Leadership and teamwork in safety-critical systems

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MASTER'S THESIS

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Abstract

Devastating catastrophes during the 1980s together with recent years' fatal accidents, including the Boeing 737 MAX plane crashes in 2018 and 2019, have altogether highlighted the need for researchers' attention within the field of safety-critical systems. Additionally, as a result from technological advancement and globalization, the prevalent complexity and ambiguity within today's systems continue to increase.

This thesis therefore aims at exploring the latest research conducted on leadership and teamwork within safety-critical systems, to see how these together can enhance system safety and facilitate the management of the previously described challenges.

This thesis work has been based on an extensive literature study together with interviews conducted with leaders from two different safety-critical systems.

The literature shows that the "Big-Five" framework can provide a lens through which teamwork and leadership can be analyzed with respect to team effectiveness and safety work. Together with information concerning historical safety theories, along with the most recent leadership and teamwork science, the information highlights important concepts that must be considered when talking about leadership and teamwork within this context.

The thesis's results show that the definition of a safety-critical system must be extended. The definition must include a multidimensional perspective since today's organizations are comprised of several collaborative and geographical dispersed teams, all of which work towards common goals. The importance of communication and coordination are emphasized and can further be facilitated through the usage of shared mental models, which in turn are enabled through a good safety culture and leadership.

Altogether, the result shows the complex and dynamical relationship between teamwork, leadership and safety, and further highlight their interrelated nature in which one concept highly impact the other two.

Keywords: Safety-critical systems, leadership, teamwork, multiteam systems, socio-technical systems, Big-Five framework, mental models

Sammanfattning

Förödande katastrofer under 1980-talet, tillsammans med de senaste årens olyckor, inkluderat Boeing 737MAX flygplanskrascherna under 2018 och 2019, har belyst behovet av forskares uppmärksamhet inom fältet säkerhetskritiska system. Som ett resultat av tekniska framsteg och globalisering, fortsätter dessutom komplexiteten och ambiguiteten inom dagens organisationer att öka.

Denna uppsats ämnar att utforska den senaste forskningen kring ledarskap och teamwork inom säkerhetskritiska system, och hur dessa komponenter tillsammans kan förbättra ett systems säkerhet, samt underlätta hanteringen av de tidigare nämnda utmaningarna. Arbetet har utförts med utgångspunkt från en omfattande litteraturstudie, som tillsammans med intervjuer med ledare från två olika säkerhetskritiska organisationer, utgör kärnan i arbetet.

Litteraturen visar att "Big-Five" ramverket kan tillhandahålla ett synsätt som tillåter teamwork och ledarskap att analyseras med avseende på dess effektivitet och säkerhet. Vidare belyser säkerhetsteorier tillsammans med senaste forskning kring ledarskap och teamwork, viktiga aspekter och komponenter som måste tas i beaktning när dessa två koncept ska studeras inom säkerhetskritiska system.

Resultatet av studien visar att definitionen av ett säkerhetskritiskt system behöver utvidgas. Definitionen måste inkludera ett multidimensionellt perspektiv, då dagens organisationer består av flertalet samarbetande och geografiskt utspridda team som arbetar mot gemensamma mål. Vikten av kommunikation och koordination belyses, vilket kan underlättas genom delade mentala modeller, som i sin tur möjliggörs genom en god säkerhetskultur och ett gott ledarskap.

Sammantaget belyser resultatet också den komplexitet och den dynamiska och beroende relationen mellan teamwork, ledarskap och säkerhet, där det ena konceptet påverkar de andra två.

Keywords: Säkerhetskritiska system, ledarskap, teamwork, multiteam system, socio-tekniska system, Big-Five ramverk, mentala modeller

Förord

Jag vill börja med att rikta ett stort tack till min handledare, Åsa Ek, som kommit med konstruktiv kritik genom hela mitt arbete och som ställt upp på möten trots semestertider. Stort tack även till er som ville ställa upp på intervju och för att ni var så positivt inställda till ämnet.

Med denna uppsats vill jag belysa vikten av ledarskap och lagarbete inom dagens säkerhetskritiska system och förhoppningsvis väcka ett intresse och nyfikenhet som kan bidra med fortsatta diskussioner inom ämnet.

Jag vill också tacka LTH och alla engagerade lärare jag har haft genom åren som student.

Lund, August 2020

Mattias Seth

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1 Introduction

The ambition with this chapter is to present theory that is necessary to acquire in order to understand the later chapters in this thesis, but most importantly, the goal is to motivate why this thesis work is worth doing.

The first section (1.1) below, briefly introduce the reader to some of the concepts that will be used in this thesis. In subsection 1.2, the goals and objectives are presented, and in section 1.3, the thesis disposition is summarized.

A more profound presentation of safety-critical organizations and accident theories is further given in section 1.4. The last chapter in the introduction, 1.5, highlights three disasters that have occurred in different safety-critical systems during the last decades, and where a common triggering factor behind these accidents were lack of adequate leadership and teamwork.

1.1 What motivates this thesis work?

The organizational structures in today's society has never been more complex. The progress of technological advanced innovations in combination with globalization, outsourcing and an increased demand for efficient decision making, have put additional pressure on organizations, teamwork, and leadership (Hollnagel, 2012; Oosthuizen & Pretorius, 2016; Righi & Saurin, 2015). As a result, the majority of today's organizations consist of a number of highly specialized teams that operate from different locations, though working towards common goals (J. Mathieu et al., 2001).

Fast and accurate decision-making in crucial situations can be the difference between a smaller incident or a devastating catastrophe, not at least in complex and hazardous working environments that constitutes a safety-critical system, such as power plants, hospitals, offshore platforms and aircrafts (Harvey et al., 2019; Oedewald et al., 2007; Perrow, 1984). The complexity in combination with this hazardous environment, requires a profound knowledge and expertise among the teams' members.

The increased demand for efficient and safe work within safety-critical systems, further highlights the crucial and fundamental role of adequate teamwork and leadership. Some examples of what can happen when leadership and teamwork fail in these kinds of systems, will be given in section 1.5.

As a result of the increased complexity within today's systems, recent years' research has focused more and more on factors that constitute an adequate, or *good* leadership and teamwork, and how these components can be implemented in organizations to promote and enhance the system's safety.

1.2 Goal and ambitions

The previously described background will act as a point of departure. The ambition with this master's thesis' work is to fill in the gaps between different theories regarding safety-critical systems, leadership and teamwork, and to study which factors and qualities that constitute good leadership and teamwork within these safety-critical settings. Additionally, the goal is to clarify how leadership and teamwork can contribute to system safety.

The result will hopefully guide future research and act as a guide for both internal and external safety audits within these systems, as well as highlight important aspects that should be considered when organizations want to develop their leadership, teamwork and safety work.

1.2.1 **Research questions**

1. What factors constitute good leadership?
2. What factors constitute good teamwork?
3. How can good leadership improve teamwork within safety-critical systems?
4. How can leadership within safety critical systems improve and preserve system safety?

1.2.2 **Delimitations**

The scope of this thesis work does not include a profound description of all the related terms and concepts that exists within the scope of leadership and teamwork. Due to the extensive information on the subjects, the work has been limited to the study of socio-technical, safety-critical, multiteam systems, even though some of the concepts mentioned are generic and can be applied to various types of organizations.

Several constellations are not mentioned in detail, for example virtual teams or multidisciplinary teams, which to various extent, share some similarities with the concepts of MTSs, but can both, individually, be considered as an own research field.

As will be mentioned in the method, in chapter 2, the included theories have all been shorten and the information has been compressed. This means that one page in this thesis, could perhaps be written in 4 pages if every detailed information should be included. Therefore, the reader should be aware that the provided information, especially concerning the historical walk-through in chapter 3.1, is extremely simplified and has been further reduced.

The main focus has been to include teamwork and leadership qualities that to some extent can be related to the "Big-Five"-framework.

The focus has further not been to highlight every aspect of teamwork and leadership. This means that for example group dynamics and group thinking are not included, nor has this study included any detailed information of different personal characteristics that belong to a leader, for example their personality. Questions concerning how leadership and teamwork should be implemented have further been omitted.

1.3 Disposition

To this point, the reader has been briefly introduced to the background that motivates the need for this thesis. The reader has got a first glance at concepts such as*, complexity, safety-critical systems,* as well as *teamwork* and *leadership.* These terms will be discussed more profoundly in chapter 3, together with other important terms.

In section 3.1, a historical "walk-through" will take the reader back to the beginning of the 1900s. The aim with this section is to shed some light on how today's safety research has evolved throughout the history, as well as its origin.

Section 3.2 explains the concept of a *system* more profoundly. After this section, the reader will hopefully be more familiar with the concepts *multiteam systems (MTS), socio-technical systems, interactions,* as well as the concept of a *socio-technical multiteam system*. The reader will become aware of the Mars Climate Orbital accident in section 3.2.2, where the consequences, as a result from poor leadership and teamwork, will become evident.

The most recent research fields covered in sections 3.1.6, 3.1.7 and 3.1.8, concerning resilience engineering (RE), HRO and safety culture, from the 1980s and onwards, will lay the foundation for the more specific sections that will cover teams, teamwork (section 3.3), and safety leadership (section 3.4). In these chapters, the reader will be acquainted with important factors that are necessary in order to achieve common goals and objectives in a safety-critical system.

Chapter 4 aims to address the question whether there are any disparities between the theories concerning how leadership and teamwork *should* be used in safety-critical systems, and how organizations actually *practice* these theories in the reality. The aim is to highlight questions concerning *if*, *how* and *why* these discrepancies exists at all. In section 4.2, the result from two interviews, conducted with leaders in two different safety-critical systems, will be presented.

Chapter 5 answers the research questions provided in 1.2.1, while the chapter 6 discuss the literature used in this thesis, as well as the thesis' content.

The last section, section 6.5, includes a conclusion.

However, the next section (1.4) provided below will present the definition of a safety-critical system, together with some accident theory, which is necessary to comprehend the theory in chapter 2.

1.4 Safety-critical organizations

According to Reiman and Oedewald (2009), a safety-critical organization constitutes a system in which failures can cause enormous destruction and damage to the environment, public or personnel, for example, in terms of significant property damage or loss of life.

In these systems, which often comprise great complexity, the personnel are subject to act under extreme uncertainties. Everyday actions need to be carefully evaluated and goals need to be balanced between efficiency and safety (Dekker & Pruchnicki, 2014). The prevailed uncertainty makes it further difficult to differentiate between a correct and an incorrect action, and due to the inherent complexity, even right decisions can, in an intrinsic way, negatively impact parts of the system that is hard to anticipate (Oedewald et al., 2007; Reiman & Oedewald, 2009).

These complex structures are further something that is incorporated in the numerous interactions and relations among the different actors within these systems (Zaccaro et al., 2012). The actors can be either technical, sociological or organizational, meaning that numerous interactive patterns exist. A system that comprises these various types of interactions is further something that is called a *socio-technical system (STS)* (Rasmussen, 1997), which will be discussed more in detail under section 3.2.

Additionally, today's socio-technical system is often composed of several *subsystems* where the interactions can extend over several teams, which put great demands on teamwork and leadership (Perrow, 1984). Different teams working together to achieve common goals are in turn called a *multiteam system (MTS)* (Reiman & Oedewald, 2009), and will be described more in detail in section 3.2.2.

The precise impact on the entire system is hard to foresee, and members of safety-critical MTSs inevitable lacks the ability to comprehend how small adjustments and decisions can propagate through the organization and lead to enormous catastrophes (Dekker & Pruchnicki, 2014; Perrow, 1984). Hence, it is impossible for the team members to understand the dynamical structure of these systems, but rather, personnel are only capable to comprehend the functions of their own subsystem (Perrow, 1984; Rasmussen, 1997). This makes it inevitable that accidents and disasters occur when people perform everyday tasks, in a suitable manner, that for them is appropriate given the prevailed conditions (Perrow, 1984). It is the non-linear interrelation between actions and outcomes in these systems that induce snowballing effects, where small accumulated changes within the organization can lead to a big disaster (Perrow, 1984).

Therefore, it is of great importance that organizations that operate in safety-critical environments, recognize how safety work can impact the system's outcomes. To cope with these complex structures, latest research suggest that leadership and teamwork are two factors to focus on (Salas et al., 2020).

1.4.1 **Categorization of safety-critical systems**

As mentioned, safety-critical systems can be defined by the severe consequences that follow a failure in these settings. Additionally, these systems are often comprised of great complexity.

To categorize these systems, with the ambition to better understand their hazardous nature, Charles Perrow (1984) developed a two-dimensional model (see Figure 1). With this model, he could categorize organizations according to their complexity and what type of *coupling* that is prevalent within the system.

The different type of couplings can be either *tight* or *loose*, and these couplings, separately, affect the organization's ability to prevent, or recover from an escalating snowballing effect (Dekker, 2019).

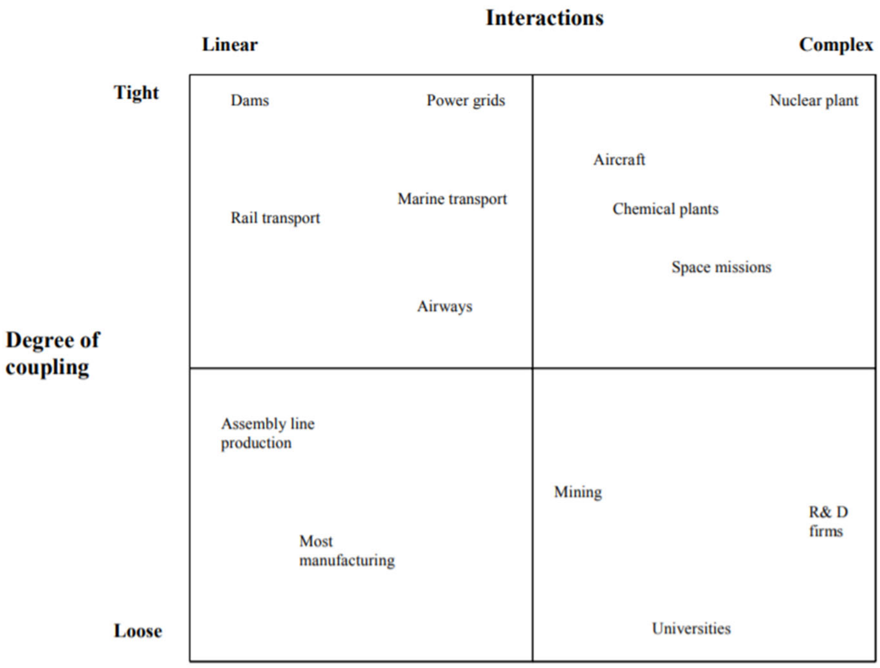

Figure 1 - Categorization of an organization according to the type of interactions and coupling (Perrow, 1984)

Organizations with both complex and tight coupled interactions, systems close to the top right-hand corner in Figure 1, are said to be *extra* susceptible to accidents (Perrow, 1984; Rosness et al., 2004).

