?' (Int07, functional top manager)*

This muti-layer pyramidal structure affects leaders' sensemaking and capability to prioritize among values and objectives (such as safety, production, rigour, questioning, etc.).

4.3.2.4. Ambiguity of safety messages

Meaning ambiguity also constitutes a barrier for effective leadership sensegiving. We analyse two key safety messages, contained in the "Safety Culture" report of International Nuclear Safety Advisory Group (INSAG) (INSAG International Atomic Energy Agency, 1991). This report compiles the basic principles for safety management, encoded in messages. We focus on two key messages from this report: 1) priority of safety over production, and 2) excellence of safety management based on questioning attitude, rigorous, prudent approach and communication. The first message underlines the importance of safety in the context of the competing goals and applicable both for managed and regulated safety. The second message emphasizes the need for a questioning attitude and rigour in the joint development of managed and regulated safety. However, definition and application of a questioning attitude are difficult. We investigated the sensemaking-sensegiving process involved in conveying messages across organizational levels.

Our results highlight that messages are ambiguous in their nature: safety and production are considered as both complementary and in tension. Requirement of rigorous compliance with the rules and coexist with requirement of questioning attitude to handle unpredictable events.

Safety priority: complementarity but also tension of safety and production. While the first message highlights safety as a priority, safety and production are considered simultaneously as both complementary and conflicting goals. The ambiguity of the message about relationship between safety and production is presents at the level of international safety institutions.

In describing the traits suggesting a healthy safety culture, WANO (2013) considers safety and production to be complements:

> *"Commercial nuclear power plants are designed, built and operated to produce electricity. Safety, production, and cost control are necessary goals for the operation of such a plant. These outcomes are quite* ***complementary****, and most plants today achieve high levels of safety, impressive production records and competitive costs, reinforced by decisions and actions made with a long-term view considered. This perspective keeps safety as the overriding priority for each plant and for each individual associated with the plant" (WANO, 2013).*

However, a 2022 INSAG IAEA report on safety culture states that*: "to take a conservative (in safety) course of action is not always easy, particularly when there are operational pressures, and this is when an organization's priorities have to be clear and genuinely accepted" (IAEA, INSAG*

15, 2022). This is in line with AIEA safety leadership and management requirements: *"processes and activities shall ... be effectively managed to achieve the organization's goals without compromising safety"* (IAEA, 2016). Thus, safety and production are clearly identified as goals that could be in tension.

Questioning attitude: comply rigorously, but critically. The second message recognizes that safety management should involve a questioning attitude, a rigorous and prudent approach and good communication, more specifically to allow management of unforeseen events and enable proactivity. This message is conveyed in the IAEA INSAG (1991) report on safety culture which understands a questioning attitude as an element in a safety culture and may be considered as precondition to be applied before the beginning of a safety related task/action. A rigorous and prudent approach describes the correct way to realize the task while good communication implies efficient feedback following an activity. The following extracts refer to the notion of a questioning attitude, based on WANO recommendations, and show some ambiguity. While they recognize the inherent uncertainty (unpredictable failures), the means to deal with it are based mainly on anticipation (evaluate and manage risk before the work, plan for mistakes).

> *"Questioning Attitude (QA): Individuals avoid complacency and continuously challenge existing conditions, assumptions, anomalies and activities to identify discrepancies that might result in errors or inappropriate actions…*
>
> *QA.1 Nuclear is Recognised as Special and Unique: Individuals understand that complex technologies* ***can fail in unpredictable ways****.*
>
> *QA.2 Challenge the Unknown: Individuals stop when faced with uncertain conditions.* ***Risks are evaluated and managed before work proceeds***
>
> *QA.3 Challenge Assumptions: Individuals challenge assumptions and offer opposing views when they believe something is not correct.*
>
> *QA.4 Avoid Complacency: Individuals recognise* ***and plan for the possibility of mistakes, latent issues and inherent risk, even while expecting successful outcomes****" (WANO, 2013: 7).*

According to WANO (2013), successful anticipation allows rigorous compliance with existing rules and plans even in uncertain conditions. **This points to a contradiction, which consists in mixing minimizing uncertainty (anticipation) with dealing with uncertainty (resilience).**

These ambiguities which cascade down from the upper levels of international safety institutions to lower level NPP organizations, may explain ATOM's choice to rely on formalization, quantification and specialization (Section 4.1) when developing managed safety capabilities. In what follows, we explore the process of leadership sensemaking-sensegiving-sensemaking about two safety messages in more depth.

4.3.3. Message 1: Safety and production: complementary or in tension?

To analyse in depth message 1, we first consider the sensemaking enacted by each level and then the resulting sensegiving. Each level of management interprets the messages and principles of "*what is central to safety culture*" from the upper levels (sensemaking) and communicates these principles to the lower-levels (sensegiving).

In the specific case of corporate-level management, sensemaking and sensegiving are captured in corporate documents. We hypothesize that sensemaking by these decision-makers is coherently reflected in the sensegiving given by the documents.

4.3.3.1. Ambiguity of managerial sensemaking

Corporate-level management sensemaking and sensegiving: complementarity of safety and production. In line with international safety institutions (upper level), ATOM corporate management considers 's*afety is the number one priority that drives performance as a whole" (Doc 04, ATOM human performance document).* At the corporate level, the complementarity of safety and production is anchored in and diffused through corporate documentation, such as the safety management guide:

> *"To ensure that safety objectives are met and that the associated requirements are complied with, management ensures in particular that:...- safety control is in line with the reality in the field, - requirements in other areas (production, HR, health, safety, environment, radiation protection, etc.) are not considered separately from safety requirements." (Doc 16, ATOM Safety management guide).*

However, following this ambiguity – complementarity and opposition between production and safety – the message changes from "*prioritizing safety*" to a slightly nuanced message "*to produce safely*":

> *"We had certain drifts in perception, we have always been [in our perceptions] between safety and production. This means that we are here to produce electricity, but safely." (Int07, functional top manager).*

This formula is interesting since, although the importance of safety is emphasized, the main objective is formulated in terms of production. ATOM safety culture guide highlights that "*leaders should be convinced that safety drives performance*" *(Doc ATOM Safety culture guide).* This message highlights that if the highest attention is paid at the same time to safety and to production and corresponding activities are done correctly, this guarantees the best result for both, safety and production.

The accompanying message, to *'produce safely',* assumes complementarity between production and safety and confidence that both can be managed in a similar way - with elements and conceptual categories typically associated with production efficiency. The following extract describes a unit manager's perception of upper-level management's representation of safety:

"I think it is the representation of safety that has changed. What was central at one time is not central any longer, it has become a bit peripheral. When we talk about the rules, I think what has become central in their representation is the procedure, the planning... Why? Because it is at the heart of the representation of common elements with the representation of production. Procedures and planning are central elements in production. I think that, in good faith, they are focused on 'produce safely'. "(Int04, top functional manager)

Thus, safety and production are considered jointly. Corporate managements' interpretation is anchored in recognition of the complementarity between safety and production goals, resulting in application of safety management mechanisms and tools typically used to ensure production efficiency. Corporate-level management communicates these principles to lower-level managers, through messages and organizational artefacts (such as corporate guides, rules, indicators, etc.),

Top and middle-level management: tensions between safety and production. The meaning built by top unit management related to the priority of safety is different from corporate level meaning. At the latter level, safety and production are complementary, whereas at the unit top and middle management level, highlights the tensions between these two goals. Although safety is seen as important, its overriding priority may be questioned.

"On the plant everyone is aware that safety is essential. Afterwards, I say that safety is essential, after that it is the absolute priority - I don't know if this is true for everyone. I wouldn't bet on it, but it is essential - yes, I am convinced of that." (Int06, head of Safety and Quality department).

The tensions between safety and production are clearly mentioned.

"Safety leadership is there, it's how in an economic environment with economic stakes you have to remember that a team manager produces to make money for the company, of course. How, while doing this, do I show that risk prevention is at the heart of my concerns? This is not easy, because tensions are sometimes high in practice." (Int14, chief of safety and quality mission)

Safety and production are no longer considered complementary, but as objectives that can be in tension or even in opposition.

Proximity management: facing trade-offs of safety-production tensions. At the level of proximity management, unresolved cascading ambiguities (complementarity and tension) complicate sensemaking in daily operational activities. More specifically, proximity managers criticized the lack of clarity and lack of support from upper organizational levels accompanying decisions that were not in line with official recommendations:

"I would say that the managerial line is less effective because the process [of sensemaking is not accompanied,] is not taken to the end, as I said before…The fact of accompanying to the end and explaining to all the people why choices were made and why such and such a decision was made and that it was the right decision to make, that they are convinced of it. We give the message, [but do not accompany them] Afterwards, what I find a pity is that we are able to give some counter examples to these messages. Not necessarily on safety, we shouldn't say we were going against safety either, but there are things…" (Int16, assistant operations shift manager)

Proximity management level deals with tensions between safety and production through trade-offs and compromises in daily activities. Trade-offs sometimes favour production (produce safely), as shown by the following statement from a proximity manager:

"Despite everything, you have to make some money too. That's kind of why we're here. So the costs - you have to manage them, to make a trade-off. Not a trade-off on safety, but a balance, a compromise on staying within a framework, respecting the rules, but afterwards, there are certain things that require trade-offs decisions, that's the way it is." (Int16, assistant operations shift manager)

It was clear that proximity managers need to balance availability of a facility (to continue production) and respect for safety requirements:

"There are often problems between availability [of installation] and safety. Safety rules would require that the reactor is shut down by respecting rules in case of a safety event. But sometimes an experienced operations manager can find a way of managing the event in order to avoid stopping production, while remaining within the rules. This is a big difficulty." (Int09, operations shift manager)

In sum, our results highlight inconsistencies in sensemaking, across organizational levels, about the safety-production relation. The next sub-part presents the analysis of the sensegiving.

4.3.3.2. Ambiguity of managerial sensegiving

Top and middle management: additivity of demands. Unit managers recognized tensions between safety and production in their own sensemaking, in terms of their sensegiving, they ask their subordinate to perform both – safety and production – at the highest level.

"In terms of a manager's view – I explain to my boss that what he is asking me is not possible. I can't be everywhere. So, at some point, you have to choose. And then to choose is to renounce.

He tells me 'No, it's not possible [not to do everything]', ***the top management wants everything done****." (Int04, top functional manager)*

This message is more or less explicit and is transmitted through rules and control indicators. As shown in the section 4.2., the use of quantification, following to control formalized rules, is done extensively. It is existence of practices corresponding to rules is controlled by quantified indicators, including practices aiming managed safety development.

While recognizing problems resulting from these tensions and lack of time, top management assign to proximity leaders the role and responsibility for making and sharing sense of all these requirements and their prioritizing in order to translate it into practice:

"How, while doing this, do I show that risk prevention is at the heart of my concerns?... If it's not perceived that way, the actors... well, okay, if the chief doesn't have it in front, so I'll put it in front?" (Int14, chief of safety and quality mission).

"On the carrying of meaning and the link between meaning and requirements [and regarding sensegiving about concretely achieving all requirements] ... there are some managers who do it very well and there are some who do it less well…" (Int13, operations shift manager department)

These interview extracts show that ATOM top managers leave sensemaking problems to the proximity leaders who are in the field.

Proximity management: acting on safety-production trade-offs. Proximity managers are required to make trade-offs decisions about daily work and choose, for example, between starting non-urgent maintenance (better safety) or continuing operations without maintenance (better production).

"To produce in a comfortable way, to have production performance [we may have to make trade-offs] We complain too often about maintenance, we'll say, it's not urgent, so it's slipped in [we can delay it without], without it causing a safety event and then... it's the "pebbles in our shoes" [it is not a comfortable situation] in everyday life and it reduces our room for actions." (Int11, reactor operator)

Another example is making trade-off judgements about control room monitoring (better safety) or outage activities (better production):

"During an outage, we have a large volume of activity to do, so it's a bit like the lack of time, but in the end, control room monitoring was something we did when we had time and had done all our activities. Now, we have a way of looking at it: we make monitoring sacred and then the activities - we do what we can do." (Int09, operations shift manager)

Interestingly, proximity managers seemed to have greater autonomy to make adaptations at their level to reframe activities to address multiple issues - safety, and also financial or human resources problems:

> *"Either we go back to the framework and try to stick to the planned, prepared framework, etc. If an activity has a risk, a safety impact, and I detect it, either I send it straight back to square one to redo the line, or, depending on the stakes involved - financial, human, etc. - we go ahead [continue activity] and adapt so that it can be carried out safely, but at our level: we take full control of the safety process, and we guarantee safety ourselves" (Int16, assistant operations shift manager*).

This shows that proximity managers feel responsible for 'guaranteeing safety' in the case of choices between activities and adapting rules to concrete situations. This is in line with ATOM documentation that highlights that "*Operations Shift Manager are responsible for safety, in real time*" *(Doc 01, ATOM Operations management note)*. However, ambiguities and inconsistencies in safety-production relationships, cascade through sensemaking-sensegiving and lead to the loss of meaning for actors at the operational level.

4.3.3.3. Loss of meaning at the operational level

Fuzzy representations of safety. As a result of inefficient sensegiving and sensemaking, representation of safety at this level lacks clarity. A field agent recognized:

> *"Safety is more a question of the operators, with our unit pilots, delegated operations managers and operations managers, who are responsible for...* ***we have a very vague notion of safety. We know that such and such a trigram*** *[material or activity naming]* ***is safety - we have to be careful, but we don't know much about it****. On the other hand, if we have a technical problem – there is a big file, we have to read it to find the answer" (Int03, field agent)*

ATOM operators were uncomfortable when questioned about key safety culture values. For example, one of them answered: "*the only value that is carried - is not to do significant safety events (annual zero events)" (Int11, reactor operator*), echoing the focus on quantification.

Proximity manager acknowledged lack of clear and aligned understanding of safety among field agents.

> *"We can have different visions of safety despite everything. If we take an agent who likes the mechanical aspect and the machine - for him, safety means that everything works 100% all the time, that it's clean and tidy, etc. You have agents who call you, who tell you: there's a bit of paint here, it's disgusting. There's a leaky pipe, but this pipe - we don't use it, or else... It's not the pipe that has a safety aspect. But for him, safety is all about that, that it's perfect."(Int16, assistant operations shift manager)*

This underlines failure to construct an aligned meaning of safety.

Perceived incoherence of meaning about prioritizing safety. Unsolved perceived ambiguities about safety priority over production lead to loss of meaning about the priority of safety *per se*. More particularly, trade-offs decisions that might contradict the rules and procedures, suggested by higher management, can be confusing, especially for new or young field actors, who have had rule compliance emphasized and who are formed to fully comply to rules. The conflicting messages about safety – full compliance with safety requirement from the top management and search for compromises by proximity managers, are confusing for new workers.

> *"There is a lot of laxity here. We do activities - we don't really care. And there's a big impression down there, for example, across field agents, when you do something - you make assumptions. If we read the paper and say - no, we can't do it. Yes, but let's imagine that it passes - there's no worry, it's passed, that's it. Afterwards, we'll see, if it doesn't pass - we may have other problems to deal with, but it's not so serious.*
>
> *I keep saying it - inconsistency, inconsistency, inconsistency. All the time, well, not all the time, but on some things it's inconsistent. You can't say - you have to do this, but in reverse - do the other thing. The messages are inconsistent." (Int03, field agent).*

For example, some agents say that local managers sometimes discourage them from implementing required safety procedures that they consider non-essential.

> *"It's complicated. I've been asked to do an activity - I say 'well, I need the risk analysis'. Okay, they take over the activity, they call someone else, another field agent who they know doesn't ask questions. So, he will do it. So, it's often conflicting for us. In fact, we are seen as lazy people who don't want to work. Too much paperwork, so too much time. Sometimes we are told clearly 'no, there is no need for a risk analysis, you can do it'. 'But wait, I was trained last week, and I was told I needed a risk analysis'. 'No-no', they're talking nonsense "(Int03, field agent)*

The following extract shows that how the lack of trust at different levels affects sensemaking. While proximity managers try to explain the choices, their explanations are perceived as "*lying*".

> *"They won't tell us clearly 'you shouldn't do it', because they would be at fault. They never say. But you can tell when they're annoyed [because this does not correspond to what they expect from us],*
>
> *- 'you don't need that'...*
>
> *-'No, it's not like that, it's not coherent, there's your superior, we asked for something - it has to be done'*
>
> *-'But, but my superior, he's in the office, he knows nothing...''*
>
> *It's not credible anymore, it's incoherent. We don't know who to turn to, people are lying..." (Int03, field agent)*

This situation of "*social conflict*" *(Int08, top operational manager)* can have a negative impact on safety: "*it's complicated. We are totally lost...*" *(Int03, field agent).*

Loss of meaning about the priority of safety. At the operational level, trade-offs judgements become increasingly difficult due to the number of rules and procedures in place, which can obstruct the sensemaking about as the overriding priority: "*it's becoming a blurred world, where we don't really know where we're going anymore, and we don't really know what the priority issues are" (Int03, field agent)*. A middle manager underlined the safety threats from this loss of meaning:

> *"We lost our landmarks in 2016-2017. That's why we implemented a plan of Safety Rigor and in this plan, we clearly identified that we had to work on the safety culture, because we had lost this sense of the priority that we should give to safety." (Int06, head of Safety and Quality department).*

This loss of meaning about the safety priority *("primary sense of safety" (Int04, top functional manager))* was considered a major problem for proximity managers:

> *"Field agents are very much at odds with the rest of the site and the direction of the Nuclear Operations Division. They think that the direction has gone in the wrong direction." (Int13, operations shift manager department)*

> *"That's the hardest thing, the hardest thing to carry - it's explaining things and the agents don't understand them, putting in place things that our agents don't share. That's when you carry something, and our agents don't understand." (Int12, operations shift manager)*

A middle manager linked lack of time and lack of trust to loss of meaning.

> *"Why there are certain things that are not done: not enough debriefing, not enough traceability, not enough...?*
>
> *These are extra things for them…There are two ways to explain it. One, anything that comes down from management - it stinks. Two, lack of time. More and more is being asked of them. And then, three, they don't see the point. They don't have the meaning, but in fact they've lost all meaning. After that, the cause, I don't know, but I think that there is a part of our responsibility". (Int13, operations shift manager department)*

This underlines the interplay among different organizational barriers to the sensemaking process and its efficiency.

4.3.3.4. Brief summary of the Message 1

Our analysis of the sensemaking-sensegiving-sensemaking process on the priority of safety, reveals cascading ambiguities and inconsistencies through and across organizational levels, leading to the loss of meaning at the operational level. Figure 4.3 summarizes our findings.

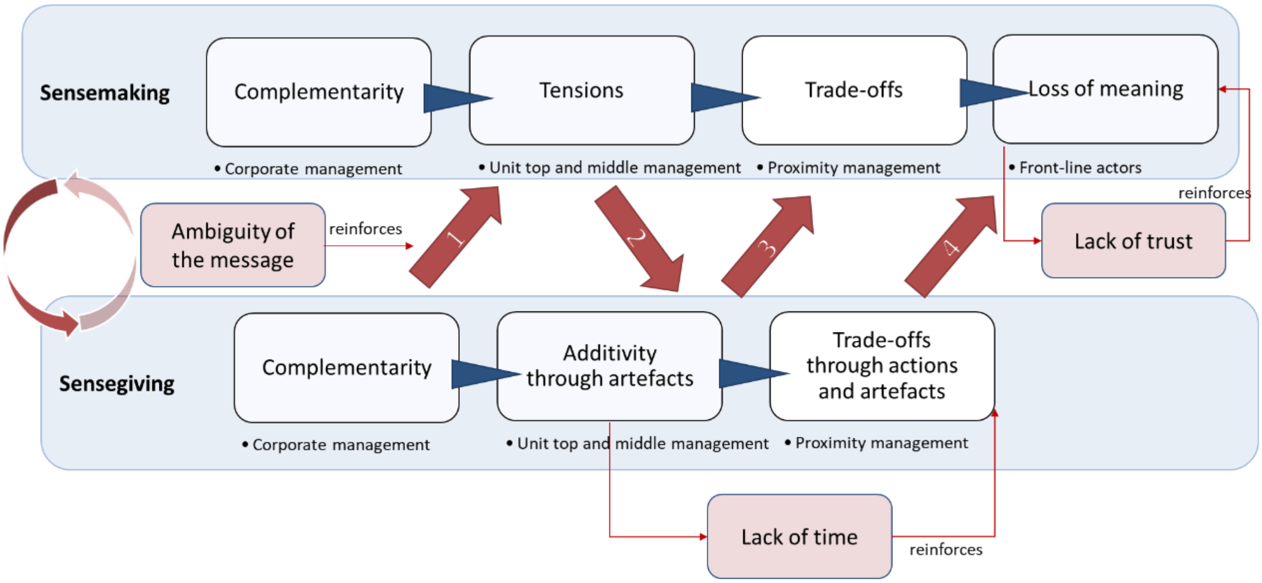

Figure 4.3. Sensemaking-sensegiving-sensemaking process about the message about safety priority and its relationships with production

Our results show multiple breaking points in the sensemaking process. While the original messages from international safety institutions include some ambiguities, corporate level make exacerbate these ambiguities by maintaining the sense about complementarity between safety and production. This complementarity logic is anchored in the message of *'produce safely'*. The ambiguity in the original message, reinforces the breaking points in the sensemaking-sensegiving-sensemaking process. The first breaking point (arrow 1) highlights the inconsistency between corporate and top unit management. Top management sensemaking highlights the existence of vivid tensions between safety and production.

However, their top managers' sensegiving differs from their sensemaking (arrow 2). Despite acknowledging the tensions, top and middle management spread the meaning of additivity of safety and production: they stress the need for both highest levels of safety and production. This meaning is conveyed in through organizational artefacts of control – quantifiable indicators accompanying all operational and managerial activities. The role of proximity manager leadership is seen as supporting the solution to accompany the sensemaking of this ambiguous message to lower levels.

At the level of proximity management, leaders have to make trade-offs: while at the upper-level, the abstract idea of additivity is possible and prevails at the level closest to operational activities, the tensions between safety and production inevitably lead to choices and decisions (arrow 3). Proximity managers, suffering from lack of time, resulting from the additivity logic promotion, intervene in the trade-off between safety and production, based on their actions and decision making (such as deciding to proceed with the activity without a risk analysis) and organizational artefacts (such as unrealistic outage planning).

Finally, all unresolved and unaccompanied inconsistencies, cascading through levels, lead to loss of meaning at the front-line actors' level (arrow 4). Perceived incoherence between upper-level messages about rigorous compliance with safety rules and decisions that might prioritize production, lead to and reinforce lack of trust. Loss of meaning about safety can reduce focus on safety and risk degradation of safety results. To shoulder this risk, the second key message is disseminated: need of questioning attitude.

4.3.4. Message 2: Questioning attitude: intelligent or normative

The analysis of the second message follows the same reasoning as first message to explore sensemaking-sensegiving-sensemaking across organizational levels.

4.3.4.1. Ambiguity of managerial sensemaking

The message requires employees to follow procedures rigorously, but with a questioning attitude (QA). 'Questioning' can be understood in different ways – as a mindful situation evaluation (intelligent QA) or as a choice among rules and planned scenarios, to apply in the case of a problem (normative QA). This results in a limited and normalized questioning attitude.

Corporate management sensemaking and sensegiving: additivity of normative (reducing autonomy) and intelligent QA (developing questioning). As discussed in Section 4.1 ATOM corporate management has developed rules (REPs), encouraging a critical approach to enable adaptation, but also at the same time insisting on the importance of rigorous compliance with existing rules. ATOM corporate documentation underlines the idea that humans are both the source of problems and the solution to them: "*if the events are often of human origin, people are also a source of progress and many events are avoided thanks to them" (Doc 04, ATOM human performance document)*.

On the one hand, the corporate level underlines that human error is problematic (humans as the source of uncertainty) and requires 'reflex-mode' safety practices:

> *"Whatever the incident, whatever the non-quality, it is often possible to find one or more human errors to explain its occurrence. This is normal and is all the more important given that profound improvements have been made to technical components in recent decades." (Doc 04, ATOM human performance document)*

On the other hand, corporate top management recognizes the importance of adaptation to manage the unexpected (humans are a source of resilience):

> *"Humans are irreplaceable when it comes to implementing the appropriate response to an unforeseen or complex situation, or to compensating for the failure of equipment or an organization" (Doc 04, ATOM human performance document)*

Thus, a needed questioning attitude is considered both as normative (choice and compliance with rules) and intelligent (situational adaptation to real, sometimes unexpected events).

> *"The analysis of the TMI accident highlighted the weaknesses and limits of people and led to a desire to* ***reduce their scope of action*** *(automation, computerization,* ***prescriptions****). The Chernobyl accident showed that, as long as people are involved in installations, their role is crucial, and it is necessary to give the actors at all levels of the organization the* ***capacity to apprehend the risks by a questioning and prudent attitude****, which makes it possible to ensure the priority of safety in all the activities." (Doc 16, ATOM Safety management guide).*

The ambiguity in the meaning given by corporate management persists. While acknowledging the importance of humans to go beyond the compliance, the solution is seen, again, in anticipation and control of the human factor (referring to compliance).

> *"Compliance with the rule is necessary. It does not guarantee performance on its own. The role of the people in the team, as a factor of reliability must be foreseen controlled and consolidated" (Doc 04, ATOM human performance document)*

To develop a questioning attitude, corporate level had formalized REPs rules, but considers reliability should be achieved by "*acquiring the reflex to put them into practice systematically" (Doc 04, ATOM human performance document)*. In an explanatory document, corporate management recognizes the possibility of unforeseen events and advocates "*finding the reflex to stop*" the activity to "*reflect*", but to avoid "*exploration by successive hypotheses*".