Additionally, in tight coupled systems, the subsystems are interdependent, and the leadership is highly centralized and rigid. Small changes cause massive ramifications and deviations spread fast, as all subsystems cannot be turned off. There are no buffers, and the work is conducted in accordance with a "just-in-time" principle (Perrow, 1984).

In loose coupled systems however, the subsystems are independent, and the leadership is decentralized. Changes has little effect on the organization and if something goes wrong, there is often enough time to correct and adjust the organization, which can prevent catastrophic consequences (Kjellén, 2000; Perrow, 1984). Examples of tight coupled systems can be found in Figure 1.

The different characteristics of tight and loose coupling types will be further discussed in later chapters.

However, safety-critical systems can consist of either loose or tight couplings and be more or less complex. But as have been described earlier, the majority of today's systems are extremely complex and tight coupled.

1.4.2 **Barriers to prevent accidents from happening**

The hazardous nature of a safety-critical system implies that accidents can, and will occur (Dekker, 2019; Hollnagel, 2004; Kjellén, 2000). Haddon (1980) concretized this statement and developed an idea that accidents happen when there is an uncontrollable release of harmful energy that, in absence of any barriers, can hit a vulnerable target. The energy can be of various forms, for example kinetic, thermal, chemical, electrical or ionization energy. However, the energy can be seen as a metaphor and must not always include the more intuitive definition of energy, for example, in the form of heat (fire) or huge pressure waves (explosions). Instead, the energy can for example be related to a person's actions (described as active failures in next section) or some organizational changes that impact personnel's behaviors, which in turn can lead to an active failure (referred to as latent conditions in section 1.4.3) (Haddon, 1980; Perrow, 1984).

The explanation to why accidents occur have been subject to several interpretations and theories throughout the years, something that will further be discussed throughout the historical "walk-through" in section 3.1. However, Haddon developed an *energy-barrier mode*l to visualize how accidents occur according to him (see Figure 2). His model is widely used today in system safety design (Haddon, 1980), and his interpretation facilitates the understanding of accidents and helps to visualize the concept.

The different barrier elements which constitute the barrier, can come in various forms. Hollnagel (2004) classified these barriers according to their nature; *material barriers* (e.g., walls, containers), *functional barriers* (e.g., passwords, software), *symbolic barriers* (e.g., instructions, signs, permits) and *incorporeal barriers* (e.g., a person's knowledge) (Reason, 1997, 2000). The function of each barrier is to separate targets from dangerous energy sources (Rosness et al., 2004).

Safety-critical systems may use several layers of defensive barriers, something that Reason (1997) further refers to as "defense in depth" and is a concept that is visualized in the "Swiss cheese"-model which will be discussed in next section.

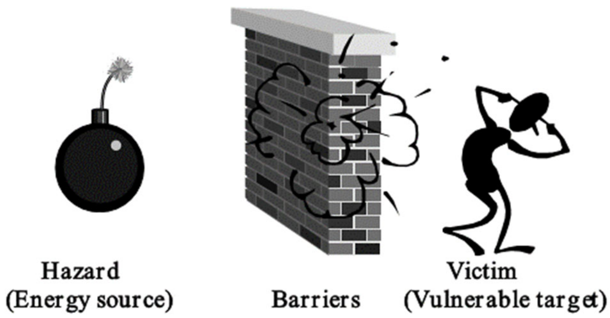

Figure 2 - The energy and barrier model (Rosness et al., 2004, p. 35)

1.4.3 **Why accidents occur**

The cause behind a failure in a safety-critical system can be both due to an *active* or a *latent* failure. An active failure is an unsafe act committed by people within a system, and arises, for example, due to stressors in the environment. An active failure shows up quickly, and the cause behind these types of failures might result from an operator who forgot to report an acute problem in time (Reason, 2000).

Latent failures, or *latent conditions*, do not appear as quickly as active failures. The resulting failure from latent conditions might show up after several years and the cause behind these kinds of failures can be due to subtle changes (e.g., managerial influences and social pressures), that in a non-obvious way negatively impact the system's safety. Latent conditions can lead to active failures if they are left to propagate through the organization unnoticed (Reason, 2000).

The concept behind thinking of accidents as something that arise due to either active failures or latent conditions, was visualized by Reason (1997) in his "Swiss cheese" model where each slice represents a barrier. An adoption of his model is seen in Figure 3.

In contrast to a real swiss cheese, the holes in Reason's Swiss cheese model, are constantly opening and shutting, and their locations may shift. The holes constitute active failures and latent conditions within an organization, and when these holes line up, the energy can pass through and cause an accident, which are represented in Figure 3 (Quayzin & Dipl, n.d.; Whitmeyer & Wilcutt, 2013).

However, as was mentioned in a previous section, accident theory has been reshaped through the history, and this historical evolvement will be further discussed in chapter 3.1.

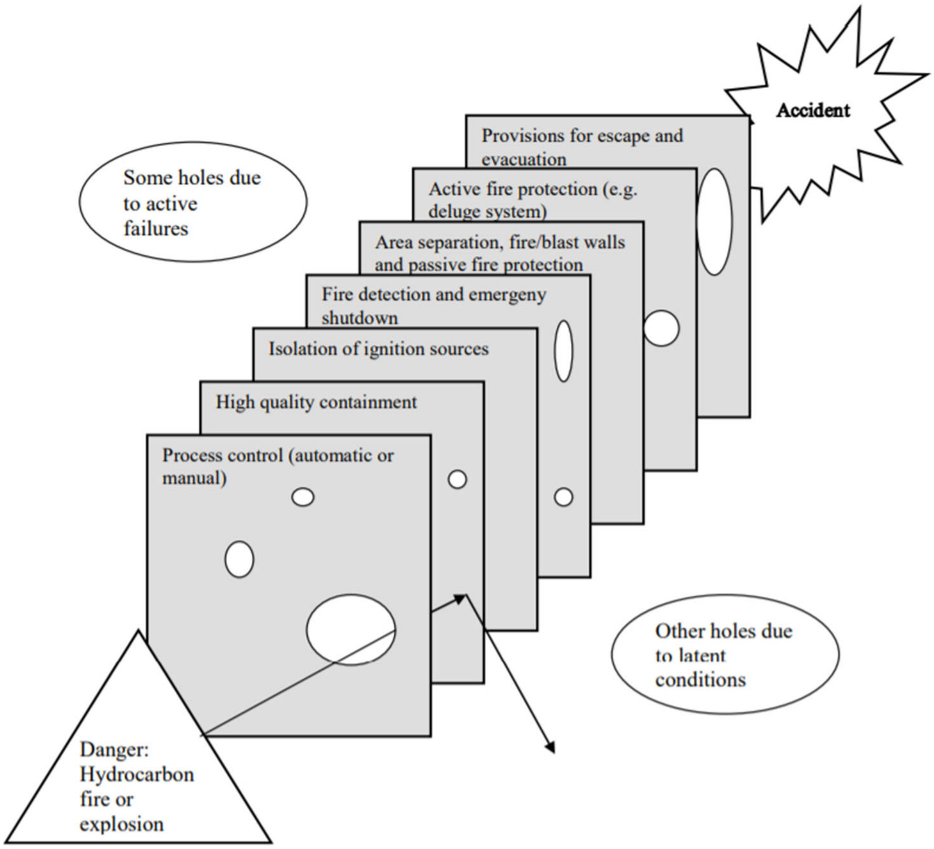

Figure 3 – The Swiss cheese model visualized as "defense in depth" (Reason, 1997, p. 12)

Furthemore, a prerequisite for the swiss cheese model to work, is that accidents are seen as *linear*, which is a simplification of the reality, something that will be discussed in the next chapter.

Instead, a more dynamical model was developed by Rasmussen (1997). He modeled the humans within a system and proposed that human behavior is constantly shaped by organizational objectives and constraints. Humans are left to act under many degrees of freedom within the working space. However, this space is bounded by functional, administrative, and safety related constraints, and once these boundaries are irreversible crossed, for example due to forces such as, tight budgets or unreasonable time plans, an accident may occur (see Figure 4) (Rasmussen, 1997).

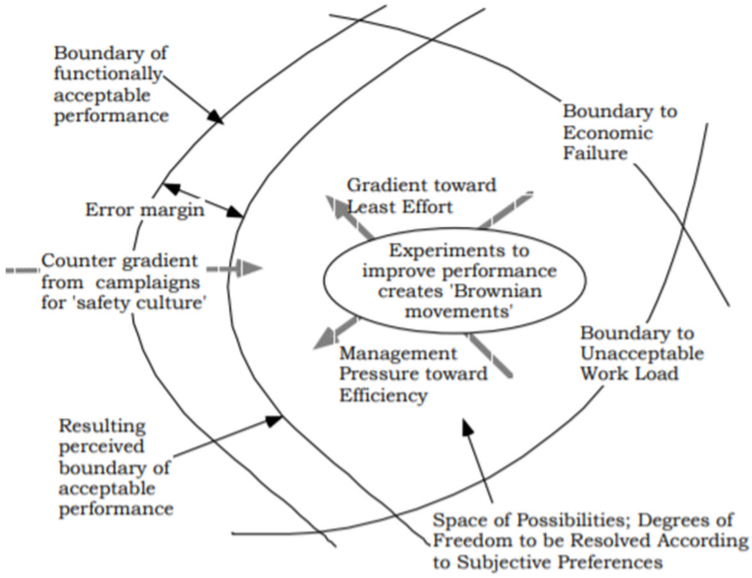

Figure 4 - The "Design Envelope"- model (Rasmussen, 1997, p. 190)

1.5 Disasters that motivates further research within the field of leadership and teamwork in safety-critical systems

Until now, the reader has been introduced to theory concerning what factors that constitute a safety-critical system, how these systems can be categorized, and how accidents occur and how they can be prevented.

The focus in this chapter will be to illustrate what a failure in a real-world safety-critical system can look like. The focus will be on exploring *how* and *why* these accidents occurred, as well as highlighting the devastating *consequences* that followed. This will be done by explaining three disasters that have taken place during the last decades. All disasters took place in a safety-critical system, and each system had several barriers. The cause behind each accident can also be explained by active failures, which were results from underlying latent conditions.

Even though three completely different disasters will be described, they all share three common factors. First, the cause of the accident can be described as a series of relatively small failures that unnoticed meandered past each barrier (recall the swiss cheese model in Figure 3). Secondly, safety-boundaries were crossed due to forces created by dubious decision-making (recall Figure 4). Third, there were an apparent lack of good leadership and teamwork in each system (Quayzin & Dipl, n.d.).

Each disaster will be explained in a chronological order below. No theory will be presented. Additionally, the more profound discussion regarding whether the leadership and the teamwork could have prevented these accidents from happening, will be based on the theory in chapter 3, and further included in the discussion, in chapter 6.

1.5.1 Challenger - the space shuttle explosion (1986)

In 1976, the American, National Aeronautics and Space Administration (NASA) presented the first reusable, manned spacecraft, called the space shuttle. A well-known problem with these space shuttles was erosion of the so-called rubber O-rings in the Solid Rocket Booster joints, used to separate burning gas inside the solid rocket from the outside environment (Presidental Comission, 1986). This problem had been observed by NASA for many years, in sufficient time to correct the issue before the launch of the Challenger in 1986, and attempts had been made to try to correct for the faulty O-ring design, though without compelling results. However, this problem seems to not have been adequately communicated to the senior management at NASA (Presidental Comission, 1986).

In 1986, the day of the launch, the outdoor temperature was significantly lower than the threshold temperature specified in the design specifications for the O-rings. However, NASA, whose ambition was to achieve 24 flights a year in accordance with their flight schedule, decided to launch the Challenger anyway, as they did not fully understand the risk of exposing the O-ring to the cold weather that January morning (Committee on Science and Technology House of Representatives, 1986).

The low temperature resulted in failure of the O-ring to withstand the turbulence, which in combination with increased throttling power (Committee on Science and Technology House of Representatives, 1986), caused the flames to break through the external tank and caused the explosion of the Challenger, only 73 seconds after takeoff, in front of the whole world watching, see Figure 5 (Ganley & Brindley, 2016). All seven crew members died.

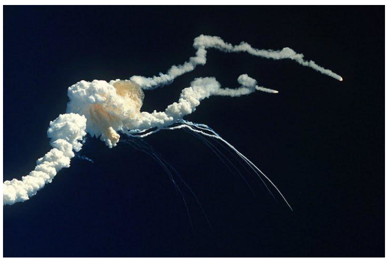

Figure 5 - Explosion of Challenger (Ganley & Brindley, 2016)

1.5.2 **Piper Alpha – the oil platform explosion (1988)**

Piper Alpha was an oil platform, located 193 kilometers northeast of Aberdeen, Scotland. The platform had four operating areas that were separated by firewalls, which in turn were supposed to serve as material barriers, separating personnel from the hazardous operating areas. The barriers were designed to withstand oil fires, and seawater pumps were further used to supply the platform's firefighting system in case of fire (Cullen & Cullen of Whitekirk, 1990).