> *"A certain number of contingencies and unforeseen events will be encountered during the work activity. Some of them are part of the general framework of the preparation, others are not and they cause the loss of the anticipation built during the briefing. If the margin of anticipation is lost, it is very important not to allow oneself to be drawn into a mechanism of exploration by successive hypotheses which could easily put us outside the limits foreseen at the start.* ***It is therefore important to stop, to find the reflex to stop, in order to be able to reflect, to make***

> ***assumptions, to see the consequences, before resuming the activity****: in short, to regain a margin of anticipation. This approach is called STAR (Stop-Think-Act-Review) in the Human Performance approach." (Doc 05, ATOM REPs)*

The meaning of "*to reflect, to make assumptions, to see the consequences"* is not defined: should this reflection be based on the existing rules, or should it allow for situational flexibility?

Top management: need to develop an intelligent QA. Regarding the message relative to the importance of questioning attitude, once again, top unit management's sensemaking differs from corporate management sensemaking. While for corporate management a questioning attitude is ambiguous (including both normative and intelligent attitude), top unit management clearly emphasizes the need for an intelligent questioning attitude.

Intelligent questioning attitude, based on a fine-grained understanding of the situation "here and now", may be considered as opposite to normative questioning attitude, based on compliance with existing norms, rules (named "administrative safety"):

> *"This is also why I say that to me vigilance is important, the ability to reflect, to question the situation, to question other people in order to make good decisions at their level, rather than systemically referring back to the hierarchy or continuing to think "I don't know, but never mind".* ***Neither foolishly continuing nor foolishly not stopping is good. You must do it intelligently****. I detect a strange situation, I stop, I question myself, I wonder if at my level I can decide or not. If not – who should I consult … I think that people who do this well, they have good safety results, because there is a good culture... a good questioning". (Int14, chief of safety and quality mission).*

This questioning attitude is seen by top managers as a part of a competence: *"competence in terms of reflection and approach to problems, this intelligence of action, intelligence of situation" (Int04, top functional manager).* Top management regret loss of this situational intelligence:

> *"Safety culture, the questioning attitude - I think it's something that gets lost over time. We don't ask ourselves questions anymore, we get into our process, into our procedure, and we are not able to step back and say to ourselves: "Finally, I'm doing this, but why am I doing this?" (Int07, functional top manager)*

The extract below highlights that an intelligent questioning attitude is threatened by extensive implementation of organizational artefacts of control and coordination, echoing the results in Section 4.2:

> *"**With all the tools we've put in place**, I think that at some point **we killed intelligence**" (Int14, chief of safety and quality mission)*

An Alpha middle manager summarized the danger of losing an intelligent questioning attitude due to the assumption that compliance with rules guarantees safety.

"It is necessary to bring in questioning: today, if I follow the procedure stupidly - nothing can happen to me, but if we follow line by line, we lose the questioning and the critical spirit.... We lose it. It is essential that an operator just follows the procedure. But, the operators end up not being able to question any more…" (Int18, chief of training department).

The interview extracts highlight that top and middle level managers have a clear understanding of the need to develop an intelligent questioning attitude.

Proximity management: QA as ability to stop and to pass on the information. While proximity managers are able to cite the INSAG 4 safety culture elements, they have difficulties to do not always understand what is meant by a questioning attitude.

"What are the key safety values that are carried by the site?

It's everything that stems a bit from INSAG 4. And other INSAGs. It is attention, being rigorous, it is the questioning and prudent attitude. As soon as you arrive, you are trained that way and you are regularly reminded of it." (Inr01, engineer)

At the proximity manager level, a questioning attitude is seen as the ability to stop ongoing operational activity and to escalate information and doubts about perceived anomalies to the direct manager:

"What are the key values that are promoted by the site? What we say all the time, what everyone else says... It's the prudent, questioning approach. If at any time I have a question about safety, I can go to my manager, and he will take into account my remarks and my questions. And we will always try to provide an answer, whatever the question is. If at a given moment I have a doubt about safety – I stop..." (Int12, operations shift manager)

This definition of a questioning attitude underlines a mainly normative understanding of the idea. However, proximity managers acknowledged the importance of an intelligent attitude enabling adaptation to manage the unpredictable: "*everyone must have a critical eye" (Int01, engineer).*

In line with the first message's analysis, our results highlight inconsistencies in sensemaking across organizational levels about questioning attitude. The next sub-part presents the analysis of the sensegiving.

4.3.4.2. Ambiguity of managerial sensegiving

Top and middle management: normative QA, it is up to proximity to complete with intelligent QA. Top unit managers' sensegiving revolves around two ideas. First, they follow the organizational control and coordination artefacts that cascade from the corporate level. By doing so, they pass on to their teams the idea that safety is guaranteed by compliance with rules and by control of human actions. Thus, sensemaking through artefacts encourages adherence to predetermined rules, engagement in set routines and behaviours (mindlessness) and not the development of situational adaptation capabilities.

Top managers recognized that this normative and rigid approach was applied even to practices aimed at development of situated intelligence. For example, pre-job briefings are conducted in a normalized (questions from a guide and formal discussion about pre-identified risks), rather than an open manner. Attention saturation and diversion (see Section 4.2) is a barrier to mindfulness development, leading to normative implementation of formal practice.

> *"The REPs are there as regulated safety, but there is no commitment" (Int04, ex-head of Safety and Quality department)*

> *"The way we do it, obviously, it's regulated safety without a doubt, it's trying to maintain this level of awareness with a briefing, just before leaving for the field we remind ourselves of the risks associated with the intervention." (Int14, chief of safety and quality mission).*

Second, top unit managers implicitly recognized the role of proximity leadership to develop followers' intelligent questioning attitude. Indeed, they highlighted that mere cascading of official messages about safety was not enough and pointed to the importance of leadership to support followers' sensemaking.

> *"I am also fighting against a phrase that exasperates me: the manager gives meaning. I always say - no, you're going to give me a pen, but you're not going to give me a meaning... If we share, if we co-construct together the meaning, then you, you have to come and see me in the field, to see if what I put behind the expected meaning is good. Then, it works." (Int07_ top functional manager)*

> *"If, as an agent, my boss does not transmit to me this culture of always questioning myself, of being concerned about the safety aspect of whatever I do, the agent will never be enculturated... He's not going to improve or develop the questioning attitude that he should have because he's not aware of it, not familiar with it. And that's something, I think, that's sorely lacking". (Int04, top functional manager)*

However, it seems that proximity managers are insufficiently supported in their development of a more fine-grained interpretation of official messages. This applies particularly to their in helping their teams develop an intelligent questioning attitude.

Proximity management: ambiguity of the meaning of QA. Proximity managers convey an ambiguous meaning about the questioning attitude. On the one hand, they use organizational artefacts (rules and tools) to convey the meaning of a normative questioning attitude, underlying the importance of formalized support to cope with unexpected events:

"We have also produced a number of tools to help us think of everything when we manage an incident, including tools for managing incidental situations, small tools that help us to provide an exhaustive diagnosis and exhaustive treatment: forms to follow, instructions indicated by alarm cards. But also a file - an A3 sheet about fortuitous events management – which highlights discovery of an incident, its consequences in terms of safety, security, production, environment, fire, radiation protection, etc. This is accompanied by a flow chart which helps us to decide about consulting the on-call team, either immediately or at.... And then try to diagnose and formalize the problem and its impact and make a risk analysis to guide the intervention." (Int09, operations shift manager).

On the other hand, management stresses the need to adapt rules to specific situations and understand the consequences of these adaptations for safety. Proximity managers, while acknowledging the limits of rules, act in field using trade-offs judgements and situational adaptation.

"Defining the rules is not enough, we must also check that they are understood, applied and do not present major difficulties. The rules that are least respected are those that they agents find difficult to apply …we must try to redefine actions, to make their meaning understood." (Int09, operations shift manager)

However, these adaptations (e.g., to cope with near-misses) are not formalized or shared beyond the confines of the team. As discussed above, sensegiving about trade-offs is constrained. First, proximity managers suffer from overload and lack time to support sensemaking and, especially, if meanings may contradict the rules and practices in place. Second, proximity managers are limited in their autonomy including the power to adapt existing rules or existing control practices. Weakly accompanied trade-offs decisions can lead to loss of meaning at the operational level.

4.3.4.3. Loss of meaning at the operational level

Perceived inconsistencies. The required rigorous and normative approach to safety may be in tension with trade-offs and shortcuts, causing confusion. Several front-line actors described that a questioning attitude is characteristic of professionalism. However, from their answer it is difficult to summarize while they mean normative or intelligent questioning attitude. Many agreed about the need to stop an activity in the case of an anomaly and highlighted the need for a collective resolution:

"So when something unexpected happens, we stop and formulate the problem. That's what we're trained to do – studying and solving problems: we stop and think. We usually don't just jump in. Yeah, we all think and that's where it's hard. Because there's always one person who's better

than the others in the team... But actually, you have to... it's called the tunnel effect. It means that there is one who speaks louder than the others, who thinks he has the right solution. And everyone else 'yes, your solution, you're right'. Everybody goes to him. And in fact, sometimes it's good (Int02, control room supervisor)

"For me, having a questioning attitude means not being sure of something and asking myself the question: "Do I really have all the elements that allow me to say - here we go, we're going to manage the event like this"? That's why you have to exchange. You shouldn't be alone…" (Int10, unit pilot)

Finally, some field actors highlighted the importance of balancing adherence to rules and accompanying people in making sense of real-life situations. They saw development of intelligent questioning attitude as closely related to learning.

"But you have to have a procedure, we don't fight against that. That's not what we're saying at all. We need procedures, that's for sure, but in fact we need a balance between procedures on the one hand and mentoring and training on the other. I think that the best balance is: the rules as a support.... but it is important leave a little room for professionalism and precisely for the agent's 'touch' [experience of technical gesture]and not being locked into the instructions...". (Int11, reactor operator)

However, despite front-line actors' acknowledgement of the need for an intelligent questioning attitude, others found it difficult to achieve meaning of this concept and their role.

Loss of meaning of a QA. Some front-line actors said that their work is mainly to strictly follow the rules with no need for a questioning attitude about safety.

"What are you waiting for to guarantee safety? Is there anything more to do?

Yes, there must be more to do. But I'm not here to... My job - I do technical work. After that, I listen to what they tell me, I'm a good soldier, but I do technical work. - I'm a good soldier." (Int02, control room supervisor)

"Because safety, in fact, everything was written in our bible. If you have a question, you just have to go and read, and you are reassured." (Int10, unit pilot).

At the lowest operational level of field agent, in particular, the meaning of questioning attitude was lost and reliance on escalating information about an anomaly was prioritized.

"What are the key elements to guarantee and maintain safety in your daily practices? For us, on the field agents' side, it's detecting anomalies, reporting the anomaly, and then it's up to them to decide whether it's a minor anomaly or whether it's a deviation in terms of safety?" (Int03, field agent)

A field agent expressed his confusion:

"Did your perception of the way to manage risks evolve?

I don't really know, I don't know anymore. I don't know if it's up to me to manage it, or if it's up to our superiors? Nowadays, we are clearly told that it is no longer up to us to manage this. It's complicated, it's become very complicated." (Int03, field agent)

A top manager summarised the issue as follows:

"Direct operational actor, most of the time, I would say, almost systematically, he has lost the meaning of the action he is carrying out. He has lost the meaning." (Int04, ex-head of Safety and Quality department)

4.3.4.4. Brief summary of the Message 2

Our analysis of the sensemaking-sensegiving-sensemaking process related to a questioning attitude for safety, reveals cascading ambiguities and inconsistencies through all organizational levels, leading to loss of meaning at the operational level. Figure 4.4 summarizes our findings.

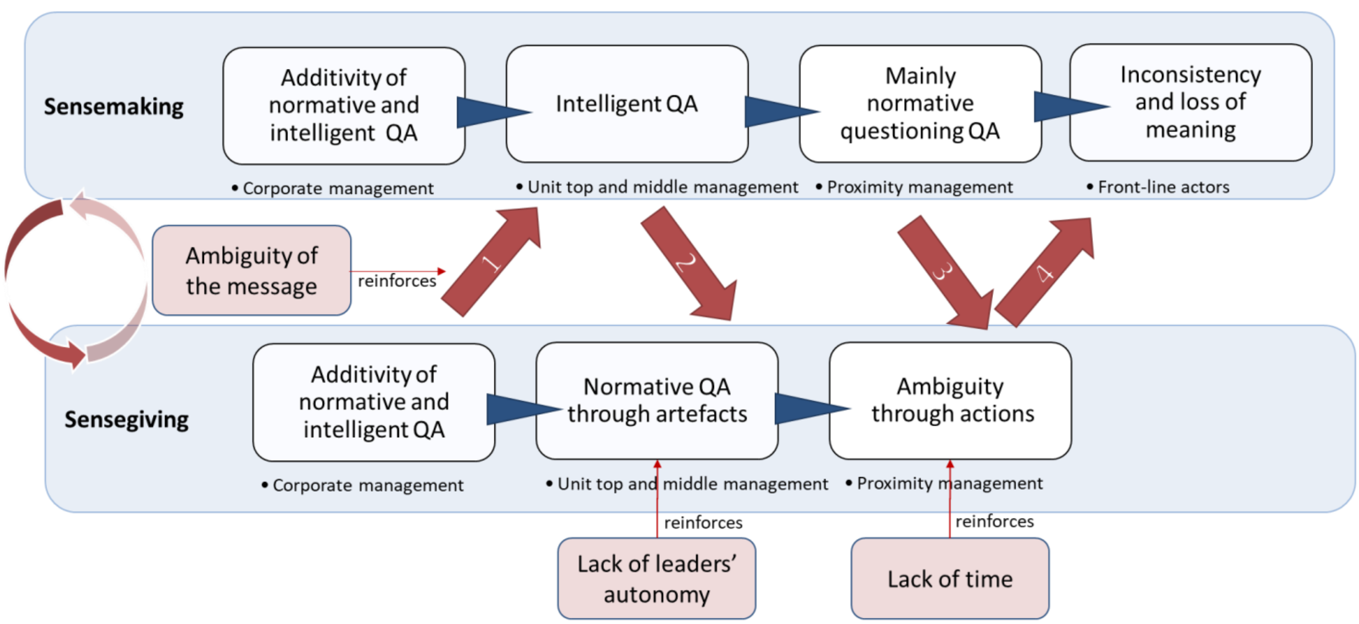

Figure 4.4. Sensemaking-sensegiving-sensemaking process about the message about the questioning attitude

Our results show multiple breaking points in the sensemaking process. Similar to the first message, there is unresolved ambiguity about questioning attitude, which cascades from the level of the international safety institutions and reinforces breaking points. Corporate management do not resolve this ambiguity and call for both a normative (compliance with right rules) and intelligent (situation adaptability, eventually outside of existing rules) questioning attitude. The first breaking point is at the top and middle management levels: this organizational level stresses lack of situational adaptability and understands questioning attitude as intelligent (arrow 1).

However, again, top managers' sensegiving differs from their sensemaking (arrow 2). Despite acknowledging the need for intelligent questioning attitude, top and middle managers face the lack of autonomy to complete a normative view of questioning attitude with an intelligent view. Instead, they promote the organizational artefacts of control and coordination – rules and quantifiable indicators to control compliance, resulting in reinforcement of normative approach. Similar to the first message, the role of proximity manager leadership is seen as the solution to completing this normative approach by developing intelligent questioning attitude among employees.

At the level of proximity management, leaders follow upper level sensemaking and express their understanding of QA mainly as normative: stop operational activities in case of anomaly and escalate the information. However, in practice, proximity managers intervene and make trade-offs judgements, underlining incoherence with a normative compliant approach (arrow 3). Lack of time constrains leaders' sensegiving activities to explain their decision-making in trade-offs.

Finally, all unresolved and unaccompanied ambiguities, cascading across all levels, lead to perceived inconsistency and even loss of meaning on the front-line (arrow 4). While acknowledging the importance of a questioning attitude as part of their professionalism, field actors did not have a clear understanding of what questioning attitude means. Moreover, some actors expressed confusion about or denial of a questioning attitude initiative.

In sum, the results in Section 4.3, show that, while ATOM recognizes the importance of the role of leader for constructing and sharing meaning, but in practice it is difficult. Based on an in-depth analysis of the meaning of two key safety messages, our findings show that unresolved ambiguities, originating in initial messages, are cascaded and even amplified across organizational levels, leading to the loss of meaning at the operational level.

Based on international safety institutions' recommendations, corporate level management passes on ambiguous messages (complementarity between safety and production, of a normative and intelligent questioning attitude). However, sensemaking at

lower organizational levels, that is, top and middle unit management, differs from sensemaking-sensegiving at the corporate level. Top and middle managers acknowledge the challenges and problems related to operational activities (safety-production tensions and need for intelligent questioning attitude), but, in their sensegiving, top and middle managers continue to convey the corporate view, in particular because of their powerlessness comparing to organizational artefacts conveying corporate view.

More specifically, organizational control and coordination artefacts (rules, tools, indicators) promote sense of additivity and of normativity of organizational demands. At top and middle level management levels, the logic of additivity consists of demanding that all corporate requirements should be applied (safety and production), and their application should be controlled. The transformation of complementarity into additivity raises practical problems, especially in terms of time at the operational level. Along the same lines, while corporate level management required simultaneous development of normative (compliance to rules) and situational intelligent behaviours (ability to analyse the situation in the here and the now, rather than the situation as expected). The way the message about questioning attitude is codified in corporate documentation, made it difficult to judge whether the corporate level sees normative and intelligent attitude injunctions as additive or complementary.

Additivity always leads to the need for trade-offs judgements at the operational level. However, these may not be fully understood or validated by the hierarchy, leading to the loss of sense. Unresolved sense ambiguities cascading through the different hierarchical levels do not disappear, but rather leave the operational level (the level closes to operational activities) with the challenging task of solving them. Implicitly, leaders at the proximity level are expected to make sense of the situation (sensemaking), to make the right decisions, and to be able to explain them (sensegiving).

Thus, complementing the additive and normative approach with finer-grained sensemaking and development of situational intelligence is assigned to proximity managers. While proximity managers have some flexibility to adapt activities in the field, they cannot give sense to contradictory organizational artefacts and messages about safety. Moreover, affected by the lack of time and trust, proximity managers' trade-offs decisions are not always accompanied by sensegiving practices to explain the meaning of their choices to lower

organizational levels. As a result, lower levels perceive inconsistencies and contradictions between corporate and top-level messages and proximity managers' actions and judgements. This perception, when reinforced by lack of trust in leaders, results in the loss of meaning about safety, which is risky for safety performance.

Finally, although complementarity can be defined on an abstract level, it is illusory to believe that it can be easily maintained in practice at the operational level. This complementarity will lead to trade-offs at the operational level, which should be helped by the organization and not made 'against' the organization (in terms of sense embodied in majority of organizational artefacts).

4.4. Conclusion of Chapter 4

The objective of this research was to explore the leadership mechanisms enabling a joint development of regulated and managed safety. The ATOM case demonstrates that, despite a clear intention to develop managed safety, management continues to use levers (formalization, quantification, specialization), designed to achieve regulated safety, and to use them extensively. Our findings point to the influence of organizational control and coordination artefacts, such as rules, indicators, tools, that divert attention, that affect construction of meaning, constrain learning and, thus, counteract efforts to develop managed safety. These side effects of control and coordination, point to the existence of organizational limits. Exceeding these limits of managerial actions leads to undesired negative effects on mindfulness and deliberate learning, crucial for dealing with unpredictable events (managed safety) and negative effects on compliance with rules, needed to manage predictable events (regulated safety).

Our results clearly show that the unintended negative effects of extensive use of formalization, quantification (and at less extend specialization) affect sensemaking, in particular. ATOM informants acknowledged that it is the responsibility of leadership to compensate for these effects by helping people make sense of their day-to-day activities.

Based on the analysis of the sensemaking and sensegiving relative to two key safety messages, our findings highlight the difficulties faced by leadership to achieve effective sensegiving across organizational levels. Despite recognizing the importance of this role, leadership practices remain poorly developed and focused mainly on reminders of official messages. They are negatively affected by organization barriers such as lack of time, lack of mutual trust between leaders and followers, lack of leader autonomy and initial ambiguity of messages. Our results show how the ATOM's control artefacts convey meaning focused on a normative approach and compliance with prescribed rules. The normative sense embodied in organizational artefacts guides the way in which the message ambiguity is conveyed. Hence, for example, although ATOM unit management is aware of the importance of an intelligent (rather than normative) questioning attitude, leaders fail to pass on this sense to followers, who are greatly influenced by normative sense conveyed by organizational artefacts. Thus, responsibility for coping with ambiguities and resulting inconsistencies is relayed to proximity managers, who are obliged to make trade-offs in real-life situation, but who are often not able to support front-line sensemaking about their trade-offs decisions. Moreover, their actions (trade-offs) at times contradict the sense conveyed by organizational artefacts, emphasizing complementarity and additivity of demands, which are difficult to implement in practice. Resolving message ambiguities is problematic and proximity managers need to be supported and accompanied by all organizational levels.

5. Discussion and contributions

This doctoral research explores how leadership for safety can enable joint development of regulated and managed safety. It discusses the results, previously presented in Chapter 4, and highlights the contributions of this research project. We first propose an emergent model describing the process of the joint development of regulated and managed safety, and its mechanisms. However, we also highlight that, in practice, the development of leadership for safety remains challenging. From this, we then deduce the organizational limits of managerial action. In particular, our case study reveals how extensive and inappropriate use of managerial control levers can lead to unintended effects resulting in diminishing of managed and also regulated safety. Finally, we develop a model of the leadership for safety process that allows to explore the mechanisms of leadership, their interplay and their modes of activation for the joint development of regulated and managed safety. Based on this model, we analyse in more depth the interactions between a particular leadership mechanism (sensegiving) and a mechanism of the joint development of regulated and managed safety (mindfulness). Our findings take account of the mediating role of the organizational structure, by highlighting the part played in effective leadership sensegiving by organizational control and coordination artefacts, such as rules, indicators and tools.

Chapter 5 begins by synthesizing the findings from the case study and proposing the construction of two emergent models: a model of the joint development of regulated and managed safety and a model of leadership for safety impacting this joint development (Section 5.1). Then the theoretical contributions are presented by underlying how this research has filled some of the gaps identified in the Chapters 1 and 2 (Section 5.2). Finally, the managerial contributions of this research are discussed (Section 5.3).

5.1.Synthesis of the findings

The findings from this doctoral research should not be interpreted as evidence that the unit studied is not sufficiently safe or that its leaders ignore safety. The significant efforts made by international safety institutions and operating companies (such ATOM) have resulted in considerable enhancements to safety and reliability in this sector. However, nuclear sector actors recognize that there is always room for improvement and this thesis tries to show how safety could be further improved. Section 5.1 starts by presenting an emergent model of the joint development of managed and regulated safety, impacted by organizational limits impeding this development (5.1.1). Then, while our case study explores in detail leadership mechanism of sensegiving, this section provides a summary of our findings about organizational barriers for activation of this mechanism (5.1.2). Finally, we propose an emergent model of leadership for safety for joint development of regulated and managed safety (5.1.3).

5.1.1. Emergent model of joint development of regulated and managed safety: impact of organizational limits

Our case study illustrates ATOM's approach to developing managed safety to complement regulated safety. ATOM acknowledges the intrinsic limits of regulating and measuring, constituting regulated safety. Rules are organizational guidelines for action but require interpretation and may not cover all situations. Similarly, measurements and indicators only partially capture human and organizational dynamics, and this is why ATOM makes continuous efforts to develop managed safety. Our case study focuses on certain organizational processes and practices, intended by ATOM to enhance managed safety– namely Reliability Enhancing Practices (REPs), the weak signals management system for Operating Experience (OPEX) and the Integrated Management System (IMS). These processes, corresponding rules and practices aim to help workers capture and interpret weak signals for adaptative responses in face of the unexpected. Thus, all these organizational changes are particularly focused on improvements to managed safety through the development of mindfulness and learning.

Our findings show that ATOM implements these processes and practices mainly using levers of managerial control and coordination, such as: formalization, quantification and specialization. These levers are embodied in organizational artefacts such as written rules, procedures, tools, reports and indicators, etc. However, despite ATOM's best efforts, the implementation of practices for managed safety is not straightforward and produces some unintended side effects. For example, Figure 5.1 depicts the effects of ATOM's practices for safety implementation on mindfulness.

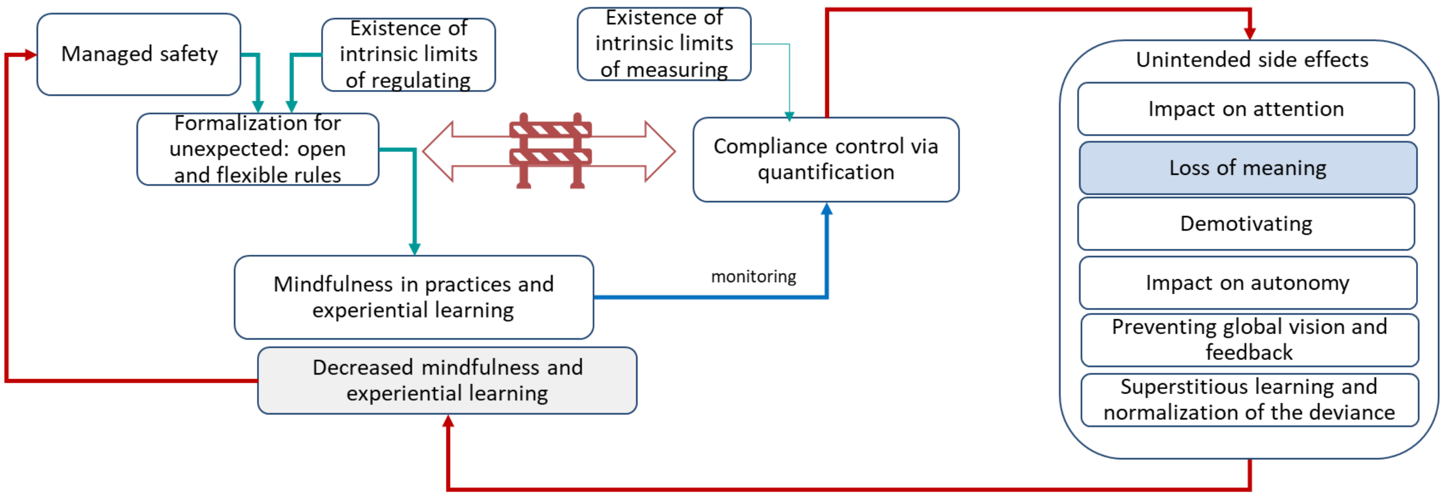

Figure 5.1. Effects of ATOM's practices for safety implementation on mindfulness

ATOM acknowledges that the development of managed safety relies on open and flexible rules, which allows for necessary adaptation to unexpected events. Such rules may allow to respond to intrinsic limits of regulating, recognized by ATOM. For example, ATOM introduces REPs, such as pre-job briefings and a processual approach enabled by IMS. However, in practice an effective use of open and flexible rules requires mindfulness and may be refuelled by experiential learning. ATOM monitors and assesses compliance with the introduced rules. However, although ATOM recognizes the intrinsic limits of measuring, control continues to be based almost exclusively on quantified indicators, which allow to monitor the application and not the effectiveness of rules (i.e., it monitors number of pre-job briefings rather than pre-job briefing practice efficiency). Our research reveals how an extensive use of quantified control produces some negative side effects. Specifically, we find that an extensive compliance control affects attention, motivation, autonomy, capacity to develop a global vision and, in particular, sensemaking. For example, the focus of organizational members' efforts has shifted from the objective of effective implementation of practices to the objective of the compliance with indicators. Such unintended negative effects of managerial control result in decreased mindfulness and reduced experiential learning. Managed safety is therefore constrained, despite ATOM initial objective of its enabling.