The day the accident occurred, 6 July 1988, a worker from the day shift had been performing a routine maintenance on one of the two condensate pumps, pump A. The worker had removed the pressure safety valve, which was used to regulate overpressure. During the maintenance, the worker temporarily sealed the open pipe with a flat metal disk, called a blank flange. The blank flange was only hand-tightened and was not designed to manage overpressure (Cullen & Cullen of Whitekirk, 1990). Since the operating day shift did not manage to finish the work until the end of their shift, the metal disk remained in place until the shift change. An engineer filled in a permit, which stated that the pump A was not ready, and must not, under any circumstances, be switched back on. When the night shift started, the on-duty custodian was busy, so the engineer could not inform him about the modifications on pump A. The permit was instead left in the control center before the engineer left the platform (Cullen & Cullen of Whitekirk, 1990).

The same evening, the night shift faced a blockage failure in the second pump, pump B. To prevent the halt of all offshore production, the night shift workers had to act fast, deciding whether to restart pump A or pump B. Since pump B could not be restarted, the workers were left with the decision to restart pump A or not. Since the permit could not be found, and no one had informed the workers about the prevailing conditions, the night shift decided to start pump A. The loosely fitted blank flank did not withstand the overpressure caused by the missing safety valve. The disaster was inevitable as the automatic firefighting system had been switched from automatic to manual control only days before. Furthermore, the material barriers were only designed to withstand fires, not explosions. The explosion killed 167 people, leaving only 61 left alive (Whitmeyer & Wilcutt, 2013) (see **Fel! Hittar inte referenskälla.** and Figure 6).

Figure 7 - Pipe Alpha, before the explosion (Macleod & Richardson, 2018)

Figure 6 - Pipe Alpha, after the explosion (Whitmeyer & Wilcutt, 2013)

1.5.3 **Boeing 737 MAX – plane crashes (2018 and 2019)**

The European jetliner manufacturer, Airbus, announced 2010 they planned to upgrade their most popular airplane model, Airbus A320. The new plane would have much larger engines, allowing the plane to reduce its fuel consumption by 15 percent. Despite the engine modification, the new plane, Airbus A320neo, would still resemble the older model, meaning that the pilots could fly the new plane with only little additional training (The House Committee on Transportation and Infrastructure, 2020).

Boeing, who is an American aerospace company and a world leading manufacturer of commercial jetliners, felt compelled to follow, as they felt a tremendous financial pressure to launch their own, upgraded plane model to compete with Airbus. Boeing decided to upgrade their rather old model, Boeing 737, instead of developing a total new model. The upgrade would include bigger engines even for Boeing. The problem was that Airbus A320neo was a much larger plane that Boeing 737, meaning that the new, larger engines could not fit the older Boeing 737 plane without further modifications. Boeing "solved" this problem by moving the new engines up on the wings (The House Committee on Transportation and Infrastructure, 2020).

Just like Airbus, Boing now announced that the new plane, Boeing 737 MAX was so similar to its predecessor, so only minimal additional training was needed for the pilots (The House Committee on Transportation and Infrastructure, 2020).

However, the oversized engines on the Boeing 737 MAX had a side effect. At full thrust, like during takeoff, the nose of the plane tended to tilt upwards, which could lead to a stall. Since the new plane was supposed to mimic the old ones, Boeing came up with a solution to this problem, a functional barrier to prevent an accident from happening, they thought. The solution was an autonomous software system which they called *Maneuvering Characteristics Augmentation System*, or *MCAS*. This system was installed into the new planes and was supposed to automatically push the nose downwards in case of a detected stall. Boeing had hidden the information regarding the new software MCAS, meaning that several pilots were unaware of the function of the new technology. Something that would lead to devastating consequences (The House Committee on Transportation and Infrastructure, 2020).

On October 29, 2018, the operating Indonesian Lion Air Flight 610 crashed into the Java Sea only 13 minutes after takeoff, killing all 189 passengers and the crew. March 10, 2019, less than five months later, another Boeing 737 MAX plane, flight 302, belonging to Ethiopian Airlines crashed six minutes after takeoff, killing all 157 passengers and the crew (The House Committee on Transportation and Infrastructure, 2020).

2 Methodology

A major literature study served as a basis for this thesis, where various scientific databases have been used, including LUBsearch, Scopus, PsychInfo, Science Direct, Sage Journals. In some cases, the search engine Google Scholar was used. Literature were further limited to either English or Swedish literature.

The knowledge and theory obtained from the literature study was to be compared with real life organizations to see if, and how they practice the theory. Additionally, the goal with the complementing interviews were to find out if there were any evident discrepancies between the theoretical framework, regarding leadership and teamwork in safety-critical systems, and the actual prevailed working conditions.

The different steps used in this thesis project are described more in detail below.

2.1 Literature study

A systematic literature study has been conducted with the ambition to sort out and grasp the numerous theories and studies that exist within the field of system safety, leadership and teamwork. The literature study consisted of two parts. The subsections below are therefore divided between the two parts, meaning that the specific method that was used in each part are mentioned separately.

The first **(1)** part in the literature study was to aim for a bigger picture and to get an overall perceptive concerning how different theories have emerged and evolved throughout the years. These theories were then mapped and placed on a timeline model to make it easier to overlook (see Figure 8). The research concerning different safety theories laid the foundation for the chapter that comprises the historical background in chapter 3.1. The first part of the literature study can therefore be said to constitute the "the historical part" of the thesis, which is composed of several theories that later laid the foundation for the second part of the literature study.

The second part **(2)** of the literature study focused more on today's latest research, with a focus on leadership and teamwork in safety-critical systems. Here, the time-line model in Figure 8 acted as a framework to ease the understanding regarding how, and why today's theories concerning leadership and teamwork have evolved and ended up the way they are today.

Since the theory on safety, leadership and teamwork is extensive and includes numerous of models, insights and revolutionary discoveries, continuous decisions had to be made, including decision concerning which factors and theories to focus on and include. How this evaluation was done is further described in section 2.1.3 and 2.1.4.

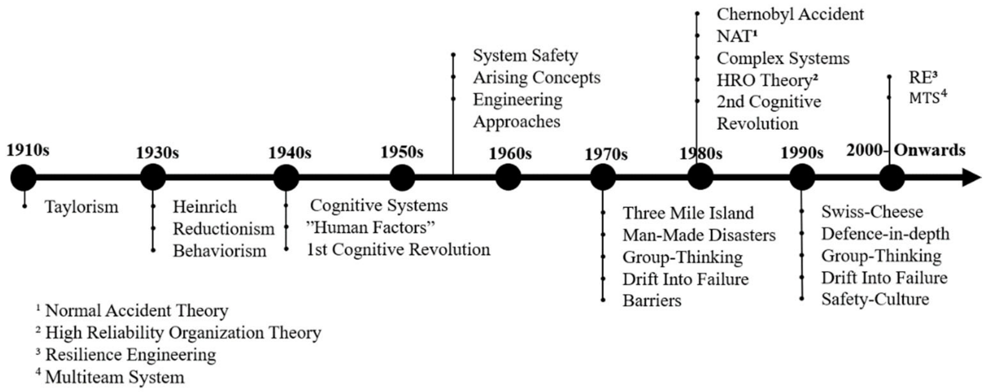

Figure 8 – Time-line model, a Sketch used to grasp the vast amount of theories (Thesis' author, 2020)

2.1.1 **Search for literature, concerning part 1**

The literature that laid the foundation for the first part were mainly obtained through historical writings, as well as summarizations and reviews conducted by external authors. The choice to complement the historical writings with more recent reviews, was motivated by the multiple perspectives this resulted in, and to prevent biases.

The historical writings composed of mainly two literature sources (see Table 1 below). Both of these sources had summarized the field of safety science in a strategic and profound way. From these sources, a snowballing method was used as a search strategy, to find more literature covering the field, and to triangulate the results (will be described in later section).

Snowballing can be performed through backwards, or forward snowballing, but in this thesis, backwards snowballing was used. This method is based on finding literature through the usage of a first source's reference list (Wohlin, 2014).

Table 1 - Example of found literature from the snowballing method conducted on the two main sources for part 1, the "Historical part" (Thesis' author, 2020).

Main Source, Author(s)	Main Source, Title	Examples of found literature, as a result from the backward snowballing method
(Dekker, 2019)	Foundations of Safety Science, A Century of Understanding Accidents and Disasters	(Woods, 2010) (Rasmussen, 1997) (Reason, 1990,1997) (Roberts, 1990)
(Rosness et al., 2004)	Organisational accidents and resilient Organisations: Five Perspectives Revision 1	(Hollnagel, 2004) (Haddon, 1980) (Turner, 1978)

2.1.2 **Search for literature, concerning part 2**

As have been mentioned, the literature on leadership and teamwork is vast and fragmented.

The literature search in the second part of the literature study was shaped by the first part. In the first part, and with help from the time-line model, it become evident what factors that are in focus today. Examples of terms that was found were *resilience* and *multiteam system (MTS)*. These terms were mainly found in literature written after the 00s, so the second **(2)** part of the literature study can be referred to as the "contemporary part". An example of this is illustrated below.

A search on Google Scholar on the term *multiteam* yields approximately 8 380 articles. If the same search is performed on the time interval between the years 1900 and 2000, the search yields approximate 417 results. If the interval is changed to cover articles published between 2010 and 2020, the number of found results are 5 520. This can be put into perspective where a Google Scholar search for *Taylorism* between 1900 and 2005 yields 14 300 articles, and 16 100 articles between 2006 and 2020. The same principle can be visualized through a search in LUBSearch. A search for *multiteam* yields no articles published sooner than 1977, whereas a search for *Taylorism* gives articles published in 1914.

To find literature covering for example leadership in *safety-critical multiteam systems* was not a trivial task. Some articles covered all fields (e.g., leadership and/or teamwork in safety-critical system), but other articles only covered limited fields, as for example, the article *leadership in multiteam system.* This article did not cover safety-critical system (the specific article did not include a single sentence containing the word *safety*). Another example was the article *Mind the gap: The role of leadership in multiteam system collective cognition*, who did not include neither of the words *teamwork* nor *safety.* However, this specific article covered more specific information regarding team interactions in terms of different attributes a leader should possess in order to facilitate team interactions. To make use of this information in relation to the field of safety-critical systems, this type of information was *triangulated.* Triangulation is further a term that refers to the use of multiple sources of information and data, to enhance a study's credibility (Rahman, 2012; Salkind, 2010).

The usage of the triangulation method ensured that specific concepts that were found in one specific article, could also be found in other articles. The aim was to validate the information through cross verification. This was done by finding at least three different credible articles, with different authors, that all covered the same concepts. In some cases, however, this was hard to accomplish due to the limited supply of information.

An example of this cross verification through a triangulation method can be seen in Table 2.

Table 2 - Visualization of triangulation method which was used to validate sources' crediablity (Thesis' author, 2020)

Author(s), in article 1 **NOTE: The information provided in the articles linked to the author(s) below, was used as a point of reference.**	**Found key concepts in article 1** **NOTE: The concepts have not necessary been precisely or explicitly described as the examples below. The concepts have been summarized as examples by this thesis's author.**	**Triangulation, other articles that confirm the same concepts as in article 1** **NOTE: The author(s) presented are independent, meaning there was no direct cross-reference between these or article 1.**
(Flin & Yule, 2004)	"A leader should facilitate team coordination" "Coordination is important for team effectiveness" "Communication is important for the safety performance"	(Murase et al., 2014) (Salas et al., 2020)
(Salas et al., 2020)	"Coordination is developed through shared mental models (SMMs)" "Leadership can enhance and facilitate the development of SMMs"	(Murase et al., 2014) (Fernandez et al., 2017)

In addition to this, a backward snowball method was used in this part as well, where references from prior literature were used to find new articles.

Examples of search words used in part 2 of the literature study were: *multiteam, multiteam systems, leadership, safety critical, safety, teamwork, socio-technical system, resilience engineering, high reliability organization.*

These search words were used alone, as well as in combination with other words. A strategy was to use as general, or generic words as possible to get as much search results as possible. Example, instead of searching for: *good leadership behaviors for safety work in multiteam systems.* The more generic search would be: *leadership safety multiteam system.*

2.1.3 **Evaluation of different safety theories, concerning part 1**

The field of human error and system safety is somewhat shattered. That means that there are numerous researchers within the field that support different theories and that prefer certain explanatory models to describe accidents and system safety.

Therefore, an assessment had to be done concerning what theories and models to include and exclude, and to evaluate those. Due to this vast amount of information, only those safety theories that were thought to be the most important were considered. To decide whether one theory should be included or not, the selection was performed late, after the timeline had been mapped. This was because, only theories that had a clear connection to another were chosen. For example, the normal accident theory and the HRO theory had a clear relation, since HRO was born out of the concept of normal accidents. The reason behind this choice was due to the strive for a clearer picture and to ease the reading, allowing the reader to comprehend why today's theories are the way they are, and how they have evolved. Furthermore, the interest for the concept of safety culture began to increase as a consequence of disasters that also shaped the HRO theory. Furthermore, safety culture are highly interrelated with leadership and teamwork qualities.

The timeline model sketch was helpful and facilitated the understanding concerning how, and from what origin today's theories and research have emerged. This further eased the understanding regarding what concepts and aspects that should be focused on.

Thanks to the time-line model, it was easier to decide what to include and what to exclude. Since the aim was to start with safety theories in the beginning of the 1900s, and end up with the most recent safety research theories concerning leadership and teamwork, the goal was to aim for a "straight line", or "common thread", and not to get carried away into too much unnecessary detailed and redundant information.

2.1.4 **Evaluation of conducted studies, concerning part 2**

When the literature that covered leadership and teamwork was searched for, the ambition was to try to find some empirical studies that significantly could argue for some success factors regarding the covered topic. The reason behind this strive for empirical studies was to substantiate the otherwise vague definitions of leadership and teamwork, and to present some concrete success factors that could be backed up with statistical evidence. The ambition with the evaluation concerning part 2, was therefore to try to triangulate the information obtained from non-empirical studies with the conclusions drawn from some empirical studies, to "back-up" the otherwise ambiguous information regarding different success factors.

Three different empirical studies were found that covered the topic of leadership and teamwork. However, the methods and mathematical models used in these studies were not further evaluated or analyzed.

2.1.5 **Real-world disasters**

The choice of including descriptive explanations of three real-world disasters was motivated by the ambition to try to arouse the readers' interest and engagement. The motive was further to present theory and models together with real-world experiences, to highlight the need for this thesis and to illustrate that the addressed thesis questions are highly topical.

The information concerning these disasters was mainly obtained through investigational reports conducted by external, independent sources. The motive behind this was to avoid biases.

The choice regarding which disasters to include and describe into detail, were mainly taken based on the information that was available.

2.1.6 **Ambiguous literature**

From the literature study, several terms showed up repeatedly in different literature. However, terms were named differently in different articles. An example of this was the term, *shared mental models* (SMMs) who was referred to as *team mental models* (TMMs) in one article. When this problem occurred, it was necessary to investigate whether the different authors meant the same thing, though under different names. This was done by reading those articles carefully and map the different definitions to see whether they could be considered to refer to the same thing.

An example of how this was done can be seen in Figure 9.

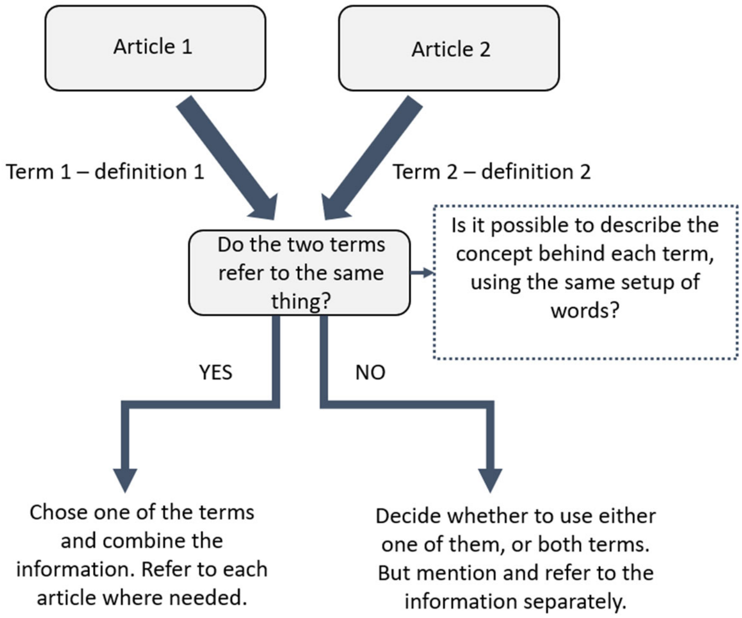

Figure 9 – Model that shows how ambiguous literature were evaluated (Thesis' author, 2020)

2.2 Interviews

The interviews were conducted via Skype and Zoom, which both are software programs appropriate for video calls, and suited well for the purpose.

2.2.1 Selection of the participating organizations

The foremost ambition with the interviews was to interview persons operating in leading positions within safety-critical systems. Therefore, informative e-mails were sent out to a total of seven different organizations, ranging from corporations within *infrastructure, nuclear power* to *healthcare*. Three answers were obtained, two leaders within the nuclear power industry and one leader with experience from hospital environments, admitted their participation. The low answering frequency might be explained due to the covid-19 pandemic and due that the e-mails were sent out late, close to the summer vacation, in June. The interviews were conducted with two of the three respondents, one leader from healthcare and one from nuclear power industry.

The organizations were chosen based on the criteria that the specific organization should have some departments that operated in safety-critical environments (i.e., a failure can result in for example, devastating property or environmental damage, or it can result in deaths).

To obtain the correct contact information, the informative e-mails were sent out to the organizations' receptionist or the HR-managers.

2.2.2 **Informative e-mails**

The informative e-mails contained background information regarding the purpose of the thesis and the goal with the interviews. The e-mails were sent out early in the process, before any theoretical knowledge had been acquired, therefore, the persons who first received the e-mails were only informed briefly about what type of interview questions that they could expect. Furthermore, the e-mails contained information regarding what necessary prerequisite and experience the interview subject should possess (a prerequisite that was mentioned was leadership experience, and knowledge about safety-critical operations). Additionally, it was asked for an approval if it was possible to record the conversation.

However, the definition of *a safety-critical operation* was not further defined in the e-mail.

2.2.3 **Interview structure**

The interviews followed a semi-structured form, allowing the participants to communicate their experiences more freely. The motive behind this choice of format was based on the assumption that the three interviewees assumed to have very different experiences, due to their different roles, gender, age and knowledge.

The interviews were conducted using the chronological structure described below.

A more detailed version of the questions is provided in the Appendix.

1. The interview started with a presentation of the interviewer. The participant was then informed more profoundly regarding the purpose and aim with the interview.
2. The participant was asked to present themselves, with focus on their current position and work, previous (leader) experiences and their view on leadership and teamwork.
3. The first interview questions included six questions regarding some theoretical knowledge about the topics of system-safety, leadership and teamwork. The interviewee was asked questions where the answer should be either *yes* or *no.* A short explanation around the answer containing only a few sentences was welcome. These short questions were supposed to

highlight the participant's specific knowledge about some important concept within the described topics.

4. After the shorter questions, the participant was asked questions taken from two themes, the first theme was *leadership*, and the second theme was *teamwork.*
5. The participant was then asked to describe their current work with focus on their leadership. The interviewer guided the participant and followed up their answers with subsequent questions. The aim was to comprehend how a "normal" day could look like and what challenges that are prevalent concerning teamwork and leadership within the specific organizational system.

During the interviews, the interviewer was cautious with not trying to "guide" the participant too much. In those cases where it was needed, the participant was asked to give real-life examples. The interviews were conducted in Swedish and were recorded. Some of the important terms were however presented both in English and Swedish, to ensure that the respondent had understood what was asked for.

During each interview, notices were written down during into the software program Word.

The recorded interviews were further transcribed, and the obtained information was analyzed in regard to the theory. The analyses were conducted in two steps. The first step was to summarize what the interviewees had said, and their answers to the specific interview questions. The second step was to compare the interview results with the theory, in order to see *if, how* and *why* the obtained interview results differed from the theories. The transcription was performed in Words.

During the interviews, this step had been in the interviewer's mind, so each of the interviews had been conducted in a way that allowed this step to be easily performed.

3 Results from the literature study

In this chapter, the result from the literature study is summarized.

The first subsection, 3.1, constitutes a historical "walk-through". In this section, the different theories that have dominated the progress of the today's safety research are emphasized and explained briefly. Several invaluable persons and their contribution to the field of human error, system safety and safety research are further mentioned.

In subsection 3.2, the definition of "system" is explained more profoundly, and the different components which constitute the majority of today's safety-critical systems are in focus. How people and teams interact and cooperate within these systems are further emphasized.

What types of qualities that individuals and teams need to possess in order to facilitate the achievement of goals and objectives in a safe way, are presented in chapter 3.3, together with other important factors.

In the last section, 3.4, the leadership is in focus. Important behavioral characteristics together with other crucial components that are necessary to facilitate the teamwork and creation of a good safety culture are further presented.

3.1 A historical background that has shaped the today's safety perspective

This chapter gives an important insight that explains the origin of today's safety research and safety science. After reading this chapter, the reader will hopefully have a better understanding and knowledge regarding how the most recent theories have emerged and evolved throughout the 1900s, and the first decade of 2000s.

In the first half of the 20th century, humans were mostly seen as the cause of accidents and safety trouble. Through safety interventions such as: aptitude testing, selection, rewards, reminders, punishments, and incentives, leaders (or *experts*, as they were called) tried to target and supervise the humans in order to control them (Dekker, 2019; Heinrich, 1931; Taylor, 1911).

In the second half of the 20th century, researchers began to explore the mechanisms *behind* accidents, and a more nuanced picture emerged. Many of the ideas and theories that came up to surface around the 1980s and afterwards, are still valid today, and safety interventions went from controlling human behaviors to target a more holistic perspective, including the study of organizational as well as sociological factors (Dekker, 2019; Uddin & Hossain, 2015). Furthermore, the increased interest for leadership and teamwork among researchers had begun to be more and more evident in the last decades of the 20th century.

3.1.1 **Taylorism, 1910s**

In the early 1900s, a man called Frederick Winslow Taylor, approached a problem concerning impaired production efficiency in slaughterhouses in a managemental way. In 1911, his human behavior analyzes from the slaughterhouses resulted in a book, *scientific management*. From this book, the term *Taylorism* was coined (Taylor, 1911).

Taylorism advocated a centralized organization, where each worker should be monitored and guided by a leader, or an expert as Taylor called them, with help from rules and procedures. Taylorism further emphasized that work should be divided into several subtasks, where each persons' working steps were in focus. Autonomy and own initiatives among the workers were undesirable, and there was only one correct way to perform a task. Furthermore, workers were seen as machines, and all their work should constantly and systematically be measured, tabulated and analyzed (Dekker, 2019; Taylor, 1911).

3.1.2 **Linear accident models and behaviorism, 1930s**

Herbert William Heinrich was an American engineer active in the insurance industry in the early 1900s, where he worked with insurance questions concerning railway workers (Dekker, 2019).

Heinrich became the first known safety researcher as he released his book *Industrial Accident Prevention, A Scientific Approach* in 1931. In his book, Heinrich had investigated insurance cases concerning railway workers, and he described the analyzed accidents as a completed *linear* sequence of events, where the last one being the accidents itself. The cause behind accidents were further explained by an *unsafe act*, a *mechanical hazard* or a *physical hazard* (Heinrich, 1931). He used an analogy of falling dominos to describe accidents, a phenomenon that later was named the "domino theory" (Oosthuizen & Pretorius, 2016).

Heinrich presented safety measures that was to control behavior. According to Heinrich's theories, safety measures to prevent accidents would be to *control behavior* to *prevent unsafe acts*, and to *report* and *eliminate* incidents (Hollnagel, 2012). To focus on changing the peoples' behavior, rather than the environment itself, is further something that constitutes the psychology field of *Behaviorism,* which characterized that time's view on how to better understand accidents (Larish et al., 1989).

3.1.3 **Human factors and the first cognitive revolution, 1940s**

After incidents with bomber planes at the end of the second World War (WW2), researchers began to explore and investigate the working environment in the bomber planes. The reason behind the researchers' enthusiasm, was the numerous destroyed planes, in which the pilots accidently retracted the landing gear when the plane was standing still, right after a landing. As a consequence, the propeller hit the ground and destroyed the engine, which left the plane useless. Even though personnel suffered no harm, the problem had left commanders furious since the problem resulted in an enormous loss of both financial and material resources (Dekker, 2019; Larish et al., 1989). Commanders had tried everything, from checklist, training and discipline and pilot dismissal, simply in accordance with the behavioristic approaches, but to blame the pilots and try to control their behavior had no effect (Hollnagel, 2004).

Researchers' asked themselves how this problem could occur again and again, even though several countermeasures had been taken. The researchers identified a problem with the levers that controlled the landing gear and the flaps. These levers had been placed close to each other in the cock pit, and the two levers both felt and looked the same. The pilots, therefore, repeatedly took the wrong lever by mistake. The term "human factor" was born, as more researchers began to examine human-machine interaction, the working environment and the human cognition more profoundly (Dekker, 2019).

The focus shifted from the behavioristic approach, where behaviors was to be controlled, to instead focus on controlling the organizational and technological attributes, as well as the working environment, a shift in focus, that is referred to as *the first cognitive revolution*. (Dekker, 2019).

3.1.4 **System safety theory, 1960s**

After the plane incidents in the WW2, increasingly large and safety-critical systems were built and put into operation, for example nuclear missiles and power plants. It was no longer suitable to let failures show up during testing, since a failure would lead to devastating consequences. Rather, safety measures should be built in from the beginning (recall the barrier perspective which was described in section 1.1.3) not just added to the completed design.

The view on safety as something that has to do with a *design problem,* was variously known as the field of *system safety,* which in turn relied on the definition of *safety* as*: the absence of unwanted events* (Smith, 2017). However, as will be seen in later sections, this definition can vary and have been modified since then. Accidents further occurs due to design flaws, or faulty requirements and specifications. To prevent accidents from happening, according to that time's theory of system safety, their potential cause must be managed. This further insinuates that accidents can be prevented by identifying their hazards (Dekker, 2019).

From the field of system safety, several engineering approaches emerged. For example, methods such as *Fault Tree Analysis* or the widely used equation for *risk*, which states that risk is the product of probability (likelihood) and consequences (example, number of fatalities). These types of mathematical approaches are widely used today by safety engineers, to calculate risks and prevent accidents, but will not be discussed further in detail in this thesis.

3.1.5 **Man-made disasters, 1970s**

In the 1970's, the complexity of safety-critical systems was evident. Several large disasters and near-accidents, such as the Tenerife collision between two Boeing 747 in 1977 which killed 583 people (Nuclear Regulatory Commission, 2018), and the Three Mile Island nuclear power plant accident in Harrisburg, USA 1978 (Dekker, 2019), had again highlighted the need for a more profound understanding of accidents and system safety. It became apparent that it was not advantageous to only rely on mathematical analyses methods.

In contrast to the theories that emerged in the beginning of the 20th century, where accidents had been seen as an engineering problem, accidents were now increasingly understood as social and organizational phenomena (Turner, 1978).

Barry Turner, who was a sociologist, said that accidents are only a *symptom* of a long-lasting *incubation period,* where the cause of the accident was rooted far before the accident's outbreak, recall *latent conditions* in section 1.1.3. Accidents do not appear out of the blue as a consequence of a simplified model of an unsafe-act or a mechanical hazard. Turner further explained in his book *Man-Made Disasters* from 1978, that accidents are not technical, but rather *social* and *organizational*. He further emphasized the importance of *organizational cognition*, rather than individual cognition which had been in focus during the first cognitive revolution in the 1940s and 1950s (Dekker, 2019; The House Committee on Transportation and Infrastructure, 2020).