Similarly, Figure 5.2 depicts the effects of ATOM practices for safety implementation on deliberate learning.

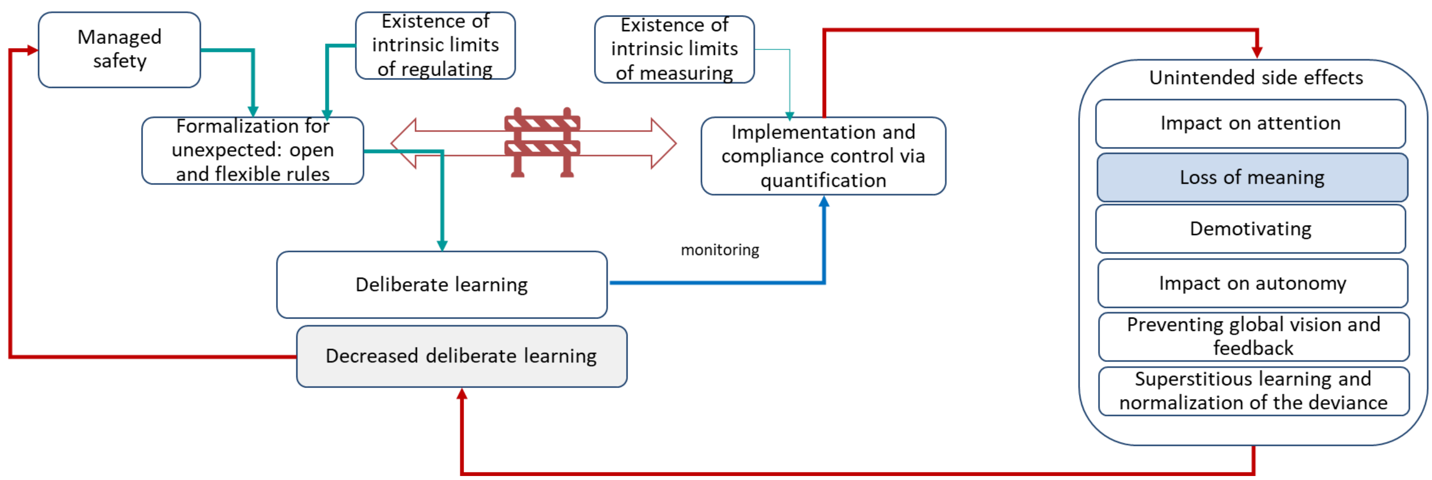

Figure 5.2. Effects of ATOM's practices for safety implementation on deliberate learning

Along similar lines, ATOM recognizes that complementing existing rules with more flexible rules can help to enhance deliberate learning. For example, the company introduces and has formalizes through rules, its OPEX system to promote the development of deliberate learning. However, the implementation of corresponding practices and control over compliance with rules are achieved through quantification. Despite the recognition of the limits of measuring, ATOM, again, relies extensively on quantified indicators to implement and monitor the OPEX system. For example, organization categorizes and follows-up all anomalies which are considered to be weak signals. Again, extensive control, based on quantified indicators, applied to monitor the compliance with rules aimed at deliberate learning development, produces undesired side effects. Such side effects on attention, sensemaking, autonomy and motivation enhance the use of superstitious learning and affect the capacity to build and to share meaning and, thus, the capacity to learn. In other words, the unintended side effects impede the development of deliberate learning. Again, despite ATOM's efforts, managed safety is constrained rather than enabled.

We found that, paradoxically, ATOM's processes and practices not only result in problems related to developing managed safety, but they also impede the maintenance of high levels of regulated safety. Figure 5.3 depicts the effects of ATOM practices for safety on compliance, which is a crucial element of regulated safety.

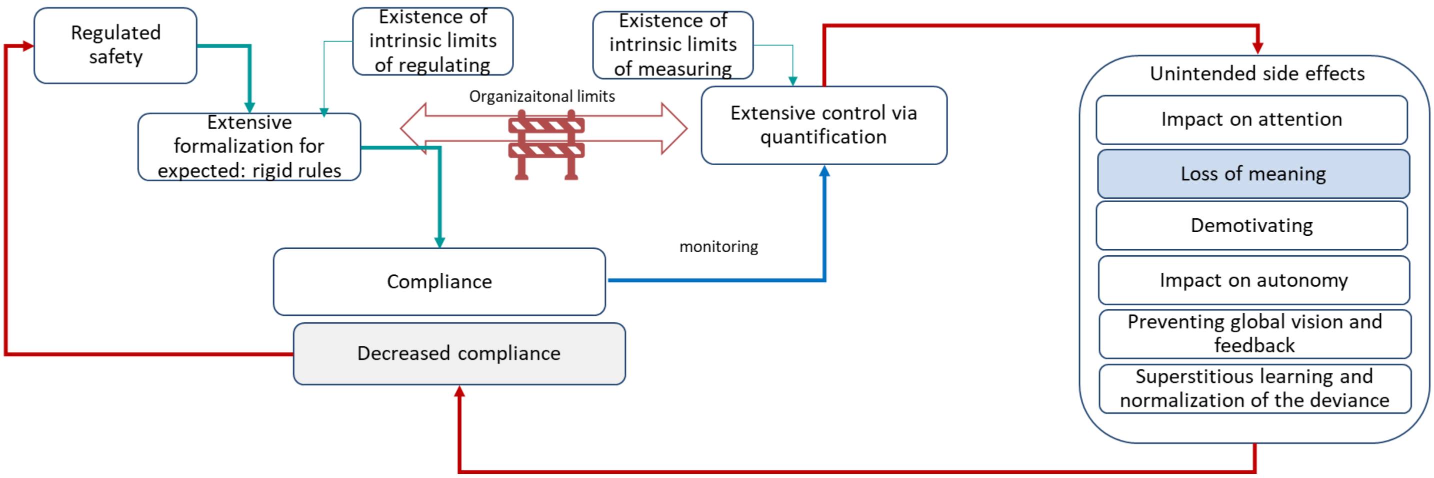

Figure 5.3. Effects of the implementation of ATOM's practices for safety on compliance (regulated safety)

Regulated safety relies mainly on rigid rules for expected situations. Despite the recognition of the intrinsic limits of regulating, ATOM continues to reinforce regulated safety by creating more and more rules (extensive formalization). However, our case study shows that this extensive multiplication of rules leads to the dilution of the real meaning of rules. In addition, since the limits of measuring are also not sufficiently considered, ATOM continues to systematically monitor compliance with rules through quantified indicators. This extensive control via quantification results in unintended side effects. The effects on attention, sensemaking, motivation and learning capabilities progressively lead to failure to comply with rules and even to the normalization of deviance from rules. Our results highlight how the side effects of extensive quantified control result in decreased compliance and, thus, constrain regulated safety.

In sum, the case of ATOM demonstrates the clear intention to jointly develop managed and regulated safety through the introduction of open and flexible rules. However, the extensive formalization and quantification used to control compliance with rules impeded the achievement of this objective, pointing to the existence of organizational limits and dangers of their exceeding Our result allows us to build the model of the joint development of managed and regulated safety, impacted by organizational limits impeding this development, presented in Figure 5.4.

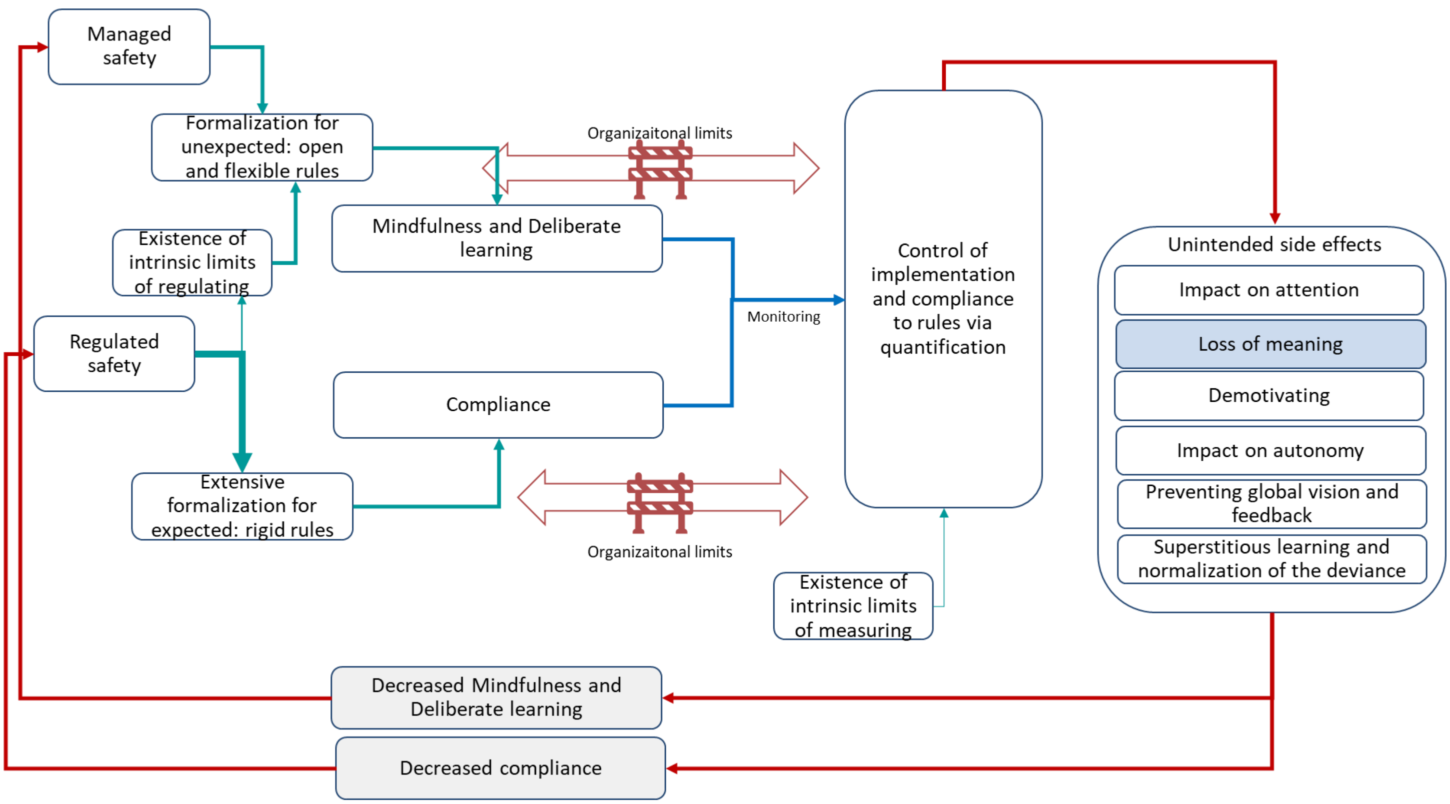

Figure 5.4. Model of the joint development of managed and regulated safety, impacted by organizational limits impeding this development

Our results show how ATOM deals with the challenge of the joint development of managed and regulated safety. The intrinsic limits of regulating are considered in part through the introduction of open and flexible rules to handle the unexpected. However, the main means of developing safety continues to be extensive growing formalization of rigid rules to handle the expected.

The implementation of both types of rules (those aimed at developing mindfulness and deliberate learning and those aimed at increasing compliance) are controlled via quantified indicators, without sufficient consideration given to the limits of measuring. Quantified control for preventing human non-compliance implies that employees are asked to follow the prescribed rules, but do not learn how to become “mindful” and apply those rules in a relevant way in order to be able to manage both predictable and unpredictable situations. This extensive control of rule compliance has unintended negative effects, leading to constrained mindfulness and deliberate learning, and reduced compliance. Ultimately, both managed and regulated safety are impeded, rather than developed.

In sum, the ATOM case points to the existence of **organizational limits of managerial control and coordination**. First, our results highlight that **extensive** use of formalization and quantification (and, to a lesser extent, specialization) saturates and divert attention, leading to demotivation and disempowerment, and thus prevents effective sensemaking and learning.

Second, the use of quantification is **not adapted** for open and flexible rules. The use of quantification is applied for managed safety, but echoes the methods used for the development of regulated safety (procedural barriers). Consequently, exceeding of these limits produce negative effects on mindfulness, learning and compliance.

Our findings show that all these negative side effects particularly affect sensemaking capabilities. Leadership can compensate for these negative effects by enabling sensegiving and supporting employees' sensemaking.

5.1.2. Organizational barriers to leadership for safety - key role of sensemaking

While ATOM recognizes the importance of the role of leaders in meaning-making and meaning-sharing, in practice, this is difficult due to organizational barriers, such as lack of time, lack of trust, lack of autonomy, and ambiguity of messages. Our analysis of two key safety messages reveals how unresolved ambiguities of these messages cascade and are amplified across organizational levels, resulting in loss of meaning at the operational level. Figure 5.5 depicts the effects of organizational barriers on the evolution of meaning, translated by organizational messages, artefacts and actions, that is, on the leadership sensegiving process.

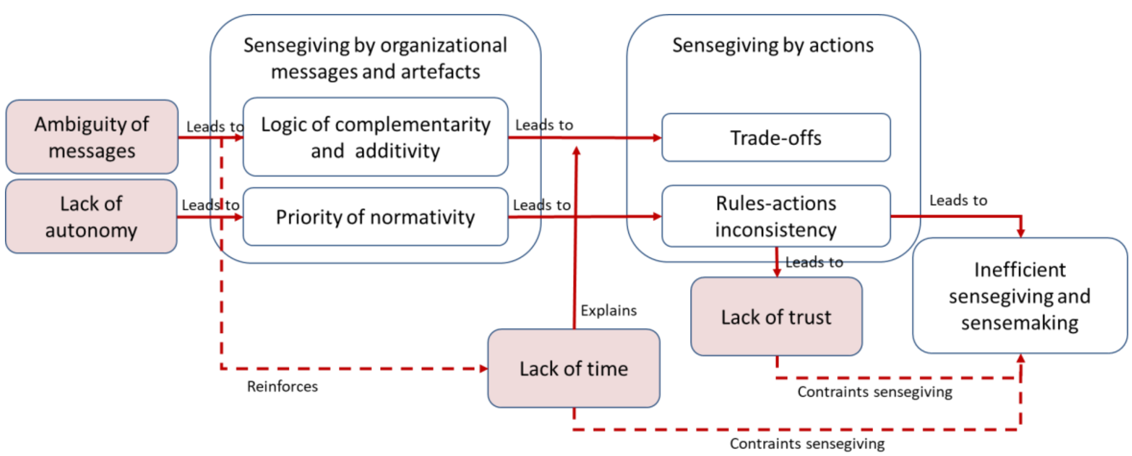

Figure 5.5. Barriers of effective process of leadership sensegiving about safety

Our analysis reveals that key safety messages are initially ambiguous and require interpretation. Upper-level management maintains this ambiguity by diffusing a logic of complementarity and/or additivity regarding diverse safety requirements (safety/production, normative/intelligent questioning attitude). This logic is conveyed through organizational discourse and artefacts and reinforces the problem of lack of time. The resolution of ambiguities is endorsed to proximity managers. However, ambiguities, that can be maintained at the abstract level, need to be resolved in the context of concrete operational activities and lead to trade-off decisions.

In addition, lack of autonomy leads to reinforcement of the logic of normativity in rule application, conveyed through official messages and organizational artefacts. In addition, artefacts designed for managerial control, such as quantified indicators, often focus on rule compliance (rule applied -yes or no), rather than the effectiveness of the practice (how the rule is applied). In the case where an indicator evaluates the practice, this evaluation prioritizes normative rule's application; for example, focusing the evaluation of self-control practice on exact gestures (voicing aloud a material/installation title by following this title by a finger) described by rule.

Lack of time reinforces the need for trade-offs resulted from additivity logic. Time pressures force proximity managers to make trade-offs that can sometimes be perceived as contradicting official safety rules. Thus, inconsistency between rules (required by upper levels) and actions (performed at operational levels) may be perceived at the front-line level, and thus leads to inefficient sensegiving, reinforcing lack of trust and resulting in inefficient sensemaking. Recursively, lack of trust reinforces this negative effect by constraining leaders' sensegiving. Moreover, lack of time affects leaders' capacities to explain the rules and the relevance of trade-offs. Thus, interpretation of ambiguities is not accompanied.

The meaning embodied in organizational artefacts and operational actions has a strong effect and impedes effective mindful sensemaking at the operational level. In addition, proximity managers, affected by organizational barriers, such as lack of time and trust, fail to explain to followers their interpretations of the rules and their actions (sensegiving) in order to accompany their sensemaking. All these constraints lead to loss of meaning about safety requirements at the front-line level.

5.1.3. Emergent model of leadership for safety for a joint development of managed and regulated safety

The objective of this research was to explore how leadership mechanisms are activated and combined with safety management mechanisms in daily activities, to achieve joint development of managed and regulated safety without exceeding organizational limits. Our case study allows us to build an emergent model of leadership for safety for an effective joint development of managed and regulated safety, suggested by the fieldwork. Based on our findings, Figure 5.6 depicts this model of expected effective joint development of managed and regulated safety.

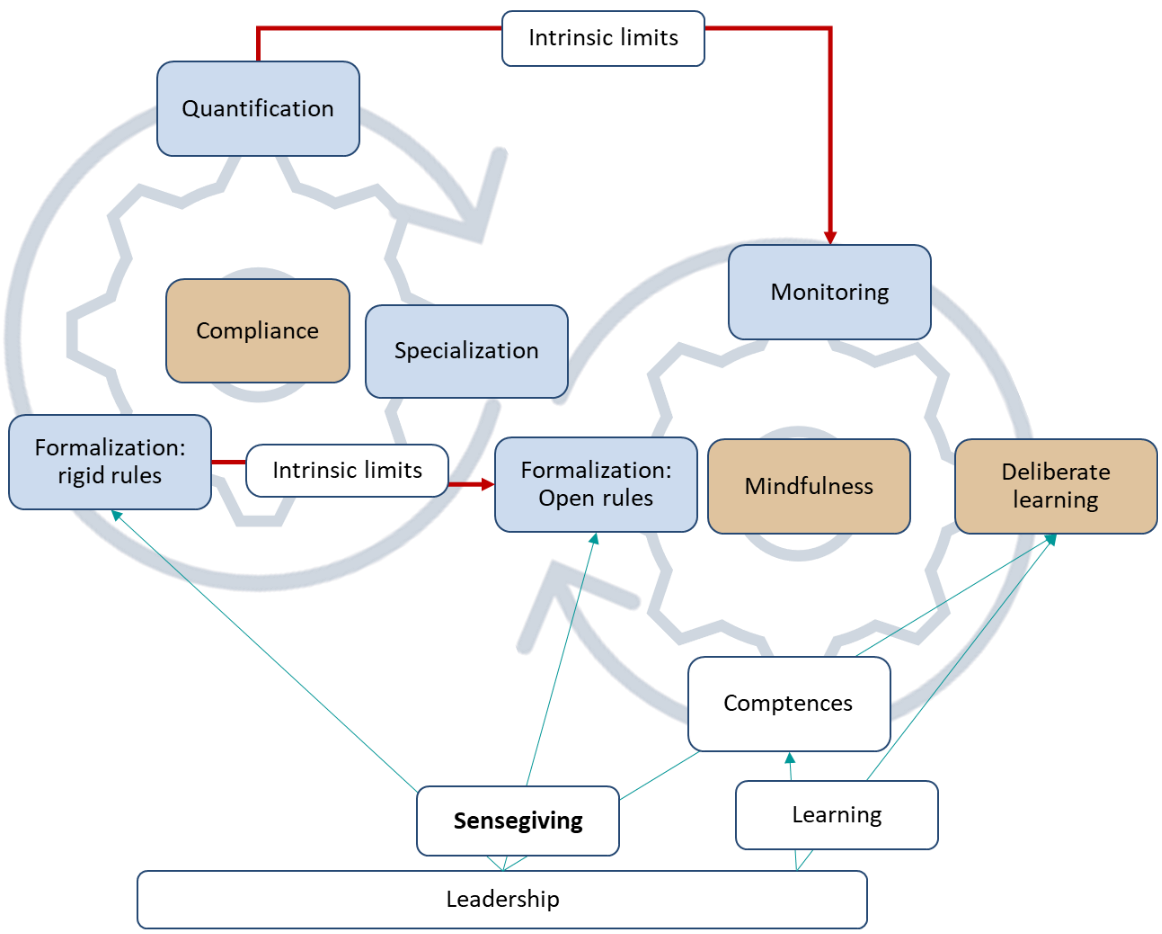

Figure 5.6. Model of expected leadership for safety process for effective joint development of managed and regulated safety

Joint development of regulated and managed safety rests mainly on two pillars: on the one hand, compliance and, on the other hand, mindfulness, supported by deliberated learning. In high-risk industries, compliance is implemented mainly through formalization, quantification and specialization. Organizations formalize rigid rules to manage expected events, control corresponding practices through quantification and coordinate implementation through specialization. In the case of non-compliance with existing rules, the organization will try to reinforce compliance by creating new rules and intensifying control.

However, organizations need to extend their capabilities by resolving the intrinsic limits of organizational levers used, in particular, to cope with unexpected events. Thus, limits of regulating (formalization) call for the design and implementation of more open and flexible rules. Also, limits of measuring (quantification) call for implementation of appropriate monitoring that complements quantified indicators with more qualitative and situation-specific types of control. These elements (open rules and adapted monitoring) allow for the development of mindfulness. In addition, efficient development of mindfulness in a high-risk industry requires deliberate learning and development of competencies. Thus, to develop mindfulness, the organization must design and implement open and flexible rules, better suited to handling unexpected events. The implementation of corresponding practices is controlled through appropriate monitoring. The results of this monitoring promote deliberate learning, which, in turn, contributes to developing competencies. More competent employees are able to follow both types of rules more mindfully and efficiently: flexible rules, which contribute to managed safety, but also rigid rules, which contribute to regulated safety.

To enable this virtuous circle, leadership intervenes mainly by activating two main influence mechanisms. First, leaders influence followers through sensegiving about rules. Leaders share and accompany rule meanings: why they exist, what they are intended to achieve, how rules are implemented and interpreted in concrete situations. In addition, leadership sensegiving facilitates successful deliberate learning. Second, leadership learning supports followers' deliberate learning and contributes to the development of competencies.

Therefore, reinforced by leadership influence, compliance, mindfulness and deliberate learning, interplay and are mutually reinforced, allowing for the joint development of regulated and managed safety. This model represents an expected interrelation among concepts and needs to be confronted by further empirical studies to examine its efficiency for the joint development of regulated and managed safety.

The analysis of the ATOM case study allows us to enrich this model by completing it with the effects of organizational limits. Figure 5.7 shows how organizational limits influence the joint development of managed and regulated safety and leadership for safety.

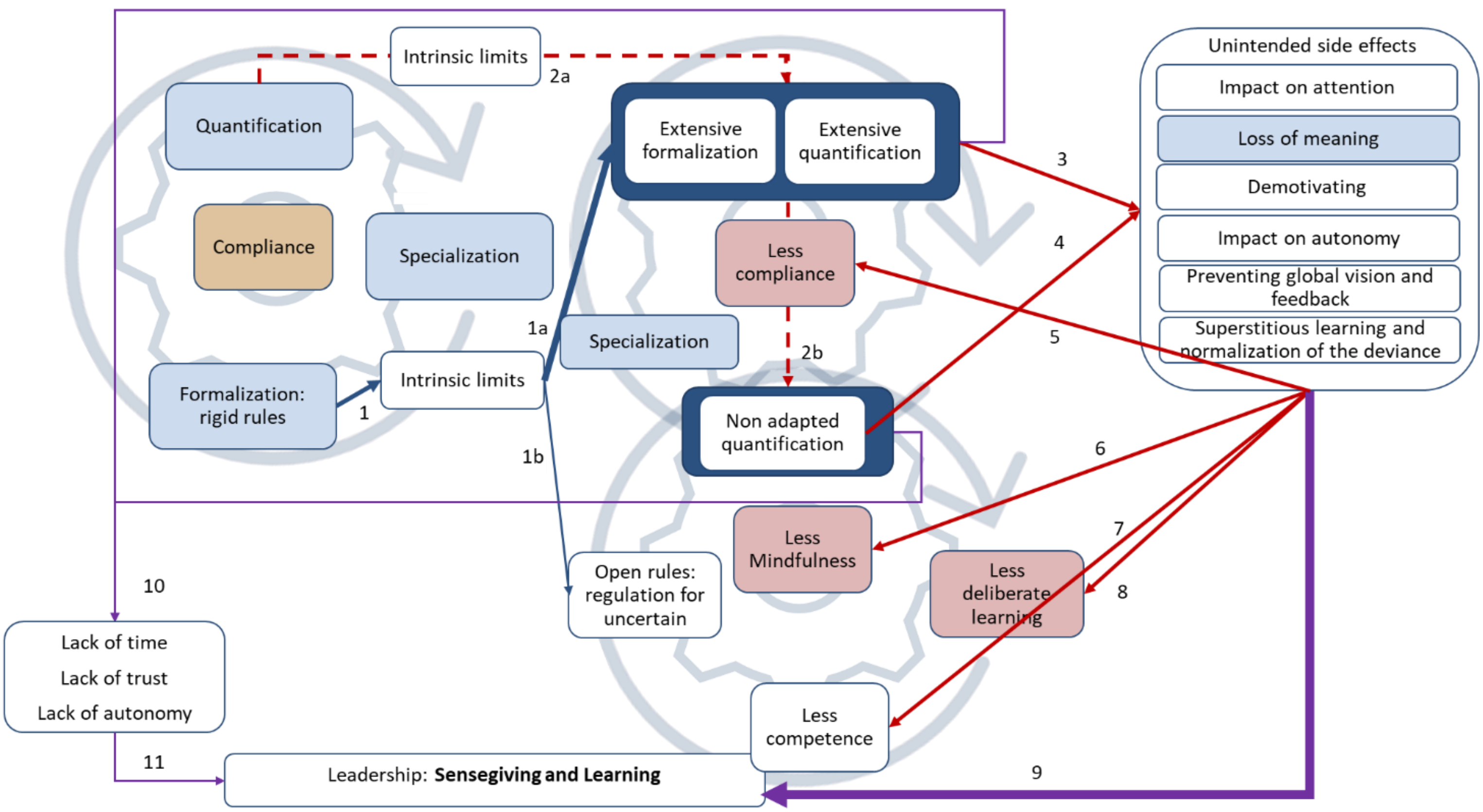

Figure 5.7. Model of leadership for safety for joint development of managed and regulated safety, influenced by organizational limits

Reinforcement of compliance is widely applied by all high-risk industries: rules are formalized and implemented by highly specialized actors, and their implementation is controlled by quantified indicators. To deal with the intrinsic limits to formalization (Figure 5.7, arrow 1), such as need of interpretation or inadequacy of rules to manage real-life situations, organization use two solutions:

first, the creation of additional rules aiming to anticipate a maximum number of situations (arrow 1a) and, second, the design of more open rules to deal with uncertainty (arrow 1b).

Our results highlight that the first solution is more easily and extensively used, echoing traditional approaches to safety management, based on reinforcement of procedural barriers. Thus, organizations use formalization extensively. Growing numbers of (often rigid) rules are accompanied by growing numbers of quantified indicators to control their implementation, leading to extensive quantification. Here, the intrinsic limits to quantification, such as the inability to model complex reality and human factors, are not sufficiently considered, leading to the addition of increasingly quantified indicators (arrow 2a). Thus, extensive formalization of rules and extensive control of their implementation (aimed at diminishing uncertainty), push organizations to exceed the organizational limits of managerial control.

The second solution to the intrinsic limits of formalization (arrow 1b) takes account of the need to manage (rather than diminish) uncertainty and relies on the introduction of open and flexible rules, referring to process-rules or goal-rules, rather than to action-rules. Such rules are better adapted to dealing with real and sometimes unpredictable situations. However, how these rules are implemented in practice is strongly related to how implementation is controlled. Our case study shows that the organization continues to monitor and control the implementation of rules via closed and quantified indicators, traditionally used for rigid action rules, while disregarding the intrinsic limits of measuring (arrow 2b). By applying inappropriate type of control, the organization once more exceeds the organizational limits of managerial control.

Beyond these organizational limits, additional rules and their control over their compliance no longer have a positive impact on safety and, paradoxically, can create new dangers. Extensive (arrow 3) and inappropriate (arrow 4) use of organizational levers (extensive formalization; extensive and inappropriate quantification) lead to unintended negative side effects on safety. Our results highlight the saturation and diversion of attention, demotivation, disempowerment, constraint on learning and, most importantly, the loss of meaning.

These side effects have multiple consequences on, both, compliance and mindfulness capabilities. First, less motivated, less autonomous, less attentive, less knowledgeable and less competent employees have difficulties to comply correctly with rules and deviation from the rules becomes normalized. Thus, compliance is decreased (arrow 5). Second, these side effects can lead to loss of attention and inefficient sensemaking. Thus, mindfulness is decreased (arrow 6). Third, these negative side effects affect the capability to learn (arrow 8), blocking competency development (arrow 7) and reinforcing decrease of mindfulness. Our results highlight a kind of vicious circle: use of rules and rigid control over their compliance impedes attention and meaning-making, demotivates, and blocks learning and the development of "*professionalism*" competences. In this context, adaptation by less motivated, less autonomous, less competent workers outside of existing rules becomes difficult, reinforcing the need to rely on compliance. This then leads to the creation of more rules and reinforcement of rigid control over their compliance (applied even in the case of open and flexible rules intended to develop managed safety). However, this approach reinforces the negative side effects of exceeding managerial control limits, and, then, lead again to the need of an additional compliance reinforcement.

Leadership is therefore seen as a force for extending organizational capabilities and addressing the negative consequences of exceeding organizational limits. More particularly, the leadership mechanisms of sensegiving and learning should help to provide necessary influence on followers to overcome the negative impact of exceeding organizational limits on mindfulness and deliberate learning. However, our findings reveal that negative impact of side effects of exceeding organizational limits has much stronger effect than the leadership's efforts to share meaning and enable learning (arrow 9). Moreover, leadership is affected recursively by organizational limits. Extensive and inappropriate use of formalization and quantification creates organizational barriers to leadership: leaders have less time and less autonomy and are considered less trustworthy by followers (arrow 10). This has a negative effect on leadership capability to activate sensegiving and learning mechanisms to influence followers (arrow 11).

In sum, our model explores how extensive use of rules and extensive and inappropriate use of quantified indicators constrain both regulated safety (because the focus on existence and control of increased procedural barriers replaces the focus on their effectiveness) and managed safety (because quantified indictors are irrelevant for monitoring competences and enabling adaptation).

5.2.Theoretical contributions

The objective of this doctoral research was to explore the role of leadership in the effective joint development of regulated and managed safety. The thesis provides several theoretical contributions in relation to safety management, leadership for safety and, additionally, organizational limits. Our research has two main and one additional contribution. It adds to the safety management literature by offering new insights into the importance of safety rules implementation while also highlighting the amplifying role of quantification in negative effects of managerial control (5.2.1). We also extend work on leadership for safety by clarifying leadership as a process and revealing the mechanisms involved, providing a conceptualization of the leadership process for safety and highlighting the importance of the sensemaking-sensegiving-sensemaking process for the joint regulated and managed safety development (5.2.2). We provide a complementary contribution to theoretical work on organizational limits by providing a better understanding of the limits that stem from managerial control and coordination (5.2.3).

5.2.1. Theoretical contributions to the field of safety management

The safety management literature examines in some depth the role of safety rules and indicators to control respect of safety rules. In this thesis research, we study both (rules and indicators) simultaneously to provide a deeper understanding of their interplay.

5.2.1.1. Crucial role of safety rules implementation for the joint development of managed and regulated safety

Safety rules are seen as a way to reinforce safety, but they can also create an impediment to effective management of safety. The limits of excessive regulation in high-risk industries are discussed extensively in the literature and in practice (e.g., Amalberti, 2001; Bourrier & Bieder, 2013; Hale & Borys, 2013a; Schulz, 1998; Wildavsky, 1988). First, the addition of more safety rules is not enough to reduce the risks (Hale & Borys, 2013a; Katz-Navon et al., 2005) and, beyond a certain threshold, additional rules result in new threats to safety, specifically, in terms of sensemaking of these rules (Amalberti, 2001; Power, 2016). Amalberti (2001, p. 111) describes the danger of rule multiplication on meaning-making about rules: "*since nobody knows really what rules/materials are really linked to the final safety level, the system is purely additive, and old rules and guidance material are never cleaned up*". The proliferation of safety rules can lead to an increase of rule violations (Hale & Borys, 2013), due to the difficulties involved in trying to make sense of the rules. Second, rules, especially, rigid rules (formulated in extension) are incomplete and are unable to anticipate and to account for all possible situations and events (C. Thomas, 2003). An approach that relies solely on rigid rules fails to prepare operators for the emergence of the unexpected and the complexity inherent in HROs, characterized by causal ambiguity and uncertainty (Daniellou et al., 2010; Grote, 2007; Morel et al., 2008). Therefore, extensive development of rules can reduce the capacity for development of operator mindfulness and adaptability to deal with unpredictable events.

To deal with these limits of regulation, several authors suggest working on ways to reconcile standardization and flexibility. For example, the importance of **rule formalization** is highlighted in several studies, pointing, more particularly, to the need of flexible rules and routines (Bourrier & Bieder, 2013; Dekker, 2003; E. Fairhurst, 1983; Grote et al., 2009; Hale & Borys, 2013b). These authors consider rules to be resources for safe practices rather than their determinant (Dekker, 2003; Hale & Borys, 2013a). Grote and colleagues (2009) suggest an appropriate balance between rules defined in extension (action rules) and rules designed in comprehension (process and goal rules). To be effective, safety rules should be formulated and managed to support not replace expertise (Hale & Borys, 2013b).

Several studies also highlight the importance of **rule elaboration** (Hale & Borys, 2013b; Kudesia et al., 2020; Ocasio, 2005; Perin, 2007; Schulman, 1993). For example, Ocasio (2005) explains that the vocabulary used to design rules can affect their efficiency: if the vocabulary does not consider uncertainty, this can lead to deficient safety practices and even accidents. Perin (2007, p. 11) also highlights that "*ambiguously or incorrectly written rules can affect configuration control and affect safety practices*". The participation of rule users in rule elaboration has also been studied. This echoes Schulman's findings suggesting more flexible and inclusive vision of formalization, in which rules are constantly renegotiated "*living documents*". This approach reduces misunderstanding and overcomes invariability of rules (Schulman, 1993). Similarly, Kudesia et al. (2020) explore the participation in rules creation and expand it to broader stakeholders of company eco-systems. Specifically, authors examine the interactions between front-line operators and external regulators, enabling rule elaboration. Thus, rules should gain in flexibility and become effective if applied by competent employees who have participated in their elaboration (Kudesia et al., 2020; Schulman, 1993).

Notwithstanding these important theoretical advances, **our results show that the problem of regulation persists**. ATOM continues to rely on rules to reinforce regulated safety. It extensively uses rules formulated in extension (in a rigid manner). The rules compilation produces negative effects and impedes sensemaking, in line with the findings in the literature (Amalberti, 2001; Hale & Borys, 2013a). Our case study reveals that, in a trade-off situations, some rules are not respected rigorously and these trade-offs are sometimes supported by proximity management (Hale & Borys, 2013a; Hynes & Prasad, 1997). Also, and in line with the literature (Daniellou et al., 2010; Grote, 2007; Morel et al., 2008), we found that despite the many written procedures, some situations remain uncovered by the rules.

In response to these limits of regulation, ATOM makes efforts to complement regulated safety with the development of managed safety. Our case study shows how a high-risk organization aims to develop managed safety by introducing open and flexible rules to develop people's competence to manage uncertainties in daily activities and to adapt behaviour appropriately (mindfulness). However, the introduction of open and flexible rules is done in parallel with and in addition to the multiplication of rigid rules. Our results reveal an additivity (rather than an integration) logic in ATOM's efforts, which is not in line with Grote et al.'s (2009) call for an appropriate balance between rules in extension (rigid) and rule in comprehension (open and flexible).

Our results show how, despite significant effort, the introduction of flexible rules (such as rules for pre-job briefing, debriefing, processual organizing, etc.) does not lead to flexible routines (Grote et al., 2009) and, thus, does not guarantee safety performance. In fact, rather than determining behaviours, rules play enabling or constraining role (Archer, 2004; Giddens, 1984; C. Thomas, 2003). Our findings suggest that the 'black box' of rules needs to continue to be open because there is continuous need for more investigation on the role of rules, in particular, how they are implemented and controlled. Our case study contributes to studies on safety rules by underlining the role of rule **implementation.** Our results highlight the unintended negative side effects of managerial control in rule implementation. Our findings also reveal the negative impact on mindfulness (through attention saturation and deviation, loss of meaning, and demotivation), on deliberate learning (by impeding autonomy and preventing the development of an overall vision, and effective feedback) and on rule compliance (through the development of superstitious learning and normalization of deviance). Therefore, rules introduced to develop mindfulness and deliberate learning fail to fulfil these objectives.

Elaboration and formulation of rules are not enough to guarantee safety outcomes, the focus needs to be on solving the ambiguity in managing open rules. Interpretation of open and flexible rules requires finer-grained sensemaking, but our case study shows that the way to implement such rules is based on formalization and quantification (and to a lesser extent on specialization). Even though the rules are formulated and elaborated as open and flexible, they are implemented in rigid ways. For example, rules conceived and formalized as open (pre-job briefing as a discussion about expected risks and unexpected dangers) are implemented rigidly (pre-job briefing as formal standardized and declarative confirmation of pre-identified risks). Another example of the rigid implementation of open rules was ATOM's implementation of an Integrated Managed System (IMS). The interface meetings of IMS macro-processes aimed at developing an overall vision of the activities performed by different departments, are controlled by simplistic indicators measuring the numbers of such meetings and percentage attendance.

Our results highlight problems related to rule implementation and, specifically, the influence of managerial control through quantification. However, studies exploring safety rules and their limits (e.g., Amalberti, 2001; Bourrier & Bieder, 2013; Grote et al., 2009; Hale & Borys, 2013a; Schulz, 1998; Wildavsky, 1988) overlook the effect of quantified indicators to control rule compliance. While Ocasio (2005, p. 110) considers that "safety is embodied in the vocabulary", our results reveal that **safety is embodied in the quantified indicators**.

5.2.1.2. Amplificatory role of quantification reinforcing negative effects of managerial control

Traditionally, the safety literature and safety practice rely on tools to minimize risk (risk management, reliability assessments, etc.), based on audits, certification and regulatory control systems (Dekker, 2014; Hale & Hovden, 1998). Control based on numbers and digital tools enables anticipation (Flyverbom & Garsten, 2021; Patriarca et al., 2019) and, thus, can be relevant for regulated safety, but not managed safety. Studies that focus on safety indicators (e.g., Erikson, 2009; Flin, 1998; Patriarca et al., 2019; Power, 2016; Webb, 2009; Zohar, 2010; Zwetsloot et al., 2017) are interested, mainly, in identifying measurable (leading and lagging) safety objectives, but mostly ignore the interplay between indicators and safety rules – with some exceptions (Bourrier & Bieder, 2013; Dekker, 2014).

Our results show that ATOM introduce rules to enable managed safety development. Some of these rules are formalized in extension, such as rules for self-control aimed at developing attention stability. However, rules for managed safety are mainly open and formalized in comprehension, such as rules for pre-job briefings, aimed at developing individual attention vividness or rules for IMS, aimed at developing collective attention vividness. We found that, regardless of the type of formalization, control over rule implementation is done in the spirit of regulated safety. Specifically, our results reveal the weight of quantification in this control. **Our findings highlight that quantification reinforced the difficulties involved in implementing flexible rules in practice. Quantification obstructs flexible rules and a processual vision**. The organization adds open rules but implements them in the same way as its rigid rules are implemented – based on simplistic, often binary (yes/no) quantified indicators (such as number of managerial visits on the field, attendance at interfaces meetings, number of pre-job briefings completed, etc).

The use of rigid control and quantified indicators stems from a focus on rule compliance and the belief that rule compliance is the most important factor for ensuring safety (Perrow, 1984). Therefore, the indicators are designed and implemented to control rule application and prevent non-compliance with rules. This logic requires simple, quantified indicators controlling compliance (rule is applied: yes or no). These easy to analyse and report indicators are aligned with managerial expectations ("*What interests my boss fascinates me*!" by Webb (2009, p. 502)).

However, simplified binary indicators (focused on compliance) do not capture whether the rule was applied correctly. As discussed, rules guide, but do not determine actions (Archer, 2004; Giddens, 1984; C. Thomas, 2003). Rules and, specifically, organizational rules, require a certain degree of interpretation (Denyer et al., 2008; Romme & Endenburg, 2006; van Aken, 2004). The degree of interpretation is lower for rules defined extension and higher for rules defined in comprehension. While "*technological rule (applied as recipe) can be proven in deterministic terms*", the indeterminate nature of organizational rules makes such proof impossible (van Aken, 2004, p. 235). Thus, the more the rule is open, the less simple control of rule application is meaningful.

However, a focus on quantified indicators confuses rule application with effectiveness of application. The objects of control are behaviour and attention (Ocasio & Wohlgezogen, 2010; Sitkin et al., 2010). For example, ATOM introduced IMS to enhance its processual approach, to obtain and share the "big picture". This IMS rule makes sense for the development of managed safety. Nevertheless, in terms of control, ATOM's focus on ensuring that all knowledge, needed to implement the process, is presented during a meeting (captured by participants' attendance indicator), does not guarantee elaboration of an intended shared vision. If, as in our case, people attended meetings just to show that they were there, even if they did not necessarily understand what the meeting was for (the meaning of the meeting) and did not participate in the building of a shared meaning, this renders these meetings ineffective and almost useless. Therefore, the control needs to be focused not on rule compliance (people are present at a meeting), but rather on the effectiveness of the meeting. Simple quantified indicators (such as attendance indicator) are insufficient, do not capture the complex and dynamic reality and need to be complemented by more complex and qualitative indicators. More attention needs to be paid to what the indicator is meant to demonstrate (application of the rule or effectiveness of its implementation) and greater commitment is needed for good design of indicators (how will focus be monitored: simple quantifiable indicator or a more qualitative indicator).

Our case study reveals that not only are quantified indicators inefficient but also their use may produce adverse effects. For example, ATOM informants referred to a waste of time (useless meetings). These effects are responsible for loss of attention (e.g., focus on self-control exact gestures, rather than on content), loss of meaning of indicators and reduced motivation. Thus, we found that quantified indicators are **inappropriate**, in particular, to control the implementation of open and flexible rules.

Moreover, since quantified indicators are applied to control every rule, the negative effects of their use are reinforced, leading to more loss of meaning and demotivation. Our findings reveal that **extensive** use of indicators deviates their meaning and results in their becoming the objective rather than means of achieving safe practices (i.e., "number games" (Dekker, 2014). Our results echo Dekker's (2014) finding of the negative impact of bureaucratic accountability on safety initiatives and capacity to deal with unexpected. Our case study identified how extensive and inappropriate use of quantification impedes mindfulness, learning and even rule compliance, resulting in diminished managed and regulated safety. **Therefore, quantification may be a powerful amplifier of inefficiency of safety rules implementation.**

Similar to the rule vocabulary problem highlighted by Ocasio (2005), quantification of rule control is both a consequence and a determinant of the organization's culture, including, in ATOM's case, the broader culture of the engineering profession and the managerial culture of the total quality movement. Although thorough examination of the underlying motivation behind quantification is beyond the scope of this research, it would be an interesting direction for future research. We can conclude that the importance given to quantified indicators may be explained by several reasons. First, it is aligned to industry practice – namely, traceability and accountability requirements. International safety institutions and, more particularly, the regulators require operators to demonstrate their safety efforts through traceability and easily controllable and comparable indicators (Dekker, 2014; Hale & Hovden, 1998). Second, the focus on quantified indicators originates from engineering spirit, relying on technological capability to always produce the desired result, based on a technical rule. In a technical engineering perspective, application of a technical rule guarantees the expected result (control focus on rules application) (Denyer et al., 2008; van Aken, 2004). However, in the case of organizational rules, due to organizational dynamics and regulation decoupling (de Bree & Stoopendaal, 2020), even well-designed rules do not guarantee the expected result (control focus on efficiency of practices corresponding to rules). Third, the focus on quantified indicators originates in the spirit of bureaucracy: organizations demonstrate confidence in quantification as an objective and neutral way to measure performance and control deviations and give the impression that risk is controlled (Dekker, 2014; Flyverbom & Garsten, 2021).

In terms of the contribution made by rules to improving safety, the literature focuses on the **number of rules**, the **types of rules** and **rule elaboration** (e.g., Amalberti, 2001; Bourrier & Bieder, 2013; Grote et al., 2009; Hale & Borys, 2013b). Our results suggest that there needs to be a focus, also, on **rule implementation** and **types of indicators** to monitor their implementation.

5.2.2. Theoretical contributions to the field of leadership for safety

5.2.2.1. Conceptualization of leadership as process

Our work makes three contributions to leadership theory. By adopting a critical realist approach, we (i) conceptualize leadership mechanisms, (ii) integrate them in a multilevel framework of leadership as a process and (iii) highlight the organizational embeddedness of leadership and the mediating role of organizational structure.

Following a call for mechanism-based theorizing about organizational phenomena (Davis & Marquis, 2005), leadership research—especially a processual approach to leadership—seeks to identify causal explanations of leadership outcomes. The leadership literature identifies multiple leadership mechanisms as "elements" that can transform inputs into outputs, but they differ widely in nature (Batistič et al., 2017; Dinh & Lord, 2012; Gottfredson & Aguinis, 2017; Hannah et al., 2009; Hazy & Uhl-Bien, 2015; Hernandez et al., 2011; Ng, 2017; Oc, 2018; Osborn et al., 2002). To enrich this literature stream, **we clarify the concept of leadership mechanisms** by distinguishing observable leadership practices from non-observable mechanisms of influence and by exploring the causal links between leaders' behaviours and organizational outcomes (Fischer et al., 2017). The leadership practices (meaning-making, demonstrating, relational monitoring, learning-development) activate leadership mechanisms (sensemaking, motivating, trust, learning), allowing to influence followers. In this perspective, we can explain, for example, why leader-member exchange (LMX) had a mediating effect on other mediating variables (Fischer et al., 2017; Gottfredson & Aguinis, 2017; Ng, 2017). It represents the quality of an exchange between leaders and followers and is performed through social exchange practices that activate different influence mechanisms. Therefore, LMX has a mediating effect as a practice that activates mechanisms rather than being a mechanism of influence.

Kempster and Parry (2011, p. 107) suggest that a critical realist perspective "*could help develop our understanding of how context and process shape the manifestation of leadership*." Although leadership mechanisms have been studied in some depth, the knowledge about them remains fragmented and requires integration (Acton et al., 2019; Anderson & Sun, 2017; Behrendt et al., 2017). Accordingly, we have developed an integrative, multilevel **framework to capture leadership as a process** (see Chapter 2 Figure 2.4). This framework takes into account different characteristics of the leadership processes proposed in previous studies (Day, 2000, p. 200; Fischer et al., 2017; Gordon & Yukl, 2004; Kan & Parry, 2004; Kempster & Parry, 2011; Osborn et al., 2002; Parry, 1998; Uhl-Bien et al., 2007; Yukl, 2013). By identifying and reordering these theoretical contributions within a coherent framework, our aim was not to identify new generative mechanisms or to be exhaustive, but rather to understand how leadership practices, mediated through structure and context, activate generative mechanisms. For this purpose, we searched for theoretical elements on the different mechanisms, practices, structure and contexts in the existing leadership literature. We adopted an approach that would allow us to 1) disassemble elements from different literature domains, 2) organize them into discrete units (practices, mechanisms, structure) and 3) combine and re-assemble these dispersed contributions to provide a more complete picture. Among the diverse literature streams from different epistemological paradigms, we identified generative mechanisms and their activation by practices and social structures. This involved interpretation of the existing literature with a focus on causal relations explaining observable practices.

Constructing an integrated theoretical framework within a critical realism perspective, combines and redistributes dispersed elements of the contexts, structures, mechanisms and observed events (Pawson & Tilley, 1997) in order to build potential explanations of the investigated phenomena. The framework also highlights the nature of the interactions among different elements constituting the leadership process: relationships among observable (context and practices), partially observable (social structure) and unobservable (mechanisms) elements (Gordon & Yukl, 2004; Kempster & Parry, 2011; Parry, 1998). It captures the "ingredients" of the leadership process and how and why they interact. Thus, by focusing on the relationships between the different levels, this framework provides a novel articulation and synthesis of the existing literature and creates new knowledge (Denyer et al., 2008).

Elaborated from a critical realist perspective, highlighting interactions captures **organizational embeddedness** and the social and dynamic nature of leadership (Fischer et al., 2017; Kan & Parry, 2004; Osborn et al., 2002; Parry, 1998; Uhl-Bien et al., 2007). The framework emphasizes the mediating role of organizational structure and clarifies the interplay between actions (practices) and organizational structures (enacted, in particular, via organizational artefacts). These interactions are not deterministic: each time agents interact, they can follow, ignore or slightly alter an existing social structure and, thus, participate in its production and reproduction (Osborn et al., 2002). This is consistent with a complex view of the organization and leadership (Lichtenstein et al., 2006; Osborn et al., 2002). In turn, our results offer a renewed and more realistic view of leadership as a process, embedded in the broader organizational dynamics, such that leaders (inputs) have indirect influences on operational safety-related practices (intended outputs). At a first glance, this might be seen as implying a limited scope the leader's role. However, a better understanding of the interplay among the context, practices, mechanisms and structures should encourage development of better ways to exercise influence.

5.2.2.2. Conceptualization of leadership process for safety

Our results extend the leadership as process framework (see Chapter 2 Figure 2.4) by including the goal-oriented dimension of leadership – namely, safety and its underlying mechanisms. Therefore, this research provides an integrative multilevel framework of leadership for safety, inspired by the critical realist approach (Archer, 1998a; Bhaskar, 1998b, 2008; Mingers, 2004; Mingers & Standing, 2017). Figure 5.8 depicts a framework of leadership for safety process.