Furthermore, in contrast to the engineering approaches in the 60s, which stated that the prevention of accidents can be accomplished through effective barriers, Turner (1978) saw a problem with the increasing number of safety measures. This can best be visualized with the example of the Boeing 737 MAX crash, where MCAS can be seen as a barrier (see section 1.2.3), a barrier that itself was one of the causes behind the accident (Reason, 1997).

3.1.6 **Normal accidents and high-reliability organizations, 1980s**

After the Three Mile Island accident 1979, Charles Perrow, a professor in sociology, studied the investigation report and was not satisfied when he figured out that the blame had been put on the operators.

According to Perrow, a *tight coupled system* (recall what was said in section 1.4.1) requires *centralization*, meaning that personnel are told what to do, and have to rely on hierarchical decision-making. However, for a *complex system* be fully controlled, Perrow implied that the leadership would have to be *decentralized*. The conclusion he drew from this was that both *complex* and *tight coupled systems* (in the top, right corner in Figure 1) is impossible to control, since these systems require to be decentralized and centralized simultaneously (Perrow, 1984; Rosness et al., 2004).

Accidents in these kinds of systems are thereby inevitable, no matter how the system is organized (Rosness et al., 2004). In 1984, Charles Perrow therefore proposed that these accidents should be considered as *normal*, and the more barriers, the more complexity, which results in even less understanding of the system's functionality and dynamics (Roberts, 1986).

As a response to the dilemma regarding the decentralization and centralization previously described, a group of researchers from the University of California, called the Berkeley group, announced the term *high reliability organizations* (HRO) in the late 80s (Roberts, 1990). These organizations had interesting characteristics, which allowed the organization to withstand hazards and accidents, even though they were constantly prone to suffer from these (Grabowski & Roberts, 2019; Harvey et al., 2019; Roberts, 1986, 1990). HRO theory emanated from a prevention perspective, which focused on questions such as, *what are going right,* rather than focusing on what had gone wrong (Dekker, 2019; Harvey et al., 2019; Roberts, 1990). According to HRO, accidents are caused by a casual chain of errors, so accidents can thereby be avoided or detected by paying attention to cues in the present (Dekker, 2019; Pruchnicki, 2014).

Several organizational characteristics in HRO have been presented by the Berkeley group. Flexibility and redundancy allow the organization to quickly recover from errors with the usage of backups, cross-checks, along with the ability to adjust the organization's decision hierarchies. The adjustment of the decision-making processes, means that it shifts from a *centralized* structure to a more *decentralized* formation, allowing personnel with the most experience or information at hand, to take adequate actions in critical situations, without having to double check with their managers (Roberts, 1990). The usage of multiple channel communication further allows the organization to be up to date with the latest information and enables the creation of cohesion among the personnel (Dekker, 2019; Salas et al., 2020; Vecchio-Sadus, 2006).

3.1.7 **Safety culture, 1990s**

As was described in the previous section, a more nuanced safety perspective had begun to consider accidents in administrative, managerial, organizational, or even *cultural terms* (Oedewald et al., 2007).

A result from researchers' substantial efforts during the late 1900s, together with many of the disasters from the 1970s and 1980s (e.g., Chernobyl, Three Mile Island, Piper Alpha), gave organizations something positive to aim for: *Safety culture.* The reasons behind this was the organization's harmful attitudes towards safety and regulations, which had been highlighted after the Chernobyl catastrophe in 1986 (Dekker, 2019).

The definition of safety culture is yet not evident, and mainly two separate perspectives have dominated the today's view on safety culture. Those perspectives are the *functionalist approach* and the *interpretivist approach* (see Figure 10). The main difference can be seen in the Figure 10. The functionalistic approach implies that safety culture can be enhanced by interventions, that for example focus on the commitment, motivation, and social stability among the organization's members. The interpretivist approach however insinuates that the ability to control safety culture is far more limited (Dekker, 2019).

Overall, safety culture can be said to consist of shared values, norms, beliefs, attitudes, and perspectives among an organization's members regarding safety (Jilcha & Kitaw, 2016; Oedewald et al., 2007; Reason, 1997). The culture is further created as members of the organization repeatedly behave and communicate in an unquestioned way and is further highly related to the commitment to safety of the management and leaders (Harvey et al., 2019).

An example of when safety culture is important is in HROs, where the free working climate allows personnel to freely communicate, allowing the organization to stay informed (Flin & Yule, 2004). Further factors that constitute a good safety culture is: high level of participation regarding incidents' reporting, non-risk taking behaviors among personnel, open climate where personnel feel free to communicate, and compliance with stablished rules and procedures (Harvey et al., 2019).

An

The Interpretivist and Functionalist Views of Safety Culture

Interpretivist View	Functionalist View
At home in culture studies, like sociology, anthropology	At home in management studies, organizational psychology, engineering
Sees culture as something an organization *does*	Sees culture as something an organization *has*
Culture is complex and emerges from interactions *between* people	Culture can be reduced to the attitudes and behaviors *of individual* people
Culture can only be influenced, by what people anywhere in it do and how that interacts with others	Culture can be controlled. It can be imposed, changed, taken away, replaced, typically from the top-down
Studies culture with qualitative methods such as observations, interviews, discussions, document study	Studies culture with quantitative methods such as surveys, measurements, questionnaires
Takes the 'emic' or inside-out perspective	Takes the 'etic' or outside-in perspective
Assumes a diversity of perspectives and ideas about safety	Assumes a homogeneity of views and attitudes ('vision zero,' 'safety first')
Leads to little other than more studying of culture	Leads to safety campaigns, behavior modification programs, posters
Typically accused of being non-pragmatic, no control over culture	Typically accused of being overly pragmatic, myth of control

Figure 10 - The differences between the interpretivist and the functionalist view on safety culture (Dekker, 2019, p. 361)

3.1.8 Resilience engineering, 2000s and onward

A rather new approach that have emerged during the last decade are *resilience engineering (RE),* which have emerged from the earlier described safety science approaches in a response to an increased organizational complexity (Grabowski & Roberts, 2019). Resilience is a term that describes an organization's ability to respond properly to surprising and disruptive events, and a resilient organization tend to embrace an adaptive approach during crises, in order to ensure a continuous operation. Resilient organizations have further the ability to quickly recover from catastrophic events (Grabowski & Roberts, 2019; Rosness et al., 2004).

The motivation for this new approach lays in the fact that in today's complex systems, it is impossible to write all the necessary rules and procedures, and it is impossible to foresee all possible risk scenarios. RE further insinuates that the usage of more and more safety barriers will not make an organization safer; it might even do the opposite (Harvey et al., 2019). Instead, RE implies that *safety* lies in the *capacity* of people, teams and organizations. The focus is *not* to trying to stop things from going wrong (called Safety-I), rather, an organization should try to understand why thing go right (called Safety-II) (Grabowski & Roberts, 2019; Harvey et al., 2019; Rasmussen, 1997). It is the peoples' adaptive capacity, that is the ability to recognize, absorb and adapt to changes and disruptions, even though this falls outside the organization's comfort zone, in which it normally operates in, that are an essential component in resilience engineering and constitutes safety, or *safety-II* (Grabowski & Roberts, 2019; Righi & Saurin, 2015; Zaccaro et al., 2012).

RE means that accidents emerge from a pressure within an organization. This pressure, which is due to necessary adaptions made to cope with internal or external forces (e.g., unreasonable production efficiency goals or budgets, recall the model in Figure 4) causes a change in the organization's perception and causes a "drift into failure", if the drift is unnoticeable. As a result, with time, even actions that are considered as "normal", can cause accidents (Thompson, 2003). Therefore, RE also insinuates that organizations must focus on everyday normal activities and operations.

A summarization of the all the explained theories, and from what approximate decade they emerged can be seen in Figure 11.

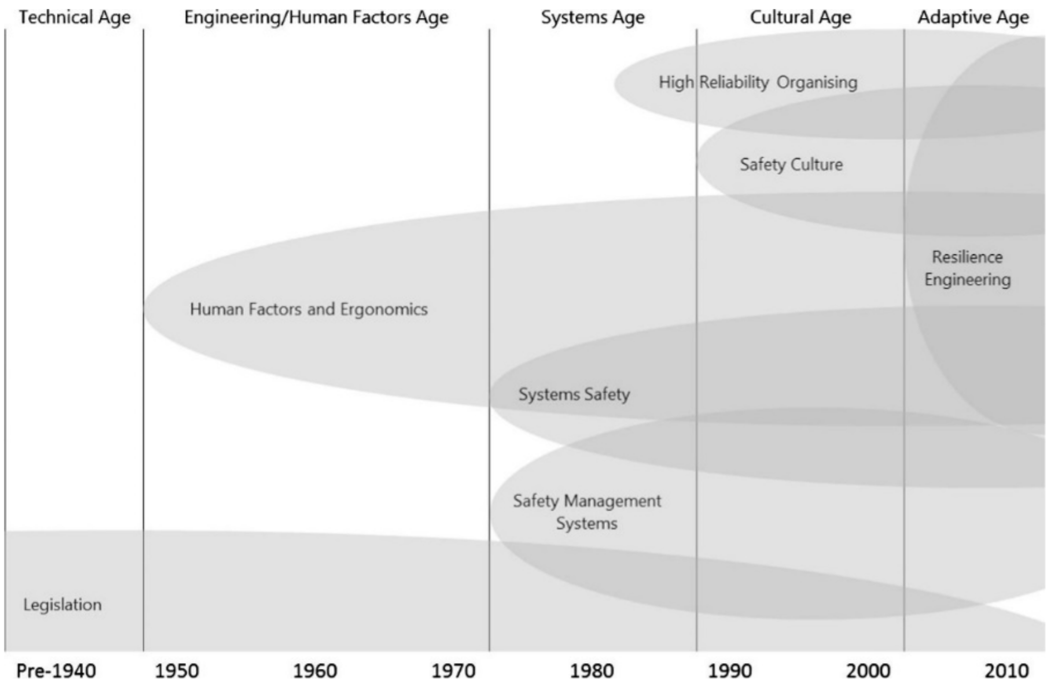

Figure 11 - A timeline illustrating the ages of different safety theories (Harvey et al., 2019, p. 4)

3.2 What is a system?

After this historical review, it is now time to define the today's *system* more profoundly. The definition of a *safety-critical* system has previously been described, so let us focus on the definition of the *system* alone.

First of all, the term *system* can be described in several ways. There are numerous variations of systems, all of which in turn have even more specific definitions among researchers (Beer, 1964). In this thesis, the two terms *system* and *organization* are used interchangeably. When one of these terms are used alone, regardless of which one, the definition is still the same, that is: A system/organization is the deliberate arrangement of parts and actors (e.g., technology, people, functions, subsystems) that are all necessary in order to achieve specified and required goals (Beer, 1964; Rasmussen, 1997).

However, in the context of this thesis, the term system refers to the more explicit definition of a certain safety-critical system, namely a *socio-technical* system, where the different actors, can be either human, technical, or organizational (Carayon, 2006; Wilson, 2000).

Within socio-technical systems, social humans use their cognitive skills (for example to think, communicate, read, learn, remember, and pay attention), to make sense of situations when making decisions (Carayon, 2006; Perrow, 1984; Wilson, 2000). The interactions occur between humans and different technical systems (See Figure 12) (Wilson, 2000).

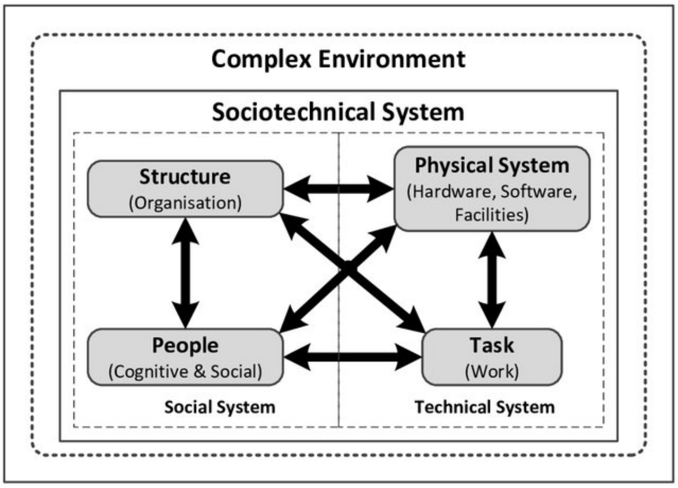

Figure 12 - Model of a socio-technical system (Oosthuizen & Pretorius, 2016, p. 17)

Additionally, the definition of complexity is not trivial. But as have been described in the introduction, the complexity can be seen as something that is related to uncertainties, that is, it is hard to predict what is going to happened, and the outcomes given a certain action is not evident, due to the numerous interactions that prevail (Wilson, 2000). These interactions types will be further discussed in the next section.

3.2.1 **Various types of interactions within today's complex, socio-technical systems**

As was mentioned in the previous section, various interactive patterns exist within the socio-technical context. In Figure 13, these interactions can be seen to comprise peoples' interaction with hardware, software, other humans and organizational components (Wilson, 2000; Zaccaro et al., 2012)

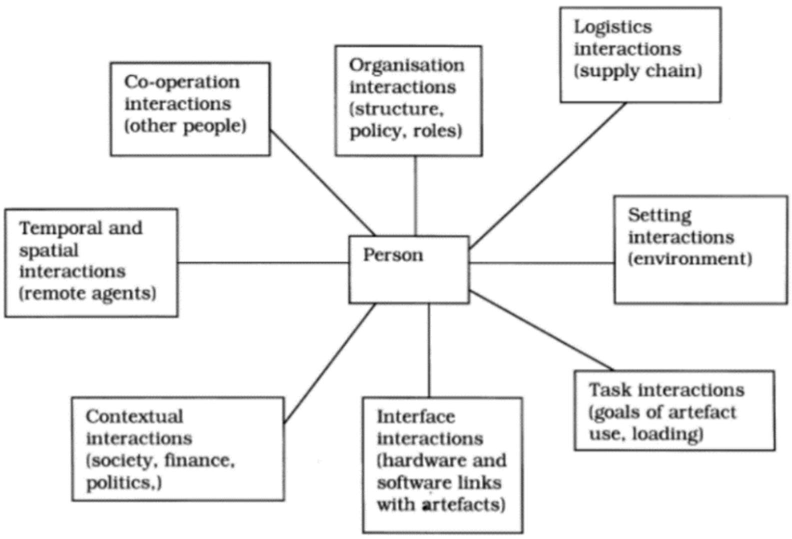

Figure 13 -A model that shows different interaction types in a socio-technical system (Wilson, 2000, p. 565)

In contrast to Heinrich's theory of linear, sequential interactions, the structures of todays' systems are significantly more intricate. The outcomes from interactive actions do not follow predefined, straight patterns, which also complicates the strategic usage of the Swiss-cheese model (recall Figure 3). Wilson (2000) visualize this dynamical and complex interactive structures of today's systems with help from Figure 14, where individuals and different teams are included, as well as technical components.