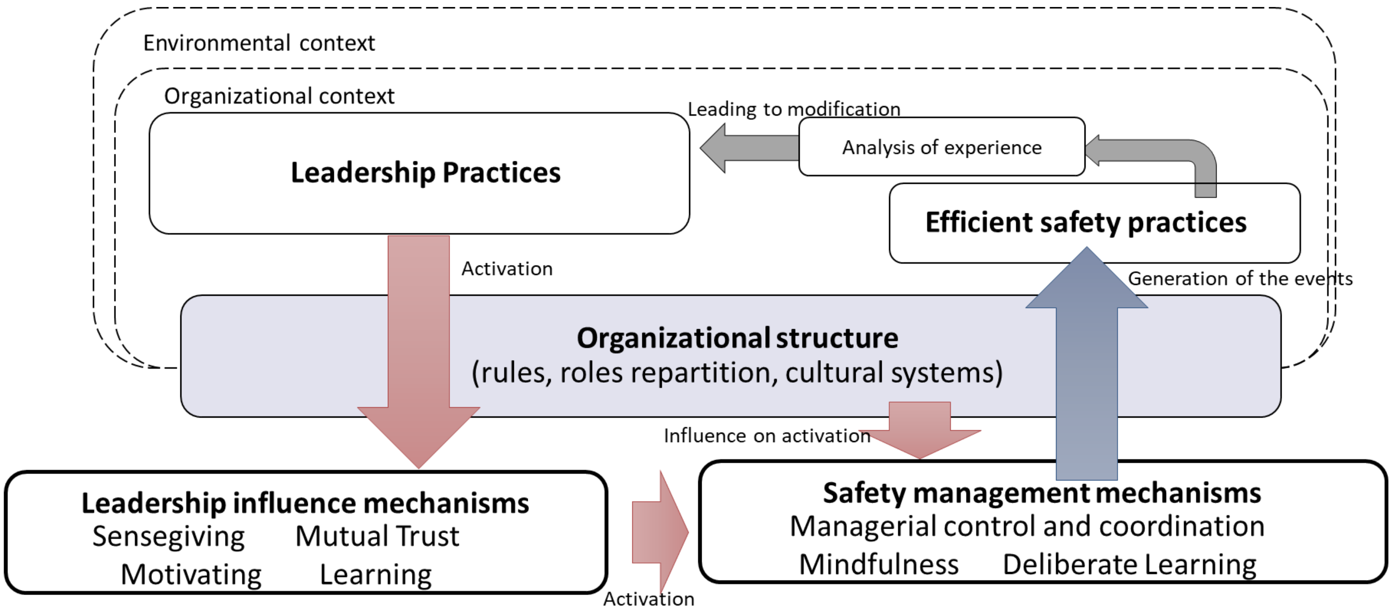

Figure 5.8. Critical-realist inspired framework of leadership for safety

The environmental and organizational contexts are observable and influence leadership practices and the organizational structure. Observable leadership practices cannot influence efficient safety practices directly, but have an effect through the activation of non-observable underlying mechanisms. First, leadership practices activate leadership influence mechanisms. The activation of leadership mechanisms (sensemaking, mutual trust, motivating, learning) influences the activation of the safety-specific mechanisms of joint development of regulated and managed safety (managerial control and coordination, mindfulness, deliberate learning).

However, this interplay between practices and mechanisms is indirect and is mediated by the organizational structure (including rules, procedures, role assignments and the cultural system), its visible part is embodied into organizational artefacts (rules, procedures, indicators, tools) that influence day-to-day practices. The organizational structure may constrain or enable the activation of mechanisms.

The interplay among the causal powers, activated by practices and mediated by the structure, generates flows of observable events, composed of more or less efficient day-to-day safety practices. Then, efficiency of observable safety practices is analysed, the result of this analysis leads to readjustment of leadership practices. Leadership practices can indirectly influence the organizational structure by readjusting rules, procedures and process, and even the cultural system, but this influence is indirect and requires continuous production and reproduction of practices over a long time period.

Our research adds to academic debate on leadership for safety. First, while most research in this area exploits leader-centric theories (Hofmann & Morgeson, 2004; Huang et al., 2004; Lekka & Healey, 2012; Pilbeam, Doherty, et al., 2016; Pilbeam et al., 2019), such as, transformation style (Barling et al., 2002; Conchie et al., 2013; Flin & Yule, 2004; M. A. Griffin & Talati, 2014; Katz-Navon et al., 2020; T. D. Smith et al., 2020), our integrative framework proposes a processual approach to the leadership process for safety. Our fine-grained analysis allowed us to identify elements referring to mechanisms, practices, contexts and structure (and their interactions), which, so far, have remained largely undifferentiated. Second, the framework distinguishes and reconciles leadership as an influence process and its relationships with a particular organizational goal of safety. Leadership mechanisms are generic and exist independent of context and activity, but they interact with mechanisms of goal-oriented activity (Antonakis & Day, 2017; Kan & Parry, 2004; Yukl, 2013). This allows to distinguish mechanisms of leadership influence from mechanisms of safety management. For example, awareness, described as a leadership mechanism by Pilbeam et al. (2019), refers to the safety management mechanism of mindfulness (Weick et al., 1999; Weick & Sutcliffe, 2006), activated by well-performed safety practices, and leadership mechanisms influence followers to perform these safety practices well.

5.2.2.3. Leadership for safety: role of sensegiving for joint development of regulated and managed safety

In line with our framework, our case study provides two main contributions to theory on sensegiving. First, we focus on sensegiving mechanisms in the interaction with sensemaking involved in mindfulness mechanism. Second, using the example of this interaction, we highlight, in general, the complex interplay between the mechanisms of safety management and leadership influence.

Our findings highlight the **focus on sensegiving** among leadership for safety mechanisms and its interplay with **sensemaking**. Leadership involvement in sensmaking explores how the perceived clarity of safety goals affects safety outcomes (M. A. Griffin & Neal, 2000; Katz-Navon et al., 2020; M. B. Nielsen et al., 2016; Tucker et al., 2016; Zohar, 2010). Following Barton et al.'s (2015) call for an examination of leadership sensemaking, our results show how the role of leadership for safety emerges through a process of construction of common meaning via the sensemaking – sensegiving – sensemaking sequence, across different organizational levels in day-to-day practice. While Zohar (2010) points to the need for safety priorities to be aligned between leaders and followers, our study of the sensemaking process across organizational levels reveals cascading inconsistencies across leaders at different hierarchical levels. While reaffirming the importance of the role of leadership in creating a common meaning for safety and resilience, in particular (Barton et al., 2020; Hannah et al., 2009; Weick, 1993; Williams et al., 2017), our findings provide strong support for the idea that it is crucial to understand the interplay between sensegiving and sensemaking (Foldy et al., 2008; Gioia & Chittipeddi, 1991), which, to our knowledge, has so far received little empirical scrutiny.

In a critical realist perspective, the underlying mechanisms may be mutually interacting, reinforcing or counteracting (Mingers, 2004; Tsoukas, 1989). In our framework of leadership for safety (see Figure 5.8), our results particularly highlight the interplay between sensegiving (leadership mechanism) and mindfulness, which requires mindful sensemaking (safety management mechanism).

To enable safety, leaders should perceive, make sense of and proactively address the resolution of ambiguities by influencing the construction of meanings (Grote, 2019; Hannah et al., 2009; Jansen et al., 2016; W. K. Smith & Lewis, 2011; Vogus et al., 2010). This process includes three-steps, involving leaders constructing meaning for themselves (sensemaking); sharing this meaning with followers (sensegiving); and, finally, helping followers reinterpret the messages and the organizational reality (sensemaking) (Day, 2000; Foldy et al., 2008; Smircich & Morgan, 1982). Our results show that this is not straightforward, since sensemaking-sensegiving-sensemaking cascades across organizational levels. Rather than being reduced, at each level the ambiguity is amplified. The level, which is forced to resolve this ambiguity is the lowest level of proximity managers who are endorsed to carry the burden of a joint development of regulated and managed safety. Our findings show the weakness of this approach: proximity managers are unable to support front-line sensemaking, at times, contradicting the sense conveyed by organizational artefacts. Resolving message ambiguities is problematic and proximity managers need support from all organizational levels.

Our findings echo construal-level theory in relation to psychological distance (Trope & Liberman, 2010): while safety message ambiguities can be easily tolerated at the abstract level, they became intolerable at the operational level, closer to concrete operational activities. In the field, abstract complementarity and additivity are transformed into tensions and result in trade-offs which, if not accompanied, can impede effective sensegiving and sensemaking and, thus, affect safety.

Our case study also highlights that sensegiving is performed via organizational artefacts, such as rules, indicators and tools. Following Sandberg and Tsoukas's (2015, 2020) discussion of the plurality of sensemaking, our results highlight the complexity involved in creating a common meaning. Sense is given not only through official messages, but it is also embodied in organizational artefacts and practices. Despite top managers' awareness of the ambiguities in initial messages, the decoupling between messages and organizational artefacts reinforces existing tensions and results in loss of meaning at the operational level. For example, while official messages convey the logic of requirements complementarity (e.g., safety drives production), organizational artefacts convey the logic of requirement additivity (e.g., need for high level of safety and production).

While some pioneering studies start to explore complex causal links between leadership actions and safety outcomes (M. A. Griffin & Neal, 2000; M. B. Nielsen et al., 2016; Pilbeam et al., 2019; Tucker et al., 2016), our results **specify mechanisms of leadership influence and the mechanisms of safety management, and explore their interplay**. Thus, we examine the organizational embeddedness of leadership for safety (Pilbeam et al., 2019), in particular, by identifying the organizational barriers to effective leadership sensegiving, impeding leadership for safety development. Figure 5.9 depicts the interplay among the different leadership for safety mechanisms.

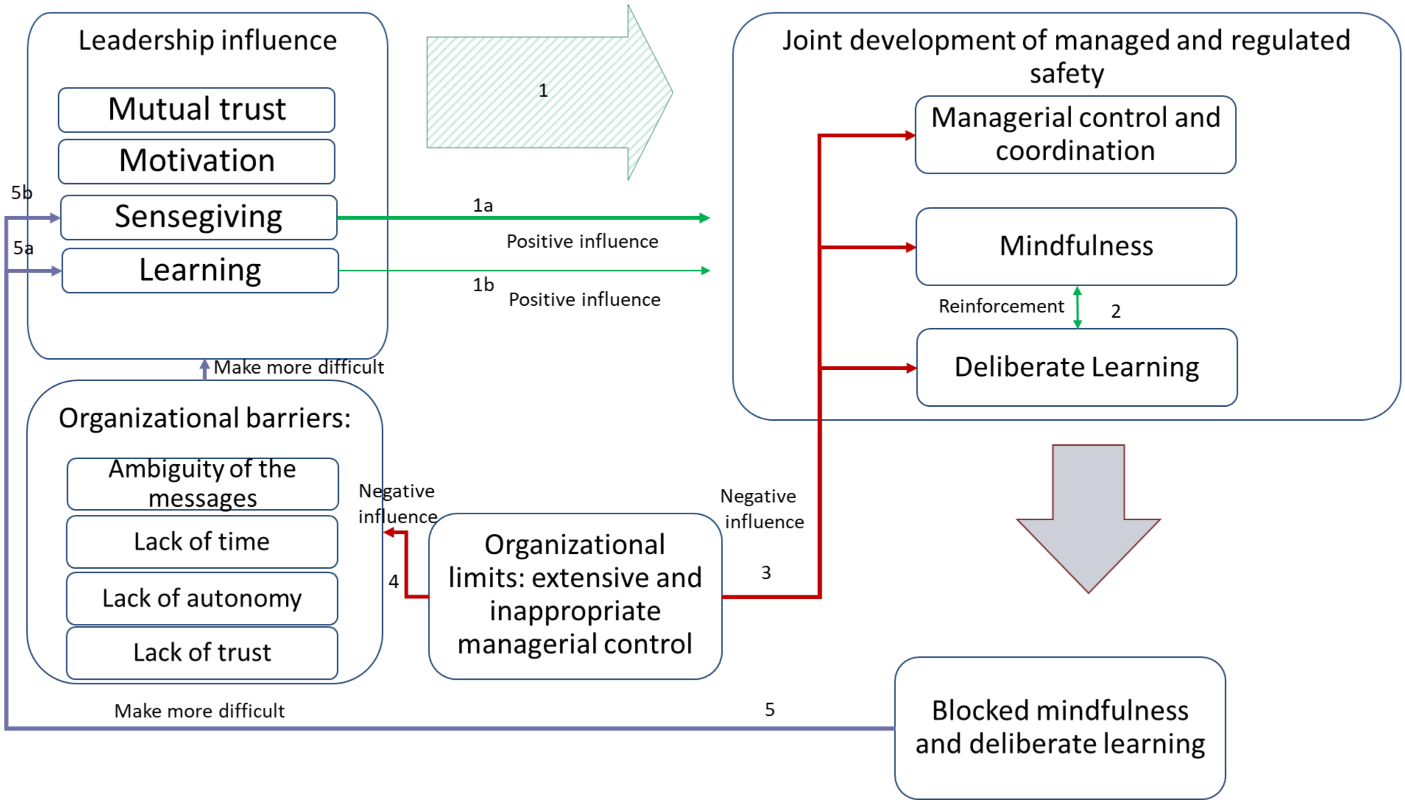

Figure 5.9. Interplay of mechanisms of leadership for safety

The literature reviewed in Chapters 1 and 2 suggest that leadership is an enabling factor of the joint development of managed and regulated safety (Figure 5.8, arrow 1). Our case allows to highlight the role of two leadership mechanisms: sensegiving (arrow 1a) and learning (arrow 1b). The impact of sensegiving is seen as essential for allowing the activation of the mechanisms of joint development of managed and regulated safety: managerial control and coordination, mindfulness and deliberate learning.

The literature reviewed in Chapter 1 suggests that organizational limits are seen as a constraining factor of joint development of managed and regulated safety. In fact, our case study reveals the negative influence of organizational limits of managerial control on safety objectives. Extensive and inappropriate managerial control points to the exceeding of organizational limits and leads to negative side effects on all the mechanisms of joint development of managed and regulated safety (arrows group 3). Our findings show how exceeding organizational limits through extensive and inappropriate use of the levers of managerial control (specifically, quantification), leads to reduced control efficiency (decreased compliance) and, more particularly, impedes mindfulness and deliberate learning, despite their mutual reinforcement (arrow 2).

However, the negative influence of exceeding organizational limits also has an impact on leadership mechanisms. Specifically, extensive or inappropriate use of managerial control promotes and reinforces organizational barriers to leadership (such as messages ambiguity, lack of time, lack of autonomy and lack of trust) (arrow 4), making the activation of leadership influence mechanisms more difficult (arrow 5).

Finally, blocked mindfulness and deliberate learning mechanisms make the activation of learning (arrow 6b) and of sensegiving (arrow 6a) mechanisms more difficult. In other words, our findings show how blocked mechanisms of safety management may block activation of leadership influence mechanisms (arrow 6).

In sum, our results contribute to work on leadership for safety by exploring the interplay among the mechanisms of leadership and the mechanisms of joint development of managed and regulated safety, by showing their looping interrelations and pointing to the role of organizational limits. Thus, our research adds also to organizational limits theory.

5.2.3. Theoretical contributions to organizational limits research

We advance knowledge on organizational limits (Farjoun & Starbuck, 2007) by showing how the effects of exceeding the limits of managerial control and coordination affect the organizational capability to deal with both predictable and unpredictable events on a daily basis. While prior organizational limits research focuses mainly on retrospective analysis of accidents (with clear limit violations), our research studies exceeding of less visible limits related to **day-to-day practices,** which responds to calls from safety and resilience research (Andersson et al., 2019).

The theory highlights two types of exogenous limits: the limits of cognition and the limits of managerial control (Farjoun & Starbuck, 2007). By focusing on managerial control limits, we enrich the work on organizational limits in the field of safety. While Oliver and colleagues (2017c, 2019) explore the interaction between cognition and technology, with a focus on the role of automation and its constraining influence on cognition, our **results are related to the impact of exceeding of managerial control limits**.

Moreover, our results allow to define organizational limits more precisely. The organizational levers of managerial control and coordination, pushed too far in their implementation, produce negative effects pointing to exceeding of limits. **This effect of exceeding limits is enacted in two ways – extensive and inappropriate use of managerial control levers** (particularly quantification); which mutually reinforce one another. First, our case study shows that extensive use of formalization and quantification leads to reduced efficiency of safety practices, in line with Amalberti's (2001) warning about regulation limits. There is no measurable managerial control threshold, allowing to alert that the limits will be exceeded. This becomes clear only when actions no longer have the expected effects and negative consequences become apparent. Second, our findings highlight non-adapted use of quantified control for the implementation of open rules. This underlines the almost ontological nature of limits – incoherence between the nature of the rules (rule formalization) and mode of control over rule compliance (rule implementation).

Finally, while Farjoun and Starbuck (2007) recognize the possibility of and difficulties related to anticipating the cascading of limits, our **results highlight the interplay between the limits related to managerial control and those related to cognition**. Exceeding organizational limits, through excessive or inappropriate managerial interventions, produces undesired effects and affects cognition. More specifically, exceeding of managerial control limits affects employees' meaning making in relation to rules and indicators and, thus, their cognitive capabilities of mindfulness and deliberate learning. These new insights into organizational limits and their impact on capabilities critical for safety add to knowledge about efficient leadership for safety and its managerial implications.

5.3.Managerial contributions

Our research defines leadership for safety **as a process of influence over individual and collective cognition and behaviours to meet safety management expectations.** Therefore, leadership is not the result of a combination of leaders' traits or behaviours, but rather a complex, organizationally embedded influence process. Mastering this influence process resides in an understanding of the 'what' (expected safety management behaviours for the joint development of regulated and managed safety) and the 'how' (the influence process and key role of the sensegiving-sensemaking process).

This final section offers some practical managerial implications.[4] These recommendations for managers refer to identification of the mechanisms of joint development of regulated and managed safety (5.3.1) and provide a better understanding of managerial control and its limits (5.3.2). We also contribute to a better understanding of the leadership for safety process (5.3.3.) and, in particular, of the key role of sensegiving-sensemaking-sensegiving (5.3.4). Finally, we offer some recommendations for leadership for safety training (5.3.5).

5.3.1. Identification of mechanisms of joint development of regulated and managed safety

High-risk industries and, in particular, the nuclear sector, recognize the need for simultaneous development of managed and regulated safety to ensure safety outcomes. While regulated safety deals with predictable events, on the basis of technical and procedural barriers (anticipation), managed safety deals with unpredictable events, on the basis of competencies and real-time adaptability to unexpected situations (resilience).

However, our case study points to the difficulties involved in this joint development and highlights how extensive regulation and quantified control (regulated safety) might jeopardize development of actors' adaptation capabilities (managed safety). Our research provides the clarification on mechanisms be addressed to enable the answer this major safety management challenge – managerial control and coordination, mindfulness, and deliberate learning.

First, the mechanism of **managerial control and coordination** affects rule formalization, elaboration and, as highlighted by our results, also the rule implementation. Rule implementation refers to how rules are monitored (to control their effective implementation) and adapted to ensure rule relevance and intelligent compliance. This mechanism aims to balance and reinforce both anticipation (face the expected) and resilience (face the unexpected) capabilities. Managerial control and coordination rely mainly on managerial practices (setting up of rules, procedures, tools and processes).

[4] Some of these managerial contributions have been presented in ATOM's NPP. We participated as external experts, in the Leadership for Safety seminar on the NPP, held on 18 October 2021, to accompany the understanding of the results of the safety culture perception survey. The principles and recommendations proposed were well received and have led to continued collaboration with the research team. More specifically, the NPP management has expressed its willingness to continue explore the notion of organizational limits and improve managerial actions to address these limits.

Second, the mechanism of **mindfulness** refers to the ability of individuals to focus their attention on a specific object while simultaneously paying attention to peripheral cues that might signal a future problem. Mindfulness involves recognition of relevant weak signals, their interpretation and the construction of appropriate (more or less innovative) responses. Mindfulness promotes the development of flexibility and adaptability (managed safety) within regulated environments, with respect to existing stable elements (regulated safety). In particular, mindfulness relies on effective sensemaking of rules and their relevance to the “here and now”. Mindfulness development relies heavily on leadership practices aimed at giving meaning and accompanying understanding.

Third, the mechanism of **deliberate learning** involves complex, intentional, systematic learning efforts. This involves building and sharing a common understanding of the causal links between actions and outcomes and helps to face causal ambiguity and avoid superstitious learning as well as learning myopia. Deliberate learning enables the development of organizational capability to both better anticipate (regulated safety) and be resilient (managed safety). Deliberate learning development relies on both managerial practices (setting up of learning process) and leadership practices (motivating and helping to learn).

Despite acknowledging that mindfulness and deliberate learning are important, in practice, high-risk organizations tend to mainly rely on managerial control and coordination. This is because, first, compliance with rules continues to be considered as a main pillar of safety development and, second, activation of this mechanism involves well-known managerial practices. Our case study provides interesting and novel results about the limits of managerial control.

5.3.2. Better understanding of managerial control and its limits

Fine-grained analysis of the empirical data from our case study allowed us to contribute to a better understanding of managerial control along two points. First, our results identify the organizational limits of managerial control. Second, our results enrich understanding of organizational rules functioning.

Our case study shows how extensive use of formalization and extensive and inappropriate use of quantification impede efforts to develop not only managed, but also regulated safety. This underlines the existence of **organizational limits of managerial control** and that exceeding these limits might be dangerous for safety. Thus, this suggests some reconsideration of managerial control. Our case study points to the conclusion, that, while control based on formal, easily traceable and reportable elements such as simple quantified indicators, leads to the "*illusion of safety control*" (Besnard et al., 2017, p. 22), it does not allow to effectively control safety development.

Our case study findings highlight the importance of a **better understanding of organizational rule implementation**. Despite ATOM's efforts to introduce more open and flexible rules (aiming at developing of managed safety), their implementation is guided by quantified means of control of compliance (originating in regulated safety development). Our results reveal that extensive control, mainly based on quantification, lead to negative effects, such as demotivation, loss of autonomy, poor learning and, in particular, sensemaking difficulties. Finally, managed and regulated safety are negatively impacted by this approach to control, leading to the decrease in mindfulness, learning and compliance. These findings underline the importance of choice of approach to control. Figure 5.10 depicts two different approaches based on difference in underlying assumptions about technical and organizational rules.

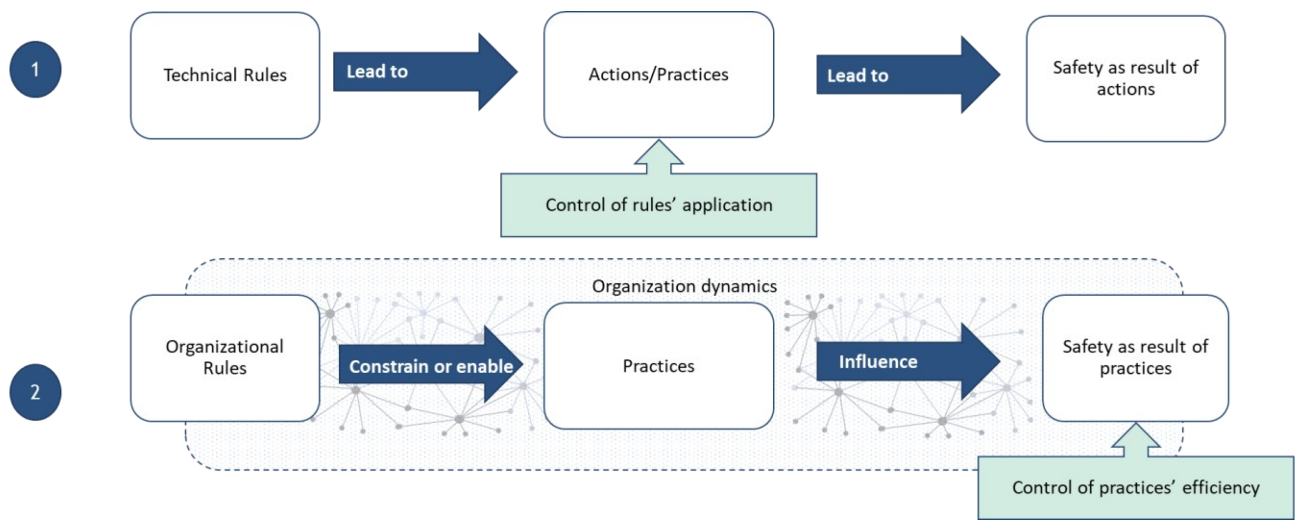

Figure 5.10. Two approaches to rules and to control

The first approach is rooted in the engineering assumptions of application of technical rules (applied as recipes), guaranteeing results (Denyer et al., 2008; Romme & Endenburg, 2006; van Aken, 2004). If rules are applied correctly (actions correspond to the rules), this leads automatically to safety as result of actions. Thus, control focuses on the application of rules. However, this approach overlooks the organizational complexity of organizational rules, impacted by multiple organizational dynamics. The second approach integrates this complexity and posits that the design of relevant rules does not automatically guarantee results. Rules guide (constrain or enable), but do not determine corresponding practices, which influence results in terms of safety. Therefore, in this approach, the control focuses on practice efficiency (effects in terms of safety are proven), rather than practice existence (the rule is applied). Systematic and exclusive use of quantified control, in particular, applied to assess compliance with open and flexible rules, should be requestioned in high-risk industries. Qualitative and context-dependent monitoring should be applied to control practice efficiency, rather than simply rule application.

Therefore, to effectively develop managed and regulated safety, organizations in high-risk industries should pay attention to: 1) the types of rules (rule formalization); 2) rule elaboration; and 3) control over rule implementation - focus of controlling (what is controlled) and way of controlling (types of indicators).

5.3.3. Better understanding of leadership for safety process

The literature on leadership as process suggests reaching beyond the focus on leaders' traits or behaviours, so that, "*rather than looking for leadership in people, we need to look for leadership in organizational practice*" (Denyer & Turnbull, 2016, p. 264). We advance along this path by highlighting the need to examine means of leadership to exert influence and by integrating leadership practices into a broader framework of leadership process for safety.

The framework of leadership for safety process represented in Figure 5.8 includes practices, organizational structures and mechanisms. Leadership practices are visible (e.g., presence in the field, pre-job briefings animation, etc.). These practices activate leadership influence mechanisms (sensegiving, mutual trust, motivating or learning). For example, the practice of rule reminders is aimed at activating sensegiving mechanisms, but, as we have shown, this practice is not sufficient nor is it effective (reminders should be accompanied by explanations of the rules to build a shared understanding of rules). The mechanisms of leadership influence interact with safety management mechanisms for joint development of regulated and manged safety (managerial control and coordination, mindfulness, deliberate learning). The interplay among the causal powers of these mechanisms generates observable safety practices.

Leadership practices seem to affect the activation of underlying mechanisms to generate observable practices. However, the activation of mechanisms by leadership practices is mediated by the organizational structure, which can play a constraining or an enabling role. First, the organizational structure includes rules, roles, resources and process. Obviously, the leader's position in the hierarchy enables his or her access to resources for influence and determines his or her capacity to influence the structure and activate mechanisms. Moreover, our results highlight the role of rules and the control of their compliance on effective joint development of managed and regulated safety. Followers should understand the role and relevance of rules, and the way of their intelligent application in real-life situations. Second, the organizational structure includes cultural systems (e.g., safety culture). In terms of culture development, the leadership role focuses mainly on the enacting of safety culture, that is on the translation of values into behaviours.

The existence and influence of in-depth mechanisms (of leadership and of safety management) and organizational structure indicate lack of a direct linear relationship between leadership practices and organizational safety outcomes. To make leadership practices more effective, it is essential that leaders understand how the generative mechanisms of both influence and safety processes can be activated in distinct organizational and environmental contexts. In sum, our results underline the organizational embeddedness of the leadership for safety process. **The idea of a direct influence of leadership practice on safety practices is illusionary and overlooks the non-easily observable influence of structure and underlying mechanisms**.

5.3.4. Key role of sensegiving-sensemaking-sensegiving process for leadership for safety

One of safety management mechanisms – mindfulness – relies on the ability to interpret the "here and now" environment, select relevant rules and implement them efficiently. Thus, the development of mindful sensemaking is crucial for joint development of managed and regulated safety. Mindful sensemaking, as mindful engagement with unfolding events, involves a combination of three elements: cue selection, cue interpretation and appropriate actions to respond to cues. Our research contributes to the improvement of leadership for safety by highlighting the pivotal role of sensegiving mechanism of leadership influence for the development of mindfulness and by underling the organizational embeddedness of this process.

Our findings clarify the **role of sensegiving-sensemaking interplay**. We found that the sensemaking (leaders make sense for themselves)-sensegiving (leaders give sense to followers)-sensemaking (leaders accompany followers' sensemaking) process cascades across organizational levels (see Figure 5.11).

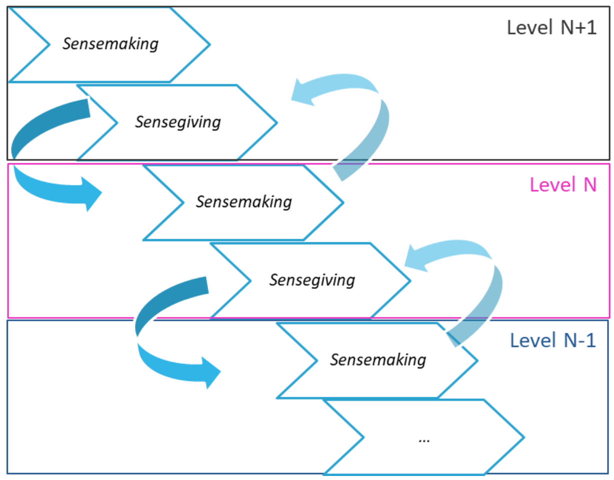

Figure 5.11. Sensemaking-sensegiving process across organizational levels

Therefore, the analysis of sensemaking and sensegiving at all levels (including those external to the organization, such as international safety institution) is needed to fully understand the process of building and sharing of meaning. Acknowledgment of this cascading process of sensemaking-sensegiving-sensemaking is particularly important in the case of the initial ambiguity of the message (e.g., safety and production are complementary, but in tension).

Our results particularly highlight the organizational **embeddedness of the sensegiving-sensemaking-sensegiving process**. Existing ambiguities persist, they are transformed and amplified across levels. Our case study highlights how initial ambiguities of safety messages, unresolved and even reinforced by organizational artefacts and actions, make leadership sensegiving very difficult. Our results reveal how unresolved ambiguities result in trade-offs made by proximity managers close to the operational level. However, such trade-offs, without accompaniment of their sense (e.g., ignoring a safety rule to improve production) and under the weights of contradictions with sense conveyed by organizational artefacts (e.g., additivity of compliance with both safety and production demands), lead to loss of meaning at the front-line level. Leaders at the operational level (proximity managers) are cannot convey meaning contradictory to organizational messages and artefacts. The solution to ambiguity of message should not be proximity manager's responsibility solely. For example, the idea that "*operational shift managers are the guarantors of safety*" is feasible only if appropriate support and coherence are provided all along the hierarchical line. The coherence of the sensegiving-sensemaking-sensegiving process should be accompanied by well-designed organization at all levels and appropriate organizational artefacts.

These recommendations also guide the approach to design and implement leadership for safety training programme.

5.3.5. Training programme in leadership for safety

Our findings provide a solid basis for discussing how to develop training programme able to address challenges of leadership for safety development. There is a large offer of leadership for safety training, developed by international safety institutions (e.g., IAEA, 2022; WANO, 2018) or developed by high-risk organizations internally. However practitioners recognize the failure of the leadership training due to the managerial and organizational barriers, which complicate the application of 'lessons learned' in daily practice (Beer et al., 2016). Our study contributes to a recognition of the organizational embeddedness of the leadership process and to a deeper understanding the interplay among leadership and safety management mechanisms, suggesting a need for innovative and more in-depth pedagogical methodologies.

First, we conceptualize leadership as a process rather than a set of leader traits and styles. This organizational approach to leadership acknowledges that leadership is part of the broader organizational dynamics, this recognition of organizational complexity is crucial for designing trainings in the domain of leadership (K. Nielsen et al., 2010; Schwatka et al., 2020; Tafvelin et al., 2019). The focus should shift from a leader-centric view (individuals) to an organizational view (individuals within the organization and its eco-system, such as international safety institutions, regulatory bodies, TSOs, etc.).

Second, our results allow to put into perspective the mechanisms of leadership influence and the mechanisms of safety management. Existing training often suggest some 'ideal' leadership for safety practices (such as being present in the field, giving meaning to safety policies, etc.), but our case study shows that these practices are difficult to implement due to the influence of context, structure, and underlying safety management mechanisms. Thus, the existence and influence of mechanisms and organizational structures provides an illusion of a direct linear relationship between leadership practices and organizational outcomes. Moreover, the leadership process should be adapted to concrete organizational goals, such as safety. Therefore, effective leadership for safety relies on an understanding not only of the generative mechanisms of leadership, but also the mechanisms of safety management, which can be activated in specific organizational and environmental contexts. Leadership practices for safety may differ from generic leadership practices depending on their goal (safety) and organizational context.

Finally, our results suggest developing long-term and innovative pedagogical methodology to enable in-depth learning. Pedagogical approaches should aim to increase training effectiveness by helping trainees apply the acquired knowledge in their professional contexts and by helping them overcome organizational barriers to change (Beer et al., 2016). Knowledge appropriation in concrete situations (e.g., through long-term tutoring project) is required, as well a finer-grained understating of concrete organizational dynamics that may constrain or enable the changes in leadership process. The application of acquired knowledge and implementation of leadership for safety practices in the trainees' organizational context could help to achieve long-term and in-depth learning objectives.

These three recommendations were followed and implemented in the frame of ELSE training, that first session took plane in 2022-2023. Appendix 7 provides details of the ELSE training programme.

5.4.Conclusion of Chapter 5

Chapter 5 began by synthesizing the findings from our research. We summarized our results and proposed their abstract formalization by introducing two emergent models. One model describes the process of the joint development of regulated and managed safety and its mechanisms (see Figure 5.4). We also develop a model of the leadership for safety process that allows to explore the mechanisms of leadership, their interplay and their modes of activation for the joint development of regulated and managed safety (see Figure 5.6 and Figure 5.7). Our findings highlight the organizational limits of managerial action. In particular, our case study reveals how extensive and inappropriate use of managerial control levers can lead to unintended negative effects (on attention, sensemaking, motivation and learning capabilities) impeding both managed and regulated safety. This model depicts the results of organizational limits influence on decreased compliance, mindfulness and deliberate learning and outlines the challenges of leadership for safety to overcome these negative consequences and the related organizational barriers. Moreover, through an emergent model of leadership for safety, we analyse, in particular, the interactions between a leadership mechanism (sensegiving) and a mechanism of the joint development of regulated and managed safety (mindfulness).

Based on these findings, we make two major contributions to the literature. First, our results contribute the field of safety management by providing finer-grained understanding of mechanisms of the joint development of regulated and managed safety. Namely, we enrich knowledge about managerial control and coordination mechanisms by highlighting the crucial role of the implementation of rules and corresponding quantified indicators for its control. Second, we contribute to the field of leadership for safety by reconceptualizing and building an integrative framework of leadership as a process, which highlights the interplay between the mechanisms of leadership and safety management and explores the pivotal role of sensegiving for a joint development of regulated and managed safety. By specifying the organizational limits of managerial control and its cascading effects on cognition, we also make an additional contribution to the field of organizational limits.

Finally, our research has important managerial implications. First, it provides a better understanding of the mechanisms of a joint development of regulated and managed safety. Second, our results enrich the understanding of managerial control and its limits and, in particular, in terms of quantified indicators to control rule compliance. Third, our results provide a finer-grained understanding of the leadership for safety process and recommendations to improve leadership for safety practices. Fourth, our case study clarifies the key role of the sensegiving-sensemaking-sensegiving process and how it cascades through organizational levels. Fifth, we provide practical recommendations for the development of training programmes in the domain of leadership for safety.

General conclusion

This general conclusion to this thesis starts with a summary of the outcomes of the research in terms of its theoretical and managerial contributions. It discusses some limitations of the research and proposes future research directions and/or potential extensions.

The objective of this doctoral research was to explore how leadership mechanisms influence safety management in its challenge of a joint development of regulated (based on procedural and technical barriers to deal with the predictable) and managed (based on adaptive capabilities to deal with the unpredictable) safety. By clarifying the concept of leadership for safety using a critical realist lens, our research focused, in particular, on exploring how leadership influence mechanisms can favour activation of the mechanisms, which lead to a joint development of managed and regulated safety. This research question is at the crossroads of two fields of scholarly interest: 1) safety management and resilience in high-risk environments and 2) leadership and leadership for safety.

Our study was carried out within a European nuclear power plant. Its originality lies in it being an explanatory case study conducted within a critical realist paradigm. This methodological choice is original in allowing the research question to be addressed based on the integration in the analysis and formalization in a coherent framework, of several different layers, namely: context, practices, underlying generative mechanisms explaining observable events and the mediating effects of organizational structure. Our findings provide a finer-grained understanding of the leadership for safety process. By clarifying the generative mechanisms that underline this process and by exploring their modes of activation, our research enriches the knowledge on leadership for safety, from both a theoretical and a managerial point of view.

Main contributions

This thesis contributes to the development of theoretical knowledge on research fields of safety management, leadership for safety, and organizational limits theory. Moreover, this research allows to formulate some managerial recommendations.

Our research extends work on safety management, by applying an organizational approach and offering a focus on managerial control. More specifically, our results point to the organizational limits originating from this control and the negative effects that emerge if these limits are exceeded.

Contributions to the joint development of regulated and managed safety.

While high-risk industries recognize the need for simultaneous development of managed and regulated safety to ensure safety outcomes, our thesis identifies the safety management mechanisms on which this joint development relies, that is, managerial control and coordination, mindfulness and deliberate learning.

The mechanism of managerial control and coordination involves rule creation and control. Rules play an essential role in the coordination within an organization and can be defined as virtual storage and registration of collective knowledge (Giddens, 1984; Reynaud, 1988). However, rules are incomplete and require interpretation; they constitute a general direction for action (C. Thomas, 2003). In interaction with mindfulness (in terms of the quality of attention and the capacity to make sense of situations and rules) and deliberate learning (as the capacity to build, share and improve knowledge about situations and rules), managerial control allows the joint development of regulated and managed safety by balancing and reinforcing both anticipation (facing the expected unexpected) and resilience (facing the unexpected unexpected) capabilities. The organizational studies literature highlights that this effective balancing relies on balancing between rules in extension and in comprehension in rule formalization (Busby & Iszatt-White, 2016; E. Fairhurst, 1983; Grote et al., 2009; Hale & Borys, 2013b; C. Thomas, 2003), suggesting flexible rules and routines (Grote et al., 2009), and balancing between top-down and a more participative approach in rule elaboration (Hale & Borys, 2013b; Kudesia et al., 2020; Schulman, 1993).

In the nuclear industry, managerial control relies considerably on the compliance to safety rules. Our results show that, in practice, there is no balance, but rather an additivity of elements of regulated and managed safety. Rules aimed at the development of managed safety add up to continuously increasing number of rules aimed at regulated safety. Our case study shows that, despite the clear intention to develop managed safety, management continues to use extensively levers such as formalization, quantification and specialization, designed to achieve regulated safety. Our findings point to the influence of organizational control artefacts, such as rules and indicators, which divert attention, affect sensemaking, constrain learning and, thus, counteract efforts to develop managed safety. Our case study shows how managerial control leads to undesired negative effects on mindfulness and deliberate learning, which are crucial for managing unpredictable events (managed safety). Moreover, we show how extensive use of formalization produces negative effects on compliance with rules, which is needed to manage predictable events (regulated safety). Thus, we confirm the limits of extensive regulation, such as sensemaking difficulties due to rule interpretation (Amalberti, 2001; Hale & Borys, 2013a), and inability of rules to cover the whole complex reality (Daniellou et al., 2010; Grote, 2007; Hale & Borys, 2013b; Morel et al., 2008). Our study offers new insights for the safety management literature, by underlining, in addition to rule formalization and elaboration (Grote, 2007; Hale & Borys, 2013b; Kudesia et al., 2020; Schulman, 2020), the importance of safety rule implementation.

Our case also study reveals that, regardless of the type of rule formalization, control over rule implementation is done in the spirit of regulated safety, pointing to the particular weight of quantification in this control. Our case study shows how control focuses on rule application (rule is applied because a practice exists) rather than on the effectiveness of the corresponding practice (practice is efficient), and how such control relies on simplistic quantified indicators (rules are applied – yes or no). The organization adds open rules, but implements them, in the same way as its rigid rules, by relying on simplistic binary quantified indicators. By confusing technical and organizational rules (Denyer et al., 2008; Romme & Endenburg, 2006; van Aken, 2004), the organization relies on simple control of rule application, expecting this to be sufficient to guarantee results, rather than on control of practice efficiency, possibly affected by complex organizational dynamics.

Our results further show, how extensive and inappropriate use of quantification for organizational rules (specifically, formalized as open rules) reinforces the loss of meaning and demotivation and, thus, impedes mindfulness, learning and even compliance with the rules, resulting in diminishing of both – managed and regulated safety. We highlight the amplifying role of quantification in the difficulties related to the implementing safety rules in practice (Dekker, 2014). Consequently, in addition to rule formalization and rule elaboration, our results suggest the need to also focus on rule implementation and the types of indicators used to monitor it.

Contributions on organizational limits.

The results discussed above, regarding the possible negative effects of managerial control, suggest the presence of organizational limits and the dangers of exceeding them. Organizational limits (Farjoun & Starbuck, 2007) can be considered as a constraining factor for the joint development of regulated and managed safety, because exceeding limits has unintended negative consequences and can become a systemic source of accidents (Farjoun & Starbuck, 2007). Recently, the literature points to the threats related to excessive automation, which makes the organization to exceed the limits to cognition and, thus, restricts cognitive capabilities (Oliver et al., 2017, 2019). Organizational limits may be invisible and be revealed only if actions have unexpected effects (Farjoun & Starbuck, 2007). We add to work on organizational limits by focusing on managerial control limits in the context of safety. If used to excess and inappropriately, the organizational levers of managerial control produce negative effects not only on mindfulness and deliberate learning, but also on compliance. First, our result show that extensive use of formalization (too many rules) and quantification (too many quantified indicators) leads to reduced efficiency of safety practices. Second, we show that the use of quantified control is not adapted to the implementation of open rules and produces side effects. While previous studies list some threats of exceeding limits (Farjoun & Starbuck, 2007; Oliver et al., 2017; Starbuck & Farjoun, 2005), our case study provides a better understanding of the limits originating from managerial control.

In line with Farjoun and Starbuck's (2007) recognition of cascading effects of limits, our results highlight the interplay between the limits originating from managerial control (related to rules and control indicators) and those originating from cognition (related to mindfulness and deliberate learning). We add to knowledge on organizational limits (Farjoun & Starbuck, 2007) by showing how the effects of exceeding the limits of managerial control affect organizational capability to deal, on a daily basis, with both predictable and unpredictable events.

In addition to the contribution to safety management, our research also contributes to work on leadership for safety, by conceptualizing leadership as process in general, and then by enriching this conceptualization through the lens of particular organizational goal of safety.

Contributions to the conceptualization of leadership as process

Conducted within a critical realist paradigm, our research allowed to conceptualize leadership mechanisms, integrate them in a multilevel framework of leadership as a process, underline the organizational embeddedness of leadership and the mediating role of organizational structure.

Several studies suggest a more processual view of leadership and outline the main characteristics of leadership as process (Day, 2000, p. 200; Fischer et al., 2017; Gordon & Yukl, 2004; Kan & Parry, 2004; Kempster & Parry, 2011; Osborn et al., 2002; Parry, 1998; Uhl-Bien et al., 2007; Yukl, 2013). However, more investigation of these mechanisms is required to explain the causal links between leaders' behaviours and organizational outcomes (Fischer et al., 2017). The literature review allowed to identify and reorder the theoretical contributions from different fields of study. By doing this, we contribute to responding to this call by distinguishing leadership influence mechanisms (sensemaking, motivating, trust and learning) from the observable leadership practices (meaning-making, demonstrating, relational monitoring, learning-development) that activate them. For example, a leader's pre-job briefing animation (practice) can help to activate sensegiving (leadership mechanism) to exercise influence to produce observable follower practices.

Moreover, by combining and redistributing dispersed elements of context, structures, mechanisms and observed practices and events (Pawson & Tilley, 1997), we constructed an integrative, critical realist-informed multilevel framework to capture leadership as a process. By highlighting the interactions across these elements and, in particular, by pointing to the mediating role of organizational structure, our framework captures the organizational embeddedness of the leadership process (Fischer et al., 2017; Kan & Parry, 2004; Osborn et al., 2002; Parry, 1998; Uhl-Bien et al., 2007).

Contributions to leadership process for safety

We extended the framework of leadership as a process by considering the organizational goal of safety and the underlying mechanisms of safety management. The literature insists on the need for a further investigation of leadership for safety mechanisms (e.g., Clarke, 2013; Epitropaki & Turner, 2020; Hannah et al., 2009; Katz-Navon et al., 2020; Zohar, 2010). While some scholars recently started to explore complex causal links between leadership actions and safety (M. A. Griffin & Neal, 2000; M. B. Nielsen et al., 2016; Pilbeam et al., 2019; Tucker et al., 2016), we contributed to leadership for safety by specifying the mechanisms of leadership influence (sensemaking, motivating, trust, and learning) and safety management for joint regulated-managed safety development (managerial control and coordination, mindfulness, deliberate learning) and highlighting their interplay. Moreover, our case study showed that the interplay between leadership practices and mechanisms is indirect and is mediated by the organizational structure (specifically, by rules and quantified ways of controlling compliance with the rules).

This influence is particularly highlighted in our study through an in-depth exploration of the sensegiving-sensemaking process. The literature points to the pivotal role of leadership in sensemaking for safety (M. A. Griffin & Neal, 2000; Grote, 2019; Katz-Navon et al., 2020; M. B. Nielsen et al., 2016; Tucker et al., 2016; Vogus et al., 2010; Zohar, 2010). Our results clearly showed that the unintended negative effects of extensive managerial control affect sensemaking in particular. In parallel, the role of leadership is highlighted as compensating for these negative effects by helping people make sense of their day-to-day activities. Therefore, our results zoomed on and explored a crucial interplay between the leadership mechanisms of sensegiving and the safety management mechanism of mindfulness (relying on sensemaking to achieve mindful sensemaking).

This interplay is captured in a process of construction of common meaning via the sensemaking – sensegiving – sensemaking sequence cascading across multiple organizational levels. Using examples of messages about safety, our research highlighted how initially ambiguous message meanings cascade through organizational levels. Rather than being reduced, the ambiguity is amplified at each level due to inconsistencies in sensemaking and sensegiving. Specifically, there are differences in meaning given via the official discourse on safety and the meaning embodied in the organizational artefacts created by the top management. While safety message ambiguities can be tolerated (or ignored) on an abstract level (the top organizational level), they are more difficult to tolerate at a concrete level (operational level). In the field, abstract complementarity and additivity logics (e.g., the need for high levels of safety and production) are transformed into tensions and result in concrete trade-offs (e.g., applying safety rules or continuing to produce by ignoring safety rules), which can impede effective sensegiving and sensemaking and, thus, affect safety.

The level forced to resolve these ambiguous messages is the lowest managerial level – i.e., the proximity managers. Proximity managers then have to resolve trade-offs but are unable to support front-line sensemaking about such trade-offs, sometimes contradicting the sense conveyed by organizational artefacts. Resolving message ambiguity is problematic and proximity managers need support from all organizational levels.

Practical contributions

The managerial contributions of our research are related to both safety management practices and leadership for safety practices. First, a better understanding of safety management mechanisms and, more generally, the leadership for safety process, should allow to improve leadership for safety practices aiming the joint development of managed and regulated safety. An integrative muti-level framework of leadership for safety offers a finer-grained understanding of the interplay between practices, organizational structures and mechanisms. This also explains why the direct influence of leadership practice on safety practices is illusory and requires consideration of non-observable underlying mechanisms. Moreover, our research suggests better understanding of managerial control and its limits, in particular, in terms of appropriate rule implementation and rule control. Finally, our research provides some recommendations for an effective training programme in leadership for safety.

The framework and emergent models developed in this doctoral research can serve as a basis for productive interactions among managers involved in designing work in high-risk organizational settings. Rather than offering easily applicable recipes, our results may be considered as a heuristic device (Romme & Endenburg, 2006), describing ideas and intentions underlying leadership for safety for the joint development of regulated and managed safety, and may guide debate and sensemaking among managers and leaders on the processes and improvements within specific contexts.

Limitations and future research

This research has some limitations, which suggest future research paths. First, some limitations stem from our methodological choice. Our study was conducted in a single organization in the nuclear energy industry, resulting in the analytical and not statistical generalization. As argued by Bhaskar (1998a, p. xii), any scientific activity is "*an ongoing irreducibly empirical open-ended process*" (Bhaskar, 1998b, p. xii), implying the need for the obtained results to be confronted with new contexts in other studies for better understanding of underlying mechanisms of leadership and safety management.

Another limitation is related to the specific context of this research. Our findings were developed on the basis of evidence from the European nuclear sector. Even if this research generated novel insights that can possibly fuel future research in other organizations and other contexts, theorization would have benefited from additional data. For example, an interesting future avenue to the present research might be its extension in the same industry, but in a different geographical context, to explore the effect of local culture (Dechy et al., 2011; Perin, 2007). It might also be interesting to conduct a comparative case study of organizations operating in two different high-risk industries (e.g., nuclear and aviation). Thanks to these possible extensions, the comparisons of these different contexts might shed new light on the specific contingent conditions in which the postulated generative mechanisms combine and operate (Tsoukas, 1989), further enriching the understanding of the leadership for safety mechanisms and their activation modes.

Second, our study focused on a particular leadership mechanism – sensegiving – and paid less attention to other mechanisms. In the frame of this research, we specifically explored the sensegiving-sensemaking process because it is presented by both the literature (M. A. Griffin & Neal, 2000; Katz-Navon et al., 2020; M. B. Nielsen et al., 2016; Tucker et al., 2016; Zohar, 2010) and the field as the main mechanism of influence. However, our case study also points to a crucial role of learning, which is also considered by the literature as a way for leaders to influence followers (Carroll, 1998; Echajari & Thomas, 2015; Levinthal & Rerup, 2006; Weick, 1987; Weick et al., 1999). Yet, we are fully aware that our investigation could have gone deeper in studying the underlying mechanisms of the leadership influence and its interplay with safety management mechanisms.

Another limitation is related to how we considered organizational limits (Farjoun & Starbuck, 2007; Oliver et al., 2017). Our results reveal the existence of organizational limits of managerial control related to extensive and inappropriate use of quantified indicators and point to the negative effects of exceeding limits. However, more investigation is required to elucidate appropriate managerial control allowing pushing organizational limits to avoid negative side effects of their exceeding. More specifically, further research could explore the effective use of indicators (Dekker, 2014; Patriarca et al., 2019), for example, by examining the combination of more and less quantified indicators. In addition, a deeper examination of the rationale for the use of quantification in high-risk industries would be a fruitful research avenue to explore.