The model in Figure 14 facilitates the explanation of the different type of interactive components within the socio-technical context. The model shows how two different components, team A and team B, operate and interact with each other and its surroundings. Team A can be thought of as a team consisting of several operators and one supervisor, a network in which all of the components (different people with different backgrounds) interact with each other, as well as working with different technical systems (Computer System 1 in Figure 14). The people included in team A could for example all be members of an operating group working at a nuclear power plant, or any other grouping with a common purpose and interest, for example a surgical team stationed in a hospital (J. Mathieu et al., 2001).

The team A can further be seen as one unity, operating at one specific time, in one specific time zoon, Time 1 (see Figure 14). Team A is interacting with team B, both directly and through the computer system 2 (Computer System 2 in Figure 14) (Wilson, 2000).

Because of different geographical locations, team B is operating in a different time zone compared to team A, that is Time 2 (see Figure 14) (Salas et al., 2005; Shuffler & Carter, 2018)(Shuffler & Carter, 2018; van Asselt & Renn, 2011; Zaccaro et al., 2012)

Remote agents could also be a part of this socio-technical system. The remote agents are components consisting of people who works at locations outside the physical domain of the main team (for example train drivers or site engineers). The operators A_n (see Figure 14) can interact with different agents via a computer system 3. These agents rely on mobile communication and on-site information, as well as communications via the Computer System 3 (Shuffler & Carter, 2018). Agents, or teams that interact with each other from distance, without direct face-to-face communication, is referred to as *virtual teams* (Gibson & Cohen, 2003). This is however a term that will not be further discussed in this thesis.

Furthermore, contrary to Taylor's idea that there is only one right way to conduct a task, in today's system, so is not the case. As can be seen in Figure 14, the numerous interactive pathways form a network, in which actors are allowed to operate in several ways, hence allowing the different teams to accomplish the same task in completely different ways. The complex systems in today's society are by their nature ambiguous, meaning that there is no "right" way to address a given task or challenge, which highlight the importance for a structured and systematic framework for how to cope with these uncertainties (Shuffler & Carter, 2018).

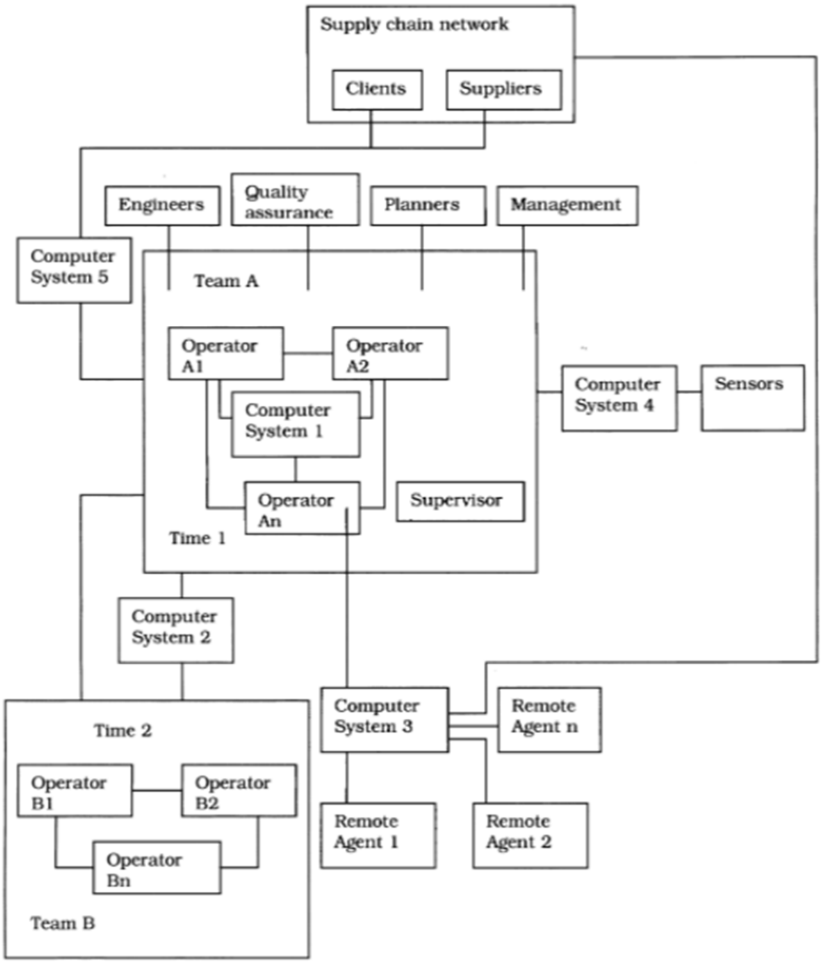

Figure 14 - Model of a complex, socio-technical system (Wilson, 2000, p. 564)

As can be noticed, these types of systems can quickly become even more complex, by for example adding even more teams or more communicative elements between the teams (Shuffler & Carter, 2018). To manage the collaboration and interactions between and within the teams in this ambiguous and complex environment, the teamwork and the leadership must function. To facilitate the teamwork, a leader can promote *coordination control mechanisms* that is composed of *routines*, *meetings*, *plans*, *schedules*, *rules* and *communications*. These mechanisms should describe *how* team members should interact with one other (Fernandez et al., 2017; Kumar Biswal & Naidu, 2019; Shuffler & Carter, 2018). Further important mechanisms that are necessary for a well-functioning teamwork and leadership will be presented later.

3.2.2 **Multi-team systems**

As was noticed in Figure 14, the socio-technical system consists of several teams, which in turn also includes human-, organizational-, as well as technological components. Furthermore, as have been discussed in the introduction, there is a big need for diverse expertise and competence in today's safety-critical organizations. As a result, socio-technical systems often consist of several, highly specialized teams, called *component teams* (see Figure 15)*,* that collaborate and work together with other teams, which members are in turn specialized in some other working field, for example team A and team B in Figure 14 (Murase et al., 2014).

Two or more teams that interact directly or independently to achieve collective goals in this way, are named *a multi-team system (MTS)* (Salas et al., 1992). This constellation is often indispensable when organizations want to achieve certain goals where uncertainty, complexity and ambiguity prevail, and where the tasks require diverse expertise (Salas et al., 2005; Shuffler & Carter, 2018). The fulfillment of common MTS goals can further be indirect accomplished by the different component teams' achievement of their respective assigned subgoals (Salas et al., 2005; Shuffler & Carter, 2018).

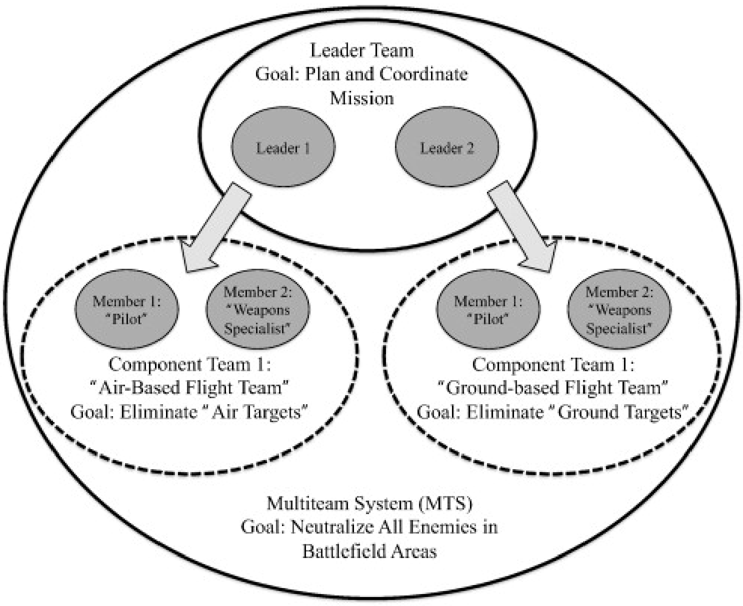

Figure 15 - A model showing the MTS structure (Murase et al., 2014, p. 976)

However, the unique situation where several teams collaborate across time and space put great demands for collaboration and a well-coordinated working climate (Shuffler & Carter, 2018). MTSs often struggle to achieve superordinate, common MTS goals due to these challenges. The importance of collaboration and coordination is further emphasized by Shuffler and Carter (2018) by an example with the loss of the Mars Climate Orbiter satellite in 1999. Luckily, there were no fatalities, but the destruction of the satellite was calculated to a total financial loss of 500 million dollars (Kumar Biswal & Naidu, 2019).

The cause behind the destruction of Mars Climate Orbiter satellite can be described as rather trifling events, where the lack of adequate teamwork and leadership eventually caused the failure (Shuffler & Carter, 2018). The members of the MTS, working with Orbiter included three component teams, a *systems development team* which created equipment and software, an *operations team* which oversaw the launch and flight of the Orbit once in space, and a *project management team* which was providing leadership. These three teams worked against one common MTS goal, to launch the Orbiter in order to better understand the climate and surface characteristics of the planet Mars (DeChurch et al., 2011; Shuffler & Carter, 2018).

The orbiter was successfully built and launched; the three components teams all accomplished their subgoals. However, major issues arose between the teams, which affected their common goal. Problems with coordination, communication and management between the system development team, and the operating team occurred. The system development which was based in the U.S, relied on the measurement unit *miles.* The operating team on the other hand, relied on the metric units (eg., *meters*) when they monitored the Orbiter in space. Further, these teams had a hard time to comprehend the others' roles, and there was a lack of adequate mechanisms to coordinate, monitor and troubleshot the Orbit once the problem was identified. These failings eventually brought the Mars Climate Orbiter too close to the upper atmosphere of the planet which caused its destruction and the devastating financial loss (Kumar Biswal & Naidu, 2019).

According to Shuffler and Carter (2018), some of the contributing factors resulting in the failure of the MTS to achieve the common goal, was inadequate communication between the teams (inter-communication), inadequate training within, and between the teams (intra-and inter-team training), as well as inadequate inter-team coordination (coordination between the different teams) (Murase et al., 2014).

Since a task can be accomplished in several ways within an MTS, it is up to the leader to encourage adequate teamwork, within and between teams, which is necessary in order to achieve the common goal in a satisfactory and safe way. The important characteristics and factors concerning adequate teamwork and leadership will be further discussed in the following sections below.

Hereafter, when the term *MTS(s)*, is mentioned alone, this refers to a socio-technical multiteam system. And when *safety-critical MTS* is mentioned, it is assumed that the system also constitutes components from a socio-technical system, that is, equivalent to a *safety-critical socio-technical multiteam system.*

3.3 Team and teamwork

A team can be defined as a group of two or more individuals, that in an adaptive, dynamic, and interdependent manner, interact to achieve *common* goals (Shuffler & Carter, 2018). The definition of team must be distinguished from a *group*, where the latter consist of individuals who coordinate their own, *separate* goals (Zoltan, 2015).

Teams have the potential to offer greater adaptability, creativity and productivity than individuals working alone (Salas et al., 1992, 2005). The failures in teams can however have far-reaching effects, especially in safety-critical MTSs, some of which consequences have been described in earlier sections. The teams' failure can result from factors such as poor planning, lack of communication and lack of adequate leadership, as well as poor training (Shuffler & Carter, 2018).

However, in MTSs, the definition of teamwork must be extended from interactions *within* a team, to interactions *between* teams. As for an example, not only collaborations between people within the team A in figure 7, but also collaboration between different teams, that is, between team A and team B in figure 7, or between the system development team and operating team in the example with the Mars Orbiter.

This broader definition of teamwork further highlights the need for a more profound understanding on how different factors affect the single team as well as the system as a whole. Something that pushes a single team (example team A in figure 14) in the right direction toward the fulfillment of a certain subgoal, may have the opposite result on the overall system, that is, it pulls apart other functioning teams (team B in figure 14) and hinder them from achieving their subgoals, which in turn negatively impact the achievement of the common, MTS goal (Salas et al., 2005).

Therefore, it is equally important to understand the functioning of teamwork *between* teams as well as *within* teams, and how teamwork should be implemented in safety-critical MTSs to enable effective and safe completions of common tasks, and the fulfillments of common goals (Mathieu et al., 2000; Shuffler & Carter, 2018).

For instance, building strong teams is advantageous and taken for granted to be one of the key components when focusing on single team systems. But in MTSs, one should be careful to focus solely on this. Since several teams collaborate in MTSs, there is a need to build a strong cohesion between the teams. Otherwise, it can result in inter-teams' conflicts and competition (Salas et al., 1992, 2005; Shuffler & Carter, 2018).

DeChurch et al., (2011) describes that a positive cohesion can create a sense of belonging among the members of the MTS, which in turn can ensure effective teams and their well-functioning. However, it is important to ensure a balance between the differences in opinions and perspectives across MTSs. Some disparities are advantageous. To attempt to merge all different teams into one bigger team, with one shared identity and goal is not effective. This tends to lead to personnel losing their motivation due to the absence of a clear vision, and a feeling that their contributions are not identifiable (Dekker, 2019). Furthermore, a leader should be observant on the different teams' endeavors towards their own subgoals. Teams that only focus on their own subgoals, might forget the shared MTS goal, which can impair the teams' capacity to engage in necessary MTS activities (Dekker, 2019; Mathieu et al., 2000).

To concretize what factors or activities that are the most important for teamwork success is not trivial. There are numerous explanatory models presented by equally as many authors, who all try to define the key factors and key concepts behind a successful and effective teamwork (Mathieu et al., 2000). However, Salas et al., (2005) have identified five core components that are required to complete a task effectively, that is: ***(1) leadership*, *(2) mutual performance monitoring***, ***(3) backup behavior***, ***(4) adaptability***, and ***(5) team orientation***. Schipper (2017) further describes that these components are all essential in MTS settings.

Beside these five core elements, which is a part of the "Big Five" framework for teamwork, Salas et al., (2005) further mention three coordinating mechanisms. The coordinating mechanisms are: ***(1) Shared mental models (SMM), (2) closed-loop communication*** and ***(3) mutual trust***.

In contrast to the previously described *coordination control mechanisms*, which Shuffler and Carter (2018) describe as mechanisms that concretize *how* team members should interact with each other, the function of Salas et al., (2005) *coordinating mechanism*s is to *ensure* that relevant information is distributed throughout the teams, which should be used in combination with the "Big Five" framework to ensure a successful teamwork.

The coordinating mechanisms and the five core concepts of teamwork success is described more in detail in following sections below.

Safety leadership, which is an essential part for effective and safe teamwork, is also mentioned in this section, but are described more in detail in section 3.4.

But first, team effectiveness and the definition of a successful team will be described.

3.3.1 **Team effectiveness and successful teams**

According to Salas et al. (1992), the success of a team is dependent on the teamwork, including both inter, and intra collaborations (Mathieu et al., 2000). Salas et al. (1992) further distinguish *team performance* from *team effectiveness*, where the former only focus on completion of the task, regardless of how the team accomplished the tasks. The latter, team effectiveness, on the other hand, takes the different interactions into account, and consider *how* the team interacted to achieve the task. Team effectiveness is a more holistic approach which is a necessary component to analyze in safety-critical MTSs, since factors external to the team may contribute to the failure of the team, and faulty behaviors may result in negative outcomes even though the goal was accomplished (Mathieu et al., 2000; Salas et al., 1992).

The creation of a team by simply putting skilled persons together does not ensure successful teams. In fact, many teams never reach their full potential, while others fail, causing devastating outcomes (Mathieu et al., 2000).

To achieve common goals effectively and successfully, that is, achieving the set of goals in a safe and efficient way by spending the least amount of energy and time needed, each team member needs to have a profound understanding of the other team members' knowledge, skill and expertise, in order to better understand other's behaviors and facilitate the communication. This is valid within teams, as well as between teams (Salas et al., 1992, 2005; Shuffler & Carter, 2018).

Furthermore, each individual must have a clear understanding of everyone's role and the resource available. In addition, there has to be a mutual trust within the MTS to freely communicate, within and between the teams, something that has been described as an essential component in HROs and resilient organizations, as well as an essential part that constitutes a good safety culture (Salas et al., 2020). An example of what can happen when the communication fails, can be seen in the failure of the Mars Climate Orbiter project, Boeing 737 MAX crashes, as well as in the Piper Alpha disaster (Entin & Serfaty, 1999; Salas et al., 1992).

3.3.2 **Coordinating mechanisms**

The main function with the coordinating mechanisms have been described earlier to be: *to ensure that relevant information is distributed throughout the teams* (Entin & Serfaty, 1999; Mathieu et al., 2000).

In stressful situations, when communication is hindered, the importance of coordinating mechanisms is evident, since teams must rely on implicit coordination rather than explicit communication (Cannon-Bowers et al., 1993; Fernandez et al., 2017; Mathieu et al., 2000).

The three coordinating mechanisms are described below.

3.3.2.1 Mechanism 1, mental models

Mental models can be said to serve three critical purposes: They help people to *describe*, *explain* and *predict* events in their surroundings. Mental models are further organized knowledge that individuals can use to facilitate and enable a satisfactory interaction with their environment (Fernandez et al., 2017; Mathieu et al., 2000).

Mental models can be described as a framework for thinking, which enable people to make adequate decisions even though the prevailing conditions are unfavorable (Salas et al., 2020).

3.3.2.1.1 Shared mental models

As been described earlier, in safety-critical MTSs, a team's members need to be able to predict what their colleagues are going to do next, and what type of resources that are needed in order for them to accomplish this (Mathieu et al., 2000). The shared mental model (SMM) theory offers an explanation behind the different underlying mechanisms which allows teams in MTSs to adjust strategies quickly and efficiently (Fernandez et al., 2017; Mathieu et al., 2000).

SMMs are essential for effective coordination and teamwork and includes a shared understanding of common goals and each member's role, something that was missing between the teams launching the Mars Climate Orbiter (Cannon-Bowers et al., 1993; Fernandez et al., 2017; Salas et al., 2005). Furthermore, it includes the team's common cognitive representation of the environment, and how to tackle problems that occur. Inconsistencies in mental models within and between teams in safety-critical MTSs can lead to confusion and devastating consequences as a result from poor coordination, leading to disasters (Fernandez et al., 2017).

The benefit that comes from SMMs includes quicker adaptions to sudden environmental alterations and to respond more efficiently, which is of great importance in stressful situations (Salas et al., 2005). SMM becomes crucial in environments where communication is difficult, since the ability to discuss the team's next move is restricted as a consequence of excessive workload, time pressure or some other environmental factors (Mathieu et al., 2000). In these cases, SMMs can act as a knowledge basis, which allows members act on their own and still be able to predict how actions affect their team members and their responses (Salas et al., 2005, 2020).

3.3.2.1.2 Different mental models

As have been described in earlier sections, teams within a socio-technical system interact with technology, as well as with other team members, teams and organizational components. This means that team members within a socio-technical system use several mental models simultaneously (see Table 3) in order to understand different aspects of the system (Salas et al., 1992; Yukl, 2008).

First of all, all team members must understand the functioning of the technology and the physical equipment that they are interacting with. The first mental model can therefore be referred to as the *Equipment Model*, which describes how personnel interact with dynamic controls within the MTS, and how personnel must understand the system's response to other team members input (Salas et al., 1992, 2020). A deficient equipment mental model was seen in the example with the Boeing 737 MAX crashes.

The second mental model, something that Mathieu et al., (2000) refers to as the *Task Model,* which describes terms, procedures or strategies regarding how the task should be accomplished (Salas et al., 2005).

The third model, the *Team Interaction Model,* describes how each team member must hold shared conceptions regarding how the team interacts (within and between teams). These mental models contain information about the different roles, responsibilities, interaction patterns, information flow and communication, as well as available resources (Salas et al., 2020). Inadequate team interaction mental models might have been one of the causes behind the Piper Alpha disaster.

The last model which the team members must share is the *Team Member Model*. These mental models contain information about each team member and their specific knowledge, skills, attitudes, preferences, strengths, weaknesses and so forth. These models are crucial for team effectiveness since they allow personnel to tailor their behavior in accordance with the expected behavior of their colleagues. How automatic and efficient this process can be are further constrained by the team members' knowledge about each other. The more profoundly and accurate the information that each team member have about the others, the more efficient and automatic the process will be (Salas et al., 2005, 2020; Shuffler & Carter, 2018). The destruction of the Mars Climate Orbiter can probably be explained by the faulty team member models.

All of these four mental models (see Table 3) are extra crucial in tasks that require high-level interactional teamwork, and interdependencies between team members. Additionally, these models are helpful in highly complex tasks that require specialized knowledge (Cole, 2000; Righi & Saurin, 2015). Furthermore, similar to what have been described earlier with the ineffectiveness of having one big team with a shared common goal instead of having different sub teams in MTS, it is not beneficial for all team members to have completely identical mental models. Large overlap between the different team member's mental models create redundancy, something that is inappropriate in situations which requires high-level of distributed expertise, for example in healthcare teams (Salas et al., 2005). An exact replication of each other's mental models would reduce the availability of alternative solutions and strategies (Murase et al., 2014).

Table 3 - Description of the different mental models, (Fernandez et al., 2017, p. 15)

Type of Mental Model	Definition	Example of knowledge content
Equipment model	Shared knowledge about the equipment and technology used or available to the team	Availability of cardiac catheterization after routine hours
Task model	Shared, organized knowledge about how a task is accomplished in terms of existing protocols, necessary team member skills, procedures, and likely contingencies	Checklist for procedural sedation
Team member model	Shared information specific to the team's membership, including individual team member's skills, attitudes, strengths, weaknesses, and preferences	Understanding limited knowledge/skills of trainees
Team interaction model	Shared conceptions of how the team interacts and which teamwork behaviors are appropriate and effective – includes roles and responsibilities of team members, role interdependencies, and information flow/communication channels	Standard role assignment during a cardiac arrest resuscitation

Yet another mental model that can serve as an extension to the team interaction model, is essential in MTSs. This model is called *multiteam interaction model,* which focus more on activities between-team, instead of activities and interaction within teams that are in focus in the third model (Murase et al., 2014).

3.3.2.2 Mechanism 2, closed-loop communication

Communication can be defined as the exchange of information between two or more individuals, irrespective of the medium (McIntyre & Salas, 1995; Salas & Cannon-Bowers, 2000). In MTSs, the communication can for example take place by using e-mails, telephones, physical meetings or other communicative IT-systems (Salas et al., 2005).

According to Salas et al., (2005), the communication is essential in order for the mental models, and thus the SMMs, to be continuously updated. The purpose with adequate functioning SMMs has further been described in previous section as an essential part that allow teams to take actions towards the achievement of shared goals (Cole, 2000; Shuffler & Carter, 2018).

In safety-critical MTSs where complex, interdependent interactions prevail, the need for adequate communication is especially important. To facilitate the communication in safety-critical MTSs, it is therefore crucial that the teams have developed SMMs (Salas et al., 2005). Communication and the enhancement of SMMs therefore go hand in hand.

As been described in previous sections, the lack of adequate communication, that is the information is not received or not fully understood, can severely impact the outcomes in a safety-critical system (Salas et al., 2005).

As have been demonstrated through the historical, catastrophic examples in this thesis, communication can fail, and there are often several reasons to why this happens. For example, the geographical distribution among the teams in a MTS, can lead to misinterpretations as a result of differences in the spoken languages, and even though people receive the same type of message, they can interpret the information differently due to differences in perspectives, as well as biases (recall the Mars Climate Orbiter accident) (Shuffler & Carter, 2018; Whitmeyer & Wilcutt, 2013).

Furthermore, stressful environments may lead to team members only focusing on their own subtask or subgoals and forget how their actions affect other team members or teams, something that again was one of the causes behind the accident of the Mars Climate Orbiter and the disaster of Piper Alpha (Salas et al., 2005).

Several authors have provided different theories and models throughout the years, in order to try to provide the best recipe on how teams should communicate. Studying numerous articles on the subject, Salas et al., (2005) concluded that the best way is *closed-loop communication*, which guaranties an effective information exchange (Salas et al., 2005).

Closed-loop communication involves three steps: (1) the sender sends a first, initiating message, (2) the receiver receives the message, interprets it, and acknowledges its receipt, and finally (3) the sender follows up the message to insure the information was both received and interpreted as intended (Quayzin & Dipl, n.d.; Vecchio-Sadus, 2006; Yukl, 2008).

3.3.2.3 Mechanism 3, mutual trust

Team members in safety-critical MTSs need to trust each other, both members of their own team, as well as members of other teams and the leaders. Without sufficient trust, time will be wasted on inspecting or double-checking others' work, which will reduce the teamwork effectiveness. Mutual trust is about helping and supportive behaviors rather than to control each other (Salas et al., 2005).

However, it must be a balance between distrust and trust. High level of trust may undermine the safety culture because team members become too comfortable, whereas a too low level of trust may hinder the collaboration which is necessary to create, enhance and preserve a safe working environment (Salas et al., 2005; Yukl, 2008).

Webber (2002, p.205) defined trust in teams as "the shared perception . . . that individuals in the team will perform particular actions important to its members and . . . will recognize and protect the rights and interests of all the team members engaged in their joint endeavor". Trust is further important for the communication, since it allows team members to disseminate information more freely within the MTSs, an essential component necessary for creating a good safety culture Marks et al., 2000; Salas et al., 2005).

Mutual trust is also important in order for the team members to accept performance monitoring and back-up behavior by their colleagues, as well as team leadership behaviors (Marks et al., 2000).

3.3.3 **"Big-Five", a framework for effective teamwork**

The five components in the "Big Five" framework for teamwork, which will be described in this section, should be combined with the previously described coordinating mechanisms in the previous section, to guarantee the most efficient teamwork (see Figure 16) (Salas et al., 2005). Therefore, when reading this section, one should have the three mechanisms described above in mind and assume they are all implemented and utilized in combination with the "Big Five" framework.

The five components included in the framework have been mentioned before, and are: ***(1) team leadership, (2) mutual performance monitoring, (3) backup behavior, (4) adaptability,*** and ***(5) team orientation***.

Although each of the five components are equally important for team effectiveness, a team's needs and composition may vary throughout given projects and challenges, meaning that the different components can be used in different ways (Salas et al., 2005). The described framework in this chapter is valid in single teams, as well as in MTSs.