Finally, another interesting research direction would be to focus on sensemaking. We studied the sensemaking process conveyed through organizational artefacts – namely, rules, and their translation into control indicators. Although we highlight the role of artefacts in sensemaking-sensegiving, we do not explore the materiality of artefacts (D'Adderio, 2011; Danner-Schröder & Geiger, 2016; V. L. Glaser, 2017), and materiality's impact on sensemaking (Cecchi, 2022; Hällgren et al., 2022). In the same line, space is not exogenous to the sensemaking process; it is enacted by sensemakers (Steigenberger & Lübcke, 2021). Therefore, future work could explore materiality and space interaction with sensemaking in high-risk environments. Finally, our results could also be extended by paying attention to other, more individual, dimensions of sensemaking, such as embodiment or emotions (Hällgren et al., 2022; Maitlis & Sonenshein, 2010).

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List of Figures

List of Tables

Abbreviations

ACSNI – Advisory Committee on the Safety of Nuclear Installation
ASN- Nuclear Safety Authority
DREI – Describe, Retroduce, Eliminate, Identify
ELSE – European Leadership for Safety Education
ENEN – European Nuclear Education Network
ENS – European Nuclear Society
ENSTTI – European Nuclear safety training and Tutoring Institute
FANC – Federal Agency for Nuclear Control
GREDEG – Groupe de Recherche en Droit, Economie et Gestion
GSR – General Safety Requirements
HRA – Human reliability analysis
HROs – High-reliability organization
IAEA – International Atomic Energy Agency (https://www.iaea.org/)
IMS – integrated management system
INPO – Institute of Nuclear Power Operations (http://www.inpo.info/)
INSAG – International Nuclear Safety Advisory Group
INSC – Instrument for Nuclear Safety Cooperation
IRSN – Radioprotection and Nuclear Safety Institute
LMX – Leader-Member Exchange
NEA – Nuclear Energy Agency
NEPIO – Nuclear Energy Programme Implementing Organization
NOD – Nuclear Operations Division
NPP – Nuclear Power Plant
OECD- Organisation for Economic Co-operation and Development (),
OPEX – operational experience
OSART – Operational Safety Review Team
PRA – Probabilistic risk assessment
QA – Questioning Attitude
REPs – reliability enhancing practices
SCS – School Case Study
TMI - Three Mile Island
TSO – technical support organizations
WANO – World Association of Nuclear Operators (https://www.wano.info/)
WEC – World Energy Council
WNA – World Nuclear Association

Appendices

Appendix 1. Demographic details of the ELSE workshop participants

(see Chapter 3 Section 3.1 Sub-section 3.1.2 "European Leadership for Safety Education (ELSE) project")

Expertise	Institutions	Country of current employment
Business administration	Fox School of Business	USA
Chemical engineering	Institute for an Industrial Safety Culture	FR
Corporate strategy and international Development	SKEMA Business School, Université Côte d'Azur	FR
Environmental and human radiochemistry	Université Côte d'Azur, Institut de chimie de Nice	FR
Environmental and nuclear safety	European Nuclear Safety Training and Tutoring Institute	FR
Ethics and risk management	SKEMA Business school and Université Côte d'Azur	FR
Finance and management	European Nuclear Safety Training and Tutoring Institute	FR
Geography	Université Côte d'Azur	FR
Healthcare management	Warwick Business School	UK
Industrial and organizational psychology	Technion – Israel Institute of Technology	IS
Industrial psychology	Aberdeen Business School & University of Aberdeen	UK
International affairs and nuclear safety	Institute for Radiation Protection and Nuclear Safety	FR
International relation for security and nuclear safety	Instrument for the Nuclear Safety Cooperation of the European Commission	BEL
Knowledge management	Institut Mines-Telecom	FR
Leadership	Haskayne School of Business, University of Calgary	CAN
Leadership and organizational change	Cranfield School of Management	UK
Leadership, organizational culture, and change	UNC Kenan-Flagler Business School	USA
Management	Université de Nantes, IAE Nantes	FR
Management	University of Edinburgh Business School	UK
Management	ISEM, Université Côte d'Azur	FR
Mining engineering	AGH University of Science and Technology	PL
Nuclear engineering	European Nuclear Education Framework	BEL
Nuclear process engineering	TRACTEBEL ENGIE	FR
Nuclear safety engineering	CEA	FR

Nuclear safety, international relations, and scientific cooperation	J Repussard Conseil	FR
Physics and nuclear engineering	IAEA	AUT
Physics and nuclear engineering	Federal Agency for Nuclear Control	BEL
Radiochemistry	CNRS	FR
Safety leadership	Safety and Accident Center, Cranfield University	UK
Safety management and human factor	EDF	FR
Social science and humanities	Institute for Radiation Protection and Nuclear Safety	FR
Sociology	National Center for the Working Environment	DEN
Sociology of organization	University of Trento	IT
Strategy and innovation	SKEMA Business School, Université Côte d'Azur	FR
Work and organizational psychology	ETH Zürich	CH

Appendix 2. Pilot International School of Nuclear and Radiological Leadership for safety: Observation and Interview Guide

(see Chapter 3 Section 3.2 Sub-section 3.2.2 “Data collection”)

Date: 20/10/2017

1. Observations:

1.1. Information Session (day 1)

- Number of participants, gender, age
- Industries-companies, countries, work positions
- Informal remarks between participants
- Questions and engaged discussion: what are the participants preoccupations?

1.2. Case study group work (one group per case study) (days 2-4)

- Case study objective
- Case study context
- Key element of safety leadership in discussion
- When and how group work takes place?
- Group’s reaction
- What do actors focus on? What is important, worrying, critical?
- What do the actors ignore that others might pay attention to?
- What symbols do actors invoke to understand their worlds? What labels do they attach to objects, events, persons, roles, settings, equipment?
- What practices, skills and methods of discussion do actors employ?
- Points of contradiction
- Points discussed within the group, but not in the plenary discussion?

1.3. Case study plenary discussion (days 2-4)

- Interaction between groups
- Differences in the focus of responses
- What discussion practices, skills and methods do actors employ?
- What is the key message of the case study?
- Do the participants agree with the results? On what do they disagree?
- How do participants formalize the results?

1.4. Session of results (day 5)

- Feedback on content: safety leadership
- Feedback on training
- What progress directions do participant suggest?

2. Interviews:

2.1. Interviews with participants (4-5 in total)

Remark: all responses will be anonymized and used exclusively for the research objectives

General

- Name
- Industry/Company
- Country
- Work position
- Why are you interested in leadership for safety?

Pilot School

- Why is attendance at this Pilot School important?
- Wass your participation due to the company's or your own initiative?
- What are your expectations about this Pilot School?
- Which case study did you find the most usefu?
- Which questions/issues need to be better developed for future School sessions? (if last day interview)

Leadership for safety

- In your view, who in your organization is most concerned about/involved in safety?
- What in your view does good safety leadership involve?
- Give an example, based on your experience, of a case when safety leadership was efficient?
- Give an example, based on your experience, of a case when safety leadership was inefficient?
- What is meant by safety culture? How can we learn about safety culture?
- As a leader involved in safety issues, what do you find the most difficult?

2.2. Interview with facilitator/trainer

Remark: all your responses will be anonymized and used exclusively for the research objectives

General

- Name
- Industry/Company
- Country
- Work position
- Why you are interested in leadership for safety?

Pilot School

- Why this Pilot School is important for you?
- How does this Pilot School differ from other courses?
- What are your expectations about this Pilot School?

Leadership for safety

- In your view, what does good safety leadership involve?
- How does interact with safety?
- Please give an example, based on your experience, of a case when safety leadership was efficient.
- Please give an example, based on your experience, of a case when safety leadership was inefficient?
- Which questions/issues need to be better developed for future School sessions?
- What is safety culture? How can we learn about it?

Appendix 3. ATOM immersion interview guide: Alpha NPP

(see Chapter 3 Section 3.2 Sub-section 3.2.2 "Data collection")

Date: 08/06/2018

Exploratory interview on safety practices
1. The interviewee
• What is your position in the plant? • What was your initial training? • What is your professional background? • Do you have managerial responsibilities?
2. Organizational structure
• What is the size of your work team? How is it organized? • What is your role in relation to safety? • Who in the plant has a specific role in relation to safety? • Who is the safety referent in your work? • Do you think that the organization of work at the plant enables the development of safety? Explain why. In your view, how could it be improved?
3. Perceptions of the generative mechanisms of managed safety
• What do you think are the key elements to ensure and maintain safety in your daily practice? o If the topics are not covered: ask additional questions (on procedures, understanding of the situation, ability to activate relationships eco-system, being vigilant, noticing weak signals, open thinking, learning) • What are the main elements that lead to safety problems? (Give examples. Explain why.)
4. Cultural systems
• What do you think are the organization's key safety messages? • Do you think they have changed in recent years? • Do you think that some messages are missing? • In your opinion, are they consistent with other messages carried by the organization? Give examples (is safety always a priority?)
5. Safety behaviours in operational practices
• What actions are you implementing in your operational practices to ensure safety? Why are they being implemented? Give examples. • Can you give me one or more examples of incidents? Why did they happen? How could they have been avoided? How were these incidents learned from? • Can you give examples of incidents that challenged normal working procedures? Why were they challenging? • Do you think that your team's work organization enables the development of safety? Explain why? How do you think it could be improved? • What operational practices allow you to improve safety? Why or why not? Give examples. • What operational practices do you think would improve safety? Give examples. Explain why. • Do you think that there are particular situations/events that increase the risks and reinforce the safety challenges? Give examples. Explain why.

•	What actions are you taking to deal with unforeseen events that may affect safety? Give examples. Explain why.
6.	**Practices of leadership for safety**
•	**Level with no managerial/ influential position**
•	What practices have your manager(s) implemented that you believe improve safety? Give examples. Explain why.
•	Which practices implemented by your manager(s) do you think should improve safety? Give examples. Explain why.
•	**Level with managerial/ influential position**
•	What practices have you implemented as a manager to improve safety? Give examples. Explain why.
•	What are the main problems you have encountered? Give examples. Explain why.
•	In your experience, which practices do not work well or do not seem very useful? Give examples. Explain why.
•	What practices would you like to implement as a manager to improve safety? Give examples. Explain why.
•	How do you, as a manager, deal with unexpected situations that may have an impact on safety?

Guide d'entretien

Intervention Alpha NPP - Juin 2018

	Entretien exploratoire sur les pratiques de sûreté
	Un organigramme qui représente la répartition des rôles et des fonctions.
7.	**La personne interviewée**
•	Quel est votre position au sein de la centrale ?
•	Quelle est votre formation initiale ?
•	Quel est votre parcours professionnel ?
•	Avez-vous des responsabilités d'encadrement ?
8.	**Structure organisationnelle**
•	Quelle est la taille de votre équipe de travail ? Comment elle est organisée ?
•	Quel est votre rôle vis-à-vis de la sûreté ?
•	Qui au sein de la centrale a un rôle spécifique par rapport à la sûreté ?
•	Qui est le référent de sûreté dans votre travail ?
•	Pensez-vous que l'organisation du travail au niveau de la centrale est propice au développement de sûreté ? Expliquer pourquoi ? Selon vous comment pourrait-elle être améliorée ?
9.	**Perceptions des mécanismes générateurs de la sûreté gérée**
•	Quels sont, selon vous, des éléments clés pour garantir et maintenir la sûreté dans vos pratiques quotidiennes ? o Si les thèmes ne sont pas abordés : poser des questions supplémentaires (procédures, comprendre la situation, capable d'activer les relations, être vigilent, repérer les signaux faibles, penser ouvert, apprendre)
•	Quel sont les éléments clés qui entrainent des problèmes à la sûreté ? (Donnez les exemples ? Expliquez pourquoi ?)
10.	**Système culturel**
•	Quels sont selon vous les messages clés sur la sûreté portés par l'organisation ?

- Pensez-vous qu'ils ont évolué ces dernières années ?
- Pensez-vous que certains messages sont manquants ?
- Selon vous, sont-ils cohérents avec d'autres messages portés par l'organisation ? Donnez les exemples (est-ce que la sûreté est toujours prioritaire ?)

11. Comportements de sûreté dans des pratiques opérationnelles

- Quelles sont les actions clés que vous mettez en place dans vos pratiques opérationnelles pour garantir la sûreté ? Pourquoi ? Donnez des exemples ?
- Pouvez-vous me citer un ou plusieurs exemples d'incidents ? Pourquoi sont-ils arrivés ? Comment auraient-ils pu être évités ? Comment a-t-on appris de ces incidents ?
- Avez-vous des exemples d'incidents qui ont remis en cause des procédures de travail habituelles ? Pourquoi ? Donnez des exemples ?
- Pensez-vous que l'organisation du travail au niveau de votre équipe est propice au développement de sûreté ? Expliquer pourquoi ? Selon vous comment pourrait-elle être améliorée ?
- Quelles sont les pratiques opérationnelles, qui vous permettent d'améliorer la sûreté ? Pourquoi ? Donnez des exemples ?
- Quelles seraient selon vous les pratiques opérationnelles qui permettraient d'améliorer la sûreté ? Donnez les exemples ? Expliquer pourquoi ?
- Pensez-vous qu'il existe les situations/évènements particuliers qui accroissent les risques et renforcent ainsi les problèmes de sûreté ? Donnez les exemples ? Expliquer pourquoi ?
- Quelles sont les actions que vous mettez en œuvre pour gérer les évènements imprévues qui peuvent avoir un impact en matière de sûreté ? Donnez les exemples ? Expliquer pourquoi ?

12. Pratiques du leadership en sûreté

- **Niveau N+1**
- Quelles sont les pratiques mises en œuvre par votre/vos managers qui, selon vous, améliorent la sûreté ? Donnez les exemples ? Expliquer pourquoi ?
- Quelles sont les pratiques mises en œuvre par votre/vos managers qui, selon vous, pourraient améliorer la sûreté ? Donnez les exemples ? Expliquer pourquoi ?
- **Niveau N-1 (pour les managers)**
- Quelles sont les pratiques mises en œuvre par vous en tant que manager pour améliorer la sûreté ? Donnez les exemples ? Expliquer pourquoi ?
- Quels sont les principaux problèmes que vous avez rencontrés ? Donnez les exemples ? Expliquer pourquoi ?
- D'après votre expérience quelles sont les pratiques qui ne fonctionnent pas bien ou vous paraissent pas très utiles ? Donnez les exemples ? Expliquer pourquoi ?
- Quelles sont les pratiques que vous aimeriez mettre en œuvre en tant que manager pour améliorer la sûreté ? Donnez les exemples ? Expliquer pourquoi ?
- Comment en tant que manager gérez-vous les situations imprévues qui peuvent avoir un impact en matière de sûreté ?

Appendix 4. Entry message ‘Leadership for safety’: Beta NPP

(see Chapter 3 Section 3.2 Sub-section 3.2.2 “Data collection”)

Natalia Jubault Krasnopevtseva

Annex 4.

Entry message ‘Leadership for safety’

1

Natalia Jubault Krasnopevtseva

Leadership for safety in complex environments: the case of the nuclear sector

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- This research project is part of doctoral research in management sciences at the Université Côte d'Azur. It is being carried out in collaboration with the Groupe de Recherche en Droit, Economie, Gestion (GREDEG) UMR - 7321 CNRS since 1 October, 2017 under the supervision of Catherine Thomas (UCA) and Renata Kaminska (SKEMA) and is supported by doctoral funding from the Ministry of Higher Education.

- This research is being conducted within the framework of the International School of Nuclear and Radiological Leadership for Safety, whose Pilot School was held in Nice, in 2017, as an initiative of the IAEA and the European Union.

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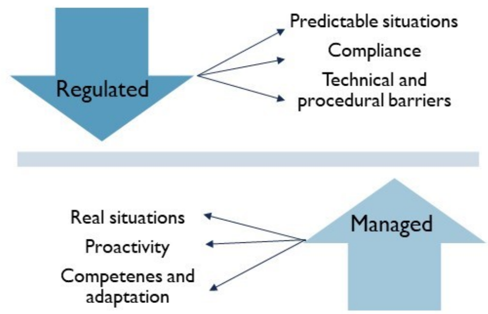
1

Research objective

- Significant scientific and industrial progress in safety.
- The study of accidents highlights their **organizational nature**.
- The organizational culture, particularly the **safety culture**, is at the centre of the research.
- Need to develop both **regulated** (prescribed) and **managed** (real) safety.
- Development of regulated safety can jeopardize the development of managed safety.
- Need to understand and resolve the tensions between these two types of safety is causing major problems for leadership for safety.



?

The aim of this research is to understand how leadership practices enable the joint development of managed and regulated safety

2

Multi-level approach

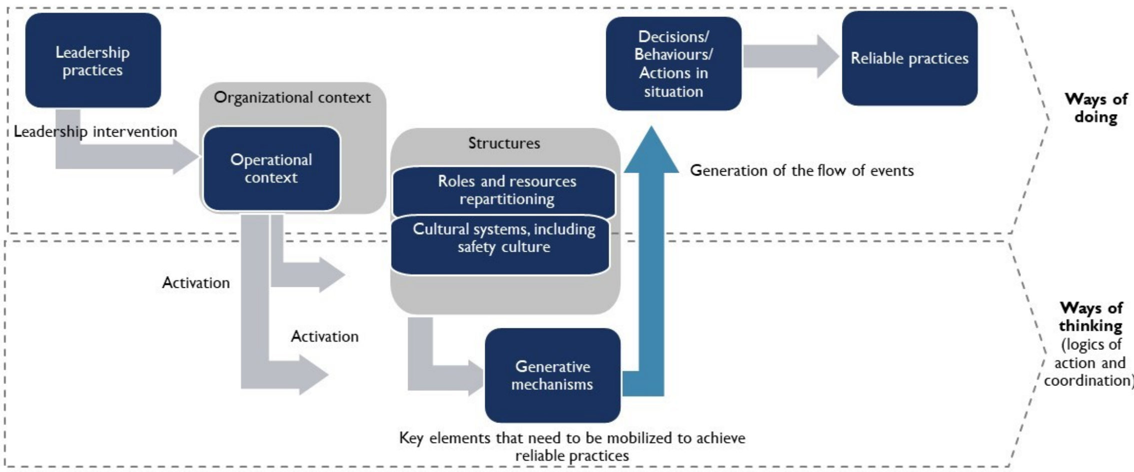
- Our research aims to identify
  - Generative mechanisms of joint development of regulated and managed safety and their modes of activation
  - Contextual conditions (organizational structures, situation)
  - Observed events (reliable practices)
- The activation of in-depth mechanisms (not directly observable) can explain the complex links between leadership actions, culture and operational behaviours.
- Generative mechanisms may or may not be activated under certain conditions

➡ This refers to the problem of translating from ways of thinking to ways of doing

3

Natalia Jubault Krasnopevtseva

Leadership for safety process



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Natalia Jubault Krasnopevtseva

Empirical study

- Methodological approach: a qualitative study based on semi-structured interviews, observations and document analysis. The anonymity of the interviewees is guaranteed in the analyses that will be conducted.
- Data collection and data analysis are based on the multi-level approach developed in the two previous slides
- Focus of the field survey :
  - Operations department
  - Independent safety authority

5

Natalia Jubault Krasnopevtseva

Expected contributions

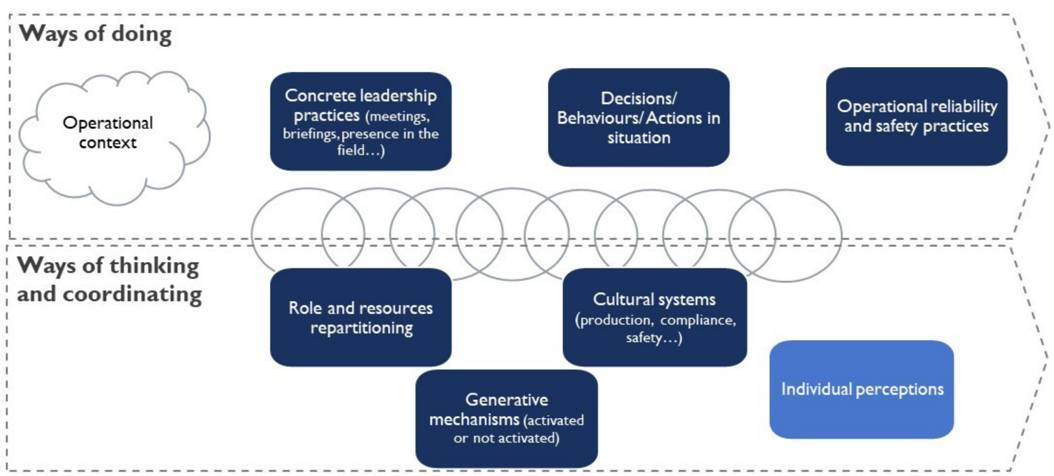
- Theoretical contributions :
  - A coherent theoretical framework to capture the unobservable
  - A new conceptualization of the roles of leaders and safety culture
- Managerial contributions :
  - Understanding how leadership practices can help activate the generative mechanisms of managed safety in the context of regulated safety
  - Develop training that focuses on leadership practices, not styles

6

Natalia Jubault Krasnopevtseva

Interviewee : ______________________________

- Function : ______________________
- Department : ______________________



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Annex 4.

Message de présentation de la recherche 'Leadership en sûreté'

Leadership en sûreté dans des environnements complexes : le cas du secteur nucléaire

natalia.krasnopevtseva@gredeg.cnrs.fr

- Ce projet de recherche s'inscrit dans le cadre d'un travail doctoral en sciences de gestion à l' Université Côte d'Azur. Il est engagé au sein du laboratoire Groupe de Recherche en Droit, Economie, Gestion (GREDEG) UMR – 7321 CNRS depuis le 1er octobre 2017 sous la direction de Catherine Thomas (UNS) et Renata Kaminska (SKEMA) et bénéficie d'un contrat doctoral avec le ministère de l'enseignement supérieur.

- Cette recherche entre dans le cadre du Projet de l'Ecole du Leadership en Sûreté Nucléaire, dont l'Ecole Pilote a eu lieu à Nice à l'initiative de l'AIEA et de la Commission Européenne en 2017.

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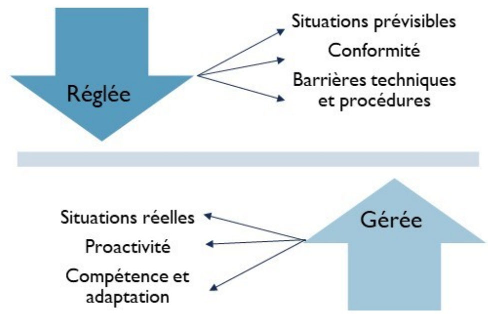
Natalia Jubault Krasnopevtseva

Objectif de la recherche

- Des progrès scientifiques et industriels importants en matière de sûreté.
- L'étude des accidents met en évidence leur **caractère organisationnel.**
- La **culture organisationnelle,** notamment **culture de sûreté** est au centre des recherches.
- La nécessité de développer conjointement la **sûreté réglée** (prescrit) et la **sûreté gérée** (réel).
- Le développement de la sûreté réglée peut être un frein au développement de la sûreté gérée.
- La nécessité de comprendre et résoudre les tensions entre ces deux types de sûreté devient un enjeu majeur du **leadership en sûreté**.



L'objectif de cette recherche est de comprendre comment les pratiques de leadership permettent le développement conjoint de la sûreté gérée et réglée ?

2

Natalia Jubault Krasnopevtseva

Approche multi-niveau

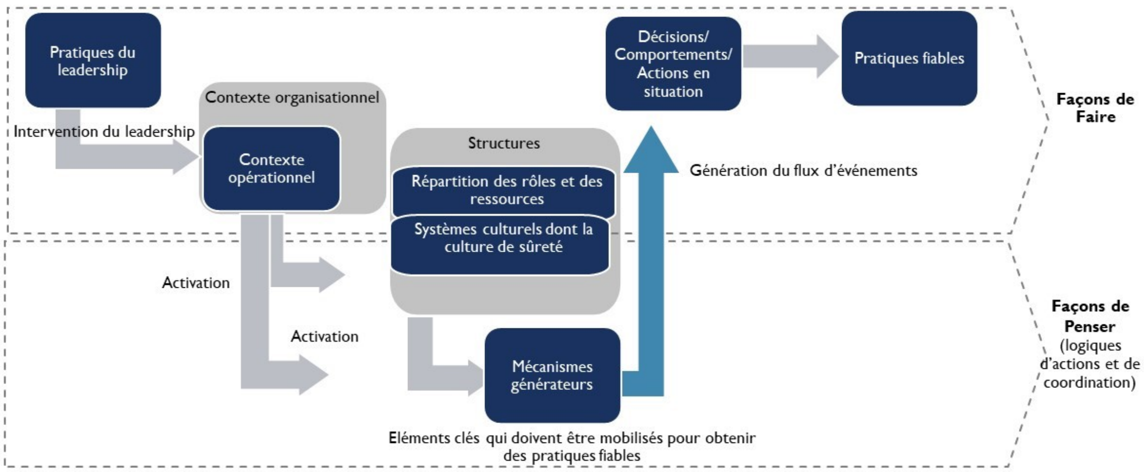
- Notre recherche vise à identifier
  - les mécanismes générateurs de l'articulation de la sûreté réglée et gérée et leurs modes d'activation
  - les conditions contextuelles (structures organisationnelles, situation)
  - les événements observés (pratiques fiables)
- L'activation des mécanismes profonds (non directement observables) peut expliquer les liens complexes entre l'action du leadership, la culture et les comportements opérationnels.
- Les mécanismes générateurs peuvent être activés ou pas sous certaines conditions

➡ Cela renvoie au problème du passage de la façon de penser à la façon de faire

3

Natalia Jubault Krasnopevtseva

Processus du leadership en sûreté



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Natalia Jubault Krasnopevtseva

Etude terrain

- Démarche méthodologique : une étude qualitative fondée sur des entretiens semi-directifs, des observations et de la documentation. L'anonymat des personnes interviewées est garanti dans les analyses qui seront faites.
- La collecte et l'analyse des données s'appuie sur l'approche multi-niveau développée dans les deux transparents précédents
- Focus de l'enquête terrain :
  - Service de conduite
  - Filière Indépendante de sûreté

5

Contributions attendues

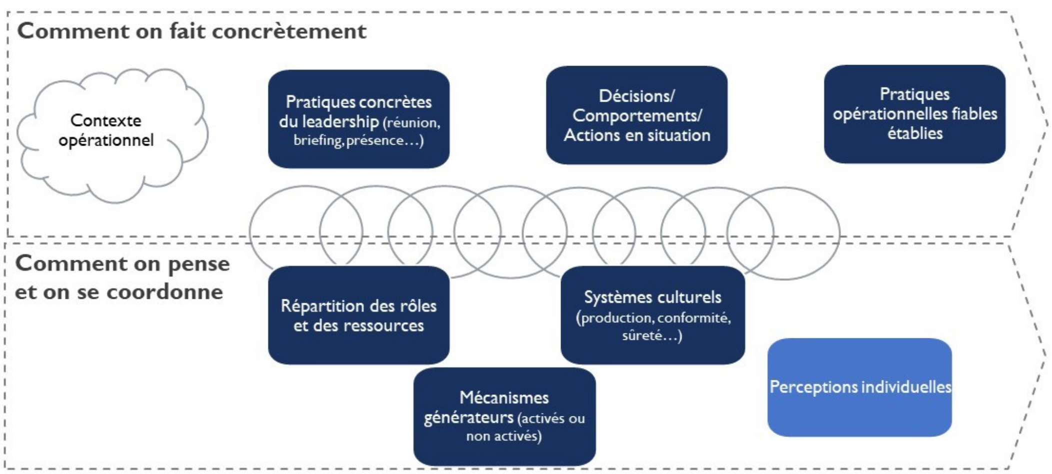
- Contributions théoriques :
  1. Un cadre théorique cohérent pour capturer l'inobservable
  2. Une nouvelle conceptualisation du rôle des leaders et de la culture de sûreté
- Contributions managériales :
  1. Comprendre comment les pratiques du leadership peuvent aider à activer les mécanismes générateurs de la sûreté gérée dans un cadre de sûreté réglée
  2. Développer des formations qui se centrent sur les pratiques et non les styles du leadership

6

Natalia Jubault Krasnopevtseva

L'interlocuteur : ______________________________

- Fonction : ______________________
- Service concerné : ______________________



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Appendix 5. In-depth case study: Beta NPP interview guide

(see Chapter 3 Section 3.2 Sub-section 3.2.2 “Data collection”)

Beta NPP - 2019

1. The interviewee
• What is your position in the plant? • What is your initial training? • What is your professional background? • Do you have any managerial responsibilities?
Ways of thinking and coordinating
2. Individual perceptions of generative mechanisms of managed safety
• What do you think are the major risks in your activities? What can cause them? • Do you think that there are particular situations/events that increase the risks and thus increase the safety problems? Give examples. Explain why. • Have your perceptions of risk changed over time? • Do you think that all risks can be controlled? • Have your perceptions of how to manage risks changed over time? • What do you think are the key elements to ensure and maintain safety in your daily practices? • Do you think there are elements beyond compliance that are key to safety?   o If the topics are not covered: ask additional questions (understanding the situation, ability to activate relationships, ability to activate relationships eco-system, being vigilant, noticing weak signals, open thinking, learning) • Do you think these main elements are shared within your team? • Do you think that these main elements are shared within your NPP? • Which national or international bodies do you think are important for safety? Do you participate in them? Is the information from these bodies shared?
3. Organizational structure: resources and roles repartitioning
• What is the size of your work team? How is it organized? • What is your role related to safety? • Do you think that the training of your team is sufficient? Do you think that the level of training has changed in recent years? • Do you think that the organization of work in your team enables the development of safety? Explain why. In your opinion, how could it be improved? • Do you think you have the resources to do this? Give examples. Explain why. • Who in the NPP has a specific role in relation to safety? • Who is the safety referent in your work? • Do you think that the organization of work in the plant enables the development of safety? Explain why. In your opinion, how could it be improved? • Do you think that the NPP has the necessary resources for this? Give examples. Explain why.
4. Organizational structure: cultural system
• What key safety values are promoted by the NPP? • Do you think they have changed in recent years? • How are safety values conveyed? How are they translated into action? • Do you think that some messages are missing?

- In your voew, are they consistent with other messages conveyed by the organization? Give examples (is safety always a priority?)
- What is the impact of the safety culture review? And of audits?
- Do you think that your team complies easily with the messages and values carried by the organization?
- Does the change in structure affect the way safety is conceived/thought about? How and why?
- Are there any organizational modes that seem to you to be conducive to the development of safety (e.g., project mode, rapid intervention team, independent safety authority, etc.)?
- In the safety culture conveyed by the plant, what is the place of uncertainty? What uncertainty are we talking about?

Ways of doing

5. Safety behaviours in operational practices

- What are the operational practices that allow you to improve safety? Why? Give examples. How could they be improved?
- Which ones are the most effective? Why or why not?
- Which are the least effective? Why or why not?
- What do you think about REPs? Which ones do you find more/less effective?
- Are there any other operational practices that could improve safety? Give examples. Explain why.
- To what extent are your safety practices influenced by national/international bodies? If so, how does this influence take place?
- Can you give me one or more examples of incidents? Why did they happen? How could they have been prevented? How was learning from these incidents?
- How was this learning implemented? Was it disseminated?
- Are the causes of the incidents identified in the preparation or in the execution in real time?
- Do you have examples of incidents that required deviation from normal working procedures? Why or why not? Give examples?
- How do discussions take place in the case of a safety problem?
- What actions do you take to manage unforeseen events that may have an impact on safety? Give examples. Explain why.

6. Leadership for safety practices

- What do you think leadership enabling safety development is?
- **Level without managerial/influential position**
- What practices have your manager(s) implemented that you believe improve safety? Give examples. Explain why.
- What practices implemented by your manager(s) do you think should improve safety? Give examples. Explain why.
- **Level with managerial/ influential position**
- What practices have you implemented as a manager to improve safety? Give examples. Explain why.
- What are the main problems you have encountered? Give examples. Explain why.
- In your experience, which practices do not work well or do not seem very useful? Give examples. Explain why.
- What practices would you like to implement as a manager to improve safety? Give examples. Explain why.
  How do you, as a manager, deal with unexpected situations that may have an impact on safety?

Guide d'interview

Unité Beta - 2019

1. La personne interviewée

- Quel est votre position au sein de la centrale ?
- Quelle est votre formation initiale ?
- Quel est votre parcours professionnel ?
- Avez-vous des responsabilités d'encadrement ?

Façon de penser et de se coordonner

2. Perceptions individuelles des mécanismes générateurs de la sûreté gérée

- Quels sont, selon vous, les risques majeurs dans votre activité ? Qu'est-ce que peut les provoquer ?
- Pensez-vous qu'il existe des situations/évènements particuliers qui accroissent les risques et renforcent ainsi les problèmes de sûreté ? Donnez des exemples ? Expliquez pourquoi ?
- Est-ce que votre perception des risques a évolué au fil du temps ?
- Pensez-vous que tous les risques peuvent être maitrisés ?
- Est-ce votre perception sur la façon de gérer des risques a évolué dans le temps ?
- Quels sont, selon vous, les éléments clés pour garantir et maintenir la sûreté dans vos pratiques quotidiennes ?
- Pensez-vous qu'il y a des éléments au-delà de la conformité qui sont clés pour la sûreté ?
    - Si les thèmes ne sont pas abordés : poser des questions supplémentaires (comprendre la situation, capable d'activer les relations, être vigilant, repérer les signaux faibles, penser ouvert, apprendre)
- Pensez-vous que ces éléments clés sont partagés au sein de votre équipe ?
- Pensez-vous que ces éléments clés sont partagés au sein de votre centrale ?
- Quelles sont, selon vous, les instances nationales, internationales qui jouent le rôle important pour la sûreté ? Est-ce que vous y participez ? Est-ce que les informations de ces instances sont partagées ?

3. Structure organisationnelle : répartition des rôles et de ressources

- Quelle est la taille de votre équipe de travail ? Comment est-elle organisée ?
- Quel est votre rôle vis-à-vis de la sûreté ?
- Pensez-vous que la formation de votre équipe est suffisante ? Est-ce que vous ressentez que le niveau de formation a évolué ces dernières années ?
- Pensez-vous que l'organisation du travail au niveau de votre équipe est propice au développement de la sûreté ? Expliquez pourquoi ? Selon vous, comment pourrait-elle être améliorée ?
- Pensez-vous que vous disposez des ressources nécessaires pour cela ? Donnez des exemples ? Expliquez pourquoi ?
- Qui au sein de la centrale a un rôle spécifique par rapport à la sûreté ?
- Qui est le référent sûreté dans votre travail ?
- Pensez-vous que l'organisation du travail au niveau de la centrale est propice au développement de sûreté ? Expliquez pourquoi ? Selon vous comment pourrait-elle être améliorée ?
- Pensez-vous que la centrale dispose des ressources nécessaires pour cela ? Donnez des exemples ? Expliquez pourquoi ?

4. Structure organisationnelle : système culturel

- Quelles valeurs clés de la sûreté sont portées par la centrale ?
- Pensez-vous qu'elles ont évolué ces dernières années ?
- Comment les valeurs de sûreté sont-elles véhiculées ? Comment sont – elles traduites dans les actes ?
- Pensez-vous que certains messages soient manquants ?

• Selon vous, sont-ils cohérents avec d'autres messages portés par l'organisation ? Donnez des exemples (est-ce que la sûreté est toujours prioritaire ?) • Quel est l'impact des renvois d'image de culture de sûreté ? des audits ? • Pensez-vous que votre équipe adhère facilement aux messages et valeurs portées par l'organisation ? • Est-ce que le changement de la structure affecte la façon de concevoir/penser la sûreté ? Comment et pourquoi ? • Est-ce qu'il y a des modes d'organisation qui vous semblent propices au développement de la sûreté ? (ex. mode projet, équipe d'intervention rapide, filière indépendante de la sûreté…) • Dans la culture de sûreté véhiculée par la centrale, quelle est la place de l'incertitude ? De quelle incertitude parle-t-on ?
Façon de faire
5. Comportements de sûreté dans des pratiques opérationnelles
• Quelles sont les pratiques opérationnelles, qui vous permettent d'améliorer la sûreté ? Pourquoi ? Donnez des exemples ? Comment pourraient-elles être améliorées ? • Lesquelles sont les plus efficaces ? Pourquoi ? • Lesquels sont les moins efficaces ? Pourquoi ? • Que pensez-vous des pratiques de fiabilisation ? Lesquelles vous semblent plus/moins efficaces ? • Est-ce qu'il y a d'autres pratiques opérationnelles qui seraient susceptibles d'améliorer la sûreté ? Donnez des exemples ? Expliquez pourquoi ? • Dans quelle mesure vos pratiques de sûreté sont-elles influencées par les organismes nationaux/internationaux ? Si oui, comment cette influence intervient-elle ? • Pouvez-vous me citer un ou plusieurs exemples d'incidents ? Pourquoi sont-ils arrivés ? Comment auraient-ils pu être évités ? Comment a-t-on appris de ces incidents ? • Comment cet apprentissage est mis en œuvre ? Est-il diffusé ? • Est-ce que les causes des incidents sont plutôt dans la préparation ou dans l'exécution en temps réel ? • Avez-vous des exemples d'incidents qui ont nécessité de déroger aux procédures de travail habituelles ? Pourquoi ? Donnez des exemples ? • Comment passent des discussions en cas de problème ? • Quelles sont les actions que vous mettez en œuvre pour gérer les évènements imprévus qui peuvent avoir un impact en matière de sûreté ? Donnez des exemples ? Expliquez pourquoi ?
6. Pratiques du leadership en sûreté
• Selon vous, qu'est-ce qu'un leadership propice au développement de la sûreté ? • **Niveau N+1** • Quelles sont les pratiques mises en œuvre par votre/vos managers qui, selon vous, améliorent la sûreté ? Donnez des exemples ? Expliquez pourquoi ? • Quelles sont les pratiques mises en œuvre par votre/vos managers qui, selon vous, pourraient améliorer la sûreté ? Donnez des exemples ? Expliquez pourquoi ? • **Niveau N-1 (pour les managers)** • Quelles sont les pratiques que vous mettez en œuvre pour améliorer la sûreté ? Donnez des exemples ? Expliquez pourquoi ? • Quels sont les principaux problèmes que vous avez rencontrés ? Donnez des exemples ? Expliquez pourquoi ? • D'après votre expérience quelles sont les pratiques ne sont pas efficaces ? Donnez des exemples ? Expliquez pourquoi ? • Quelles sont les pratiques que vous aimeriez mettre en œuvre en tant que manager pour améliorer la sûreté ? Donnez des exemples ? Expliquez pourquoi ? • Comment en tant que manager gérez-vous les situations imprévues qui peuvent avoir un impact en matière de sûreté ?

Appendix 6. Open coding codebook (Nvivo extraction)

(see Chapter 3 Section 3.2 Sub-section 3.2.3 “Data analysis”)

Open coding	0	0
Leadership	17	220
Leadership Practices	14	56
Leadership Practices for empowerment	3	4
Leadership Practices for learning	4	7
Leadership Practices of the presence on the field to control behaviours	4	8
Leadership Practices to enhance vigilance	3	3
Leadership Practices to give and to share a sense of the rules	6	8
Leadership Practices to remind safety culture and fundamentals	8	13
Management Practices	2	6
Practices for leadership development	4	7
Problems of leadership implementation	15	108
Problem of alignment of leadership practices	2	3
Problem of limits in leadership implementation actions	3	5
Problem related to middle managers blocking compliance	2	11
Problem related to followers’ trust in leaders	6	18
Problem related to leaders’ trust in followers	3	5
Problems related to cumulation of technical and leadership activities	9	17
Problems related to trade-offs and of absorbing new demands	3	6
Problems related to leaders’ sensemaking	7	10
Problems related to leadership competencies	2	2
Recognition of social conflict	4	8
Recognition of the lack of leadership	7	18
Role of structure in the leadership inefficiency	2	5
Representations of leadership (values)	14	56
Difficulty in defending the concept	7	7
Representation of leadership role	10	49
Need for field presence to improve safety	5	8
Leadership role - Understanding in hindsight	2	3
Leadership role - Building meaning	2	3

Leadership role - Giving meaning	6	9
Leadership role - Building trust and responsibility	4	7
Leadership role –Carrying the requirements to motivate	5	6
Leadership role - Embodying values, setting examples	5	13
Safety management	23	1139
Competences and learning (theme from problems)	15	157
Challenges and limits of competence	12	58
Difficulties related to competence management	10	24
Insufficient competences	8	19
Mitigated options about training	8	15
Challenges to and limits of learning	10	58
Difficulty to implement learning (except OPEX)	4	26
Implementation except OPEX	14	22
Self-training (based on rules)	2	3
Mutual support and sharing of experience	4	5
Simulator training	3	9
Internal cross-auditing	1	1
Companionship	1	1
Collective learning practices	3	3
Learning limitations	1	2
Problems related to targeting training	2	4
Problems related to trainer's competence	2	3
Problems related to training to use new tools	3	3
Problems related to lack of motivation to engage in (unpaid) mentoring	2	3
Problems related to motivation to undertake training	2	6
Problems related to relevance of planned training	1	1
Problems related to knowledge transfer	3	4
Difficulties related to implementing learning (OPEX)	10	32
Recognition Slowness of gaps processing for OPEX	2	4
Recognition Information not looped back	1	1
Recognition Situations caught up but not analysed	2	2
Difficulties related to sharing with all the shift teams in the rotation	1	2
Implementation of OPEX	0	0

Debriefing fuels OPEX	4	4
Analysis of a significant safety event and its root causes	4	5
Weak signals analysis (trends)	4	6
Problems related to learning (sharing OPEX)	6	7
Problems related to of the meaning of handling gaps (deviation experienced as a sanction)	2	5
Role and limits of writing in learning	6	11
Role of competences	12	24
Role of learning for safety	9	17
Safety management Practices	18	168
Operational practices	7	28
Practice adaptation of actions to the reactor's behaviour	1	1
Practice modification of procedure	1	2
Practice of coordination meetings	2	2
Practice of problem resolution and decision making	3	5
Practice of try and requalification	3	9
Practice to centralization of information	4	9
Safety practices	18	140
Practices to face anomalies	7	25
Practice of stopping in case of problems or doubts	5	8
Practice of independent safety analysis and unit hierarchy	2	7
Practice of reporting anomalies and prioritization	4	10
Practices of information exchange and information centralization	6	10
Start-of-shift briefing practice	6	7
Changeover practices	2	3
Practice of interaction with regulators	9	18
Practice of ten-year regulator inspections	1	3
Practice of national and international audits	8	15
Reliability enhancing practices	13	55
Self-control	6	8
Secure communication	5	8
Cross-checking	3	3
Debriefing	6	12

Stopping	2	2
Pre-job briefings	8	19
Practice of small gesture of professionalism	4	10
Practice to maintain vigilance	6	12
Risk analysis	1	2
Safety messages	2	3
Control room monitoring	4	7
Practice to share values	4	10
Ten commitments of operations department	3	4
Operations fundamentals	2	6
Problems of implementation	18	488
Problem of implementation of values and safety culture	16	256
Adaptations to practices	9	24
Emergence of a context requiring adaptation	3	3
Vectors of increased adaptation and initiative	6	7
Vectors of decreased adaptation and initiative	5	14
Compliance in practices	12	36
Lack of rigour	3	5
Vectors for increasing procedural adherence in practice	6	11
Vectors of decreased adherence to procedures	9	20
Difficulties to translate values into practice	10	31
Recognition Safety culture in retreat	5	15
Problems related to implementing values in behaviour	8	16
Questioning and sensemaking of practices	15	63
Loss of meaning	7	13
Vectors for increasing sensemaking	4	6
Vectors of decreased sensemaking	12	44
Regulated vs managed safety	11	43
Regulated safety practice replacing managed safety practice	7	27
In-between situations - neither normal nor accident (incident temporality)	6	16
Transparency of practices	8	26
Vectors for increasing transparency	2	3
Vectors for decreasing transparency	4	11

Silence - Lack of free speech	6	10
Vigilance to risks involved in some practices	10	21
Reduced vigilance	6	6
Vectors of increased risk vigilance	8	15
Wellbeing	5	12
Vectors for increasing serenity	3	3
Vectors for decreasing serenity	4	9
Fear of punishment	2	4
Stress and doubt about doing a practice	4	14
Problems related to implementing certain practices	16	137
Communication problems	7	11
Problems related to individual differences	2	4
Reduced motivation due to lack of recognition	6	9
Planning problems	11	24
Lack of recognition of the importance of safety	3	5
Inefficient practices	15	68
Reduced safety levels	3	4
Difficulty involved in implementing REPs	9	19
Difficulty involved in implementing security practices outside REPs	8	13
Failure to implement operational practices	3	4
Difference in the practices of the operations shift teams	9	14
Examples of incidents, significant safety events	7	9
Normalization of deviations from rules – Deviation becomes routine	3	5
Reproduction of supervisors' behaviours for personal interest	3	7
Resistance to behaviour change	5	9
Problems related to implementing structure (organization)	17	95
Silos	12	31
Inability to organize face to face meetings	9	19
'Manager' and 'field worker' silos	2	2
Silo decision making and implementation	3	3
Anomaly detection and decision-making silos	6	7
Too heavy organization	10	18
Reorganization problems	11	27
Problems related to different roles	13	19

Structure	18	326
Roles, procedures, and responsibilities	16	140
Procedures	8	12
Reorganization	0	0
Description of operating department reorganization	7	14
Description of IMS (integrated management system)	3	6
Role repartitioning	16	128
Description of the roles in the operations department	14	94
Operation of shift teams	7	12
Operation of off-shift teams	2	2
Head of the operations department	2	6
Consignment manager	2	3
Field agent	5	12
Reactor operator	2	6
Operations shift manager	11	23
Assistant shift manager	7	11
control room supervisor	10	18
Role description (others)	6	6
Role description of the operator	7	12
Role description of FIS and SSQ	6	12
Everything is done top down	4	4
Values and efficient organization representations	16	61
Importance of clear roles	4	7
Importance of communication	2	5
Importance of ability to manage cumulated activities	5	8
Lack of distance about organizations	1	3
Use of audits to improve safety	8	11
Use of REPs	10	19
Reasons why efficient organization is important	5	8
Values and safety culture representations	15	125
Balance between competence and rigour	9	19
Changed perception about how to deal with risk	11	23
Fuzzy representation of safety	4	5
Interrogation and questioning	11	26
Justice	1	3
Learning	3	3
Transparency	3	6
Trust on steering the installations and risk management	10	20
Vigilance	8	16
Wellbeing at work	2	4

Appendix 7. ELSE training programme

(see Chapter 5 Section 5.3 Sub-section 5.3.5 "Training programme in leadership for safety")

Project funded by the European Union

ELSE - European Leadership for Safety Education

Training Programme

I. PROGRAMME

The training is organized in three complementary and closely interconnected modules. Modules 1 and 2 involve face-to-face training over a period of two weeks and build on the knowledge basis presented in the ELSE preparatory MOOC. Module 3 consists of a personal, 6-month tutored project on the theme of leadership for safety, developed by trainees on a part-time basis and in the context of their current professional position.

1. **MODULE 1: From regulated safety to managed safety in high-risk environments**
   - **1.1. Managing human and organizational risk factors**
     - 1.1.1. Evolution from risk management to safety management: regulated versus managed safety, paradoxes, and tensions
     - 1.1.2. Crisis versus routine management
     - 1.1.3. Safety culture and safety climate
     - 1.1.4. International safety standards in the nuclear industry: historical perspective and evolution
   - **1.2. Dealing with uncertainty in high reliability organizations**
     - 1.2.1. High reliability organizations and resilience: characteristics
     - 1.2.2. Uncertainty, complexity, and organizational limits: implications for safety
     - 1.2.3. Collective and individual ways of dealing with uncertainty
       - A. Dealing with uncertainty in a collective context: mindfulness, flexible rules, autonomy
       - B. Understanding Individual responses to uncertainty: a psychology outlook
     - 1.2.4. How to foster learning in organizations
       - A. Knowledge management: key concepts and their practical use
       - B. Organizational learning: key processes
       - C. Knowledge management: practical use in the nuclear industry
2. **MODULE 2: Leadership for safety**
   - **2.1. Understanding organizational dynamics**
     - 2.1.1. Organizational components and their interactions
     - 2.1.2. Social and emotional aspects of organizations – human–technology interactions
     - 2.1.3. Global approach to risk management
   - **2.2. Leadership: Definition, mechanisms, practices**
     - 2.2.1. Leadership: Definition and historical evolution of key concepts
     - 2.2.2. Mechanisms and practices of leadership as process
   - **2.3. Developing leadership for safety**
     - 2.3.1. From leadership to leadership for safety
     - 2.3.2. Mechanisms and practices of leadership for safety
     - 2.3.3. Leadership for safety in the nuclear sector context
3. **MODULE 3: Developing effective leadership practices for improving safety in the nuclear sector**
   - **3.1. Personal project**
     - 3.1.1. Application of knowledge acquired in Modules 1 and 2 to identify and implement new leadership practices for improving safety in trainees' organizational context
     - 3.1.2. Written report
   - **3.2. Oral presentation of results**

II. **PEDAGOGICAL METHODS AND LEARNING PROGRESSION**

The progression and complementarity of learning between the MOOC, the face-to-face training and the personal project carried out in the trainee's company are depicted in Figure 1.

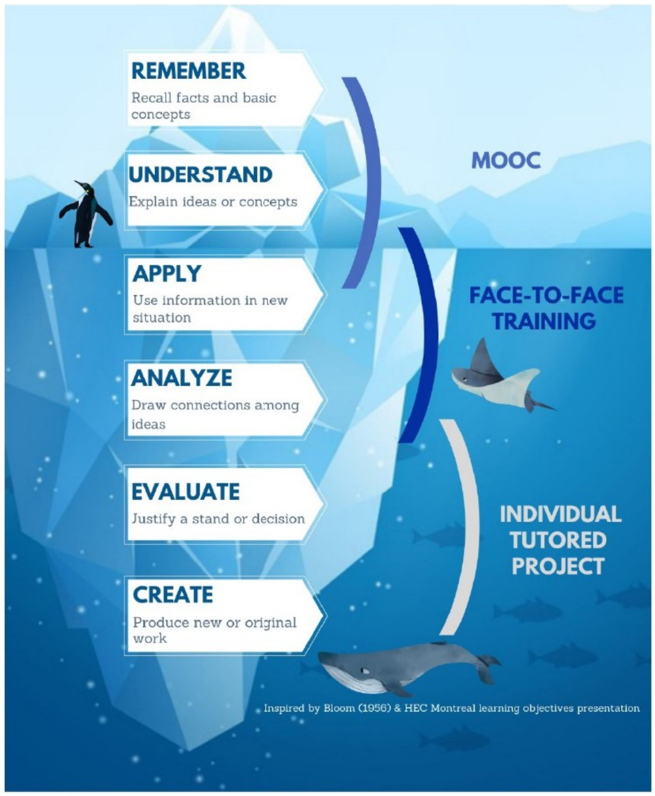

Figure 1: ELSE training learning progression

The MOOC presents and explain the main concepts of the training. Becoming familiar with them and understanding them constitutes the first level of knowledge appropriation.

The face-to face training will strengthen the appropriation process by discussing it with the different professors and experts and applying it in numerous case studies (10). Apply these concepts and analyse concrete situations mobilising it constitutes the second level of knowledge appropriation.

Finally, the individual tutored project allows to apply these new concepts to daily practice and to develop a critical look at the processes and practices implemented to increase safety. Evaluating safety processes and practices and creating new ones constitutes the third level of knowledge appropriation.