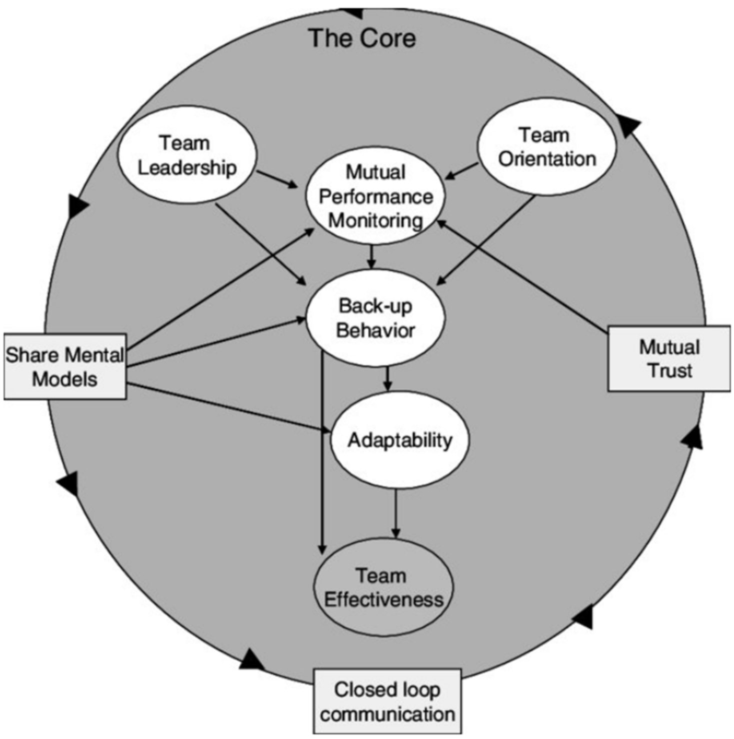

Figure 16 - Graphical Representation of the Relationship Among the Big Five Components (white, circular) and the Coordinating Mechanisms (rectangular) (Moe & Dingsøyr, 2008, p. 14)

3.3.3.1 Component 1, team leadership

The definition of leadership is vague and has been frequently reformulated since the beginning of the 20th century. To recall, Taylor defined a leader as an expert, superior to the workers, and whose main task was to control the workers' behavior (Salas et al., 2005).

Today, researchers still have numerous, though more nuanced, definitions of the term leadership. Yukl (2008, p.8) uses the following definition: "Leadership is 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". The more current definition of *safety leadership* is presented in chapter 3.4.

For the leader to be able to influence the team, there has to be trust between the team members and the leaders (Salas et al., 2005). How this could be achieved will be discussed in chapter 3.4.

Salas et al., (2005) present three overarching functions that a leader should oblige to, in order for an effective teamwork. First **(a)**, the team leader has the formal responsibility to provide an accurate and comprehensive picture to the team, regarding information of available resources, everyone's role, and different constraints affecting the teams' work. The leader's task is further to define the teams' goals, organize the resources in order to maximize the performance, and to guide the team members towards those goals. The leader's responsibility further includes the creation, maintenance, and accuracy of the team's SMM (Johnston & Briggs, 1968; Salas et al., 2005).

The second **(b)** overarched function says that a leader should monitor internal and external environment to facilitate team adaptability and prepare the team for the alternating environmental conditions. The information regarding the external environment is used to coordinate the team's behavior and their interactions (Salas et al., 2005).

The final function **(c)** of the team leader is to promote a working climate in which the three behavioral components of the "Big Five" framework (mutual performance monitoring, backup behavior, and adaptability) is encouraged (Salas et al., 2005; Shuffler & Carter, 2018).

The theory on *safety leadership* is further described in section 3.4 where more concrete functions are presented.

3.3.3.2 Component 2, mutual performance monitoring

An effective team aims for *team effectiveness* which accounts for the team members' interactions, and how the team accomplished a task. As have been described earlier, studying *how* teams achieve goals are important in safety-critical MTSs. The team members should further be aware of the team functioning by continuously monitor their fellow colleagues. With help from monitoring, mistakes, slips, and lapses can be cached shortly after they occur, or in best cases, prevented from happening. Mutual performance monitoring is especially important in stressful situations (Mathieu et al., 2000).

In order for the monitoring to function, team member must have a profound understanding of the team members' tasks, their respective responsibility, as well as the next step in the process, something that SMMs can provide (Mathieu et al., 2000; Salas et al., 2005, 2020). Furthermore, as have been mentioned before, the importance of mutual trust and communication is evident when it comes to monitoring. Without mutual trust, team members may view the monitoring process negatively, and in turn react critically to the given feedback (Salas et al., 2005).

Additionally, without a functioning safety culture, where members can communicate freely, the feedback may never reach the intended person, which in turn complicates *backup behaviors* (something that will be described in next section).

3.3.3.3 Component 3, backup behavior

Backup behavior is used in combination with mutual performance monitoring. If a team member's workload has surpassed any reasonable workload level, and this is observed by the colleagues, the work responsibilities should be shifted in order to ease that person's workload (Salas et al., 2005).

The goal with backup behavior is to assist teammates when they are performing a task, by providing a solution where the workload can be shared with other colleagues any time an overload is detected (Entin & Serfaty, 1999). In order for this to function, team members must recognize when it is time to step in and provide backup, something that, again, is made possible through SMMs (Salas et al., 2005).

Backup behavior increases team performance by ensuring that all goals and subgoals among the teams are being completed. This leads also to flexibility, which increases team effectiveness (Guzzo & Salas, 1995). Additionally, the ability to adjust one's workload in periods with high stress, is not just a factor influencing the team effectiveness, but it also leads to fewer errors, as the team's ability to constantly adapt to its changing environment increases (recall RE and HRO) (Mathieu et al., 2000).

An adequate backup behavior and performance monitoring allows team members to collect information regarding the internal and external environment, and to disperse it throughout the team in order to ensure that everyone has acquired the necessary, updated, and latest information (Salas et al., 2005).

3.3.3.4 Component 4, adaptability

Team adaptability is an important factor within complex environments where the prevailing conditions constantly and randomly change (Schipper, 2017). In MTSs, where several and global teams may cooperate, adaptability requires that the different team has a common and global perspective on the team tasks. Furthermore, it is necessary that everyone is aware of how changing working conditions may alter each team member's roles.

Teams with adaptive members, are more effective than non-flexible teams (Bienefeld & Grote, 2014; Schipper, 2017). However, for a team to benefit from team adaptability in terms of effectiveness and performance, the team's adaption must be focused, as well as purpose driven. This means that the current team processes must be constantly evaluated and assessed, regarding to the prevalent environmental conditions. Furthermore, it is up to the leaders to adjust the team's processes if needed, in order to guide the teams to achieve their objectives (Quayzin & Dipl, n.d.; Vecchio-Sadus, 2006).

For an effective adaption to function, it is required that the teams have SMMs, an effective engagement in mutual monitoring, as well as backup behavior. An example of when adaptability is important is in the emergency room, where a worsening of a patient's medical condition drastically change what type of treatment model that is needed (Salas et al., 2005, 2020).

3.3.3.5 Component 5, team orientation

The last component in the "Big Five" framework is attitudinal in nature, rather than behavioral. As have been described earlier in this thesis, an MTS consists of members from different professions with different backgrounds. In addition, there are often several ways in which a task can be handled, meaning that each person's perspective and knowledge adds specific value to the problem solving and task management (Bienefeld & Grote, 2014; Fernandez et al., 2017; Marks et al., 2005). Team orientation facilitates the collaborative work through an increased task involvement among team members, increased information sharing, strategizing, and specific goal settings. Each member's specific contributions must be considered, and together, the team must evaluate others' perspectives (Salas et al., 2005). In order for this to work in practice, a prerequisite is a positive attitude towards mutual monitoring and backup behavior, something that can be fulfilled through a good safety culture (Dechurch & Marks, 2006).

Team members with team orientation are more prone to consider other teammates inputs before deciding on a final course of action. The team effectiveness and performance are further affected positively by performance monitoring and feedback through backup behavior (Bienefeld & Grote, 2014; Dechurch & Marks, 2006).

3.4 Safety leadership

An apparent challenge in MTSs is to accomplish separate, and sometimes competing team goals, and to simultaneously strive to carry out shared MTS objectives (Cannon-Bowers et al., 1993; Fernandez et al., 2017; Murase et al., 2014). This places unique challenges on leadership, as it has to function within teams, as well as across teams (Luke, 2018). In previous section, the functioning of leadership was summarized. In this section, a more profound description of safety leadership will be included, with a focus on behavioral characteristics and leadership strategies.

The definition of *safety leadership* is not trivial. Even if general leadership share some similarities with safety leadership, some differences exist (Luke, 2018).

Luke (2018) visualize the definition's ambiguity by giving examples of what safety leadership is *not* about. This example is further linked to the work of Sobh and Martin (2011), where individuals have shared some thoughts about safety leadership. The thoughts included, "it is not about smashing your guys when they make a mistake" (Luke, 2018, p. 7), or a safety leader should, "trying not to focus on statistics to drive change" (Luke, 2018, p.7).

This ambiguity concerning the definition of safety leadership has further been subject for misinterpretations, since it is a concept that is demonstrated through the leader's *behavior*, which sometimes is hard to put words on (Cooper, 2010).

But for the reader to comprehend this chapter and ensure that a shared understanding of what the concept of safety leadership should include, two different definitions will be presented. Luke (2018) uses the definition, *safety leadership* is about: "the demonstration of safety values through the creation of a vision and the promotion of well-being through the art of engagement, honesty and discipline" (Luke, 2018, p.7).

Additionally, another definition of safety leadership is defined by Cooper (2010) as: "the process of defining the desired state, setting up the team to succeed, and engaging in the discretionary efforts that drive the safety value".

The ambition with this chapter is to highlight the different concepts that safety leaders should possess in order to enable the usage of the "Big-Five"- framework and safety work. The focus is further on the enhancement of values related to safety culture, and components allowing organizations to be high reliable, as well as resilient.

The different concepts described below are all interrelated. The division into subsections is only intended to ease the reading.

3.4.1 **Safety communication**

As was described in section 3.3.3.1, the main function of a leader in MTSs is to strategically communicate an accurate picture regarding the environment and objectives to the teams, allowing the team members to develop SMMs through updates and feedback communication (Vecchio-Sadus, 2006). Communication has further been described as the most critical and essential leadership component in safety-critical MTSs (Fernandez et al., 2017), since it allows the leader to coordinate the teams' actions, establishing team members roles and their responsibilities (Murase et al., 2014; Vecchio-Sadus, 2006). The use of closed-loop communication, which was one of the three coordinating mechanisms described in section 3.3.2.2, further ensures that everyone has received and interpreted the message as intended.

A leader who encourages employees to feel free to communicate opinions and report incidents, contributes also to the establishment of a good safety culture (Cole, 2000; Vecchio-Sadus, 2006).

3.4.1.1 Facilitate coordination and enhance safety culture

Studies conducted in simulators have shown that communication frequency between leaders and teams is related to an increased performance in safety-critical systems (Vecchio-Sadus, 2006). This is also valid for the more specific communication type, *feedback*, which is defined as the delivery of information regarding one's performance, with the aim to inform the person what they did in relationship to what they should, or was expected to do (Fernandez et al., 2017). Giving brief and specific feedback messages over weeks or months are more preferable than giving fewer but longer feedback sessions (Vecchio-Sadus, 2006).

Safety communication and feedback should be open and include information about near-misses and incidents. Positive as well as negative information should be included as well (Fernandez et al., 2017). A leader should also provide information regarding who should communicate with who, and how often (Murase et al., 2014).

The way the communication and feedback are delivered, influence how team members perceive system safety and how they learn from the provided information, which in turn affect the organization's safety culture. The safety culture gets underpinned if information is not received properly, somethings that also negatively impact the organization's ability to be resilient or an HRO (Whitmeyer & Wilcutt, 2013). Extensive use of emails may for example desensitize some people to informational messages regarding safety (Whitmeyer & Wilcutt, 2013). Instead, communication should be delivered in an appropriate way that ensure that all teams are informed and updated regarding the critical information. Sensitive information should be delivered during physical meetings, by telephone or video conferences (Salas et al., 2005; Shuffler & Carter, 2018).

In healthcare settings for example, the feedback can be delivered through debriefing sessions. This can be done with help from debriefing frameworks, to ensure that relevant information is delivered and that the content is discussed and interpreted correctly (Fernandez et al., 2017; Vecchio-Sadus, 2006). Overall, it is of great importance that feedback is constructive, meaning that risky behaviors should be immediately followed up, and specific instructions on how behavior can be improved should further be provided (Fernandez et al., 2017; Salas et al., 2005).

3.4.1.2 Language and words

When communicating with team members and teams, the choice of words and languages can significantly impact the outcome of safety communication. This is especially important in MTSs where people may speak different languages, as well as having different perspectives and knowledge. Safety information and feedback should therefore be communicated with clarity, credibility and impact, and leaders should feel comfortable to provide evidence and give examples to why team members should listen to the given information (Salas et al., 2020). Luke (2018) further highlights the need for using words that invokes emotions, which positively impact the way the messages are received and remembered.

Examples of positive phrases that positively impact safety communication is presented in Figure 17.

Negative Phrase	Positive Phrase
What's the problem?	*How can I help?*
You should have….	*From now on….. or Next time……*
You don't understand	*Let me run through that again*
I've told you before not to…..	*How about trying it this way*
This will cost money	*This is an investment in your health and wellbeing*

Figure 17 - Examples of positive phrases that should be chosen over negative phrases. (Vecchio-Sadus, 2006, p. 5)

Additionally, since safety communication is critical for system safety, the information should be delivered in an unambiguous language, preferable by using closed loop communication described in section 3.3.2.2. Feedback should also be given using straightforward and objective words, so the person that receives the feedback can learn from it (Salas et al., 1992, 2020; Shuffler & Carter, 2018).

Communication skills among team members and teams can further be improved by practicing problem solving together (Reason, 1997).

3.4.2 **Enhance the functioning of mental models**

The function of SMMs is to create team cognition in order to create a collective understanding among component teams and their members, which facilitates between team coordination, which in turn prevents misunderstandings (Fernandez et al., 2017). Enhancing the creation of SMMs, can be accomplished through boundary-spanning activities and adequate communication strategies. The activities could further include various training methods such as different simulation exercises, where leaders and team members from different teams practice each other's roles, which in turn increases the team's coordination and backup behaviors (Fernandez et al., 2017).

Training, with the ambition to develop SMMs, can also be carried out by the coordination control mechanisms which was described in section 2.2.1, that is, routines, meetings, plans, schedules and rules (Ramthun & Matkin, 2012).

In hospital settings, where common, training activities among the personnel are limited, individual training, and the coordination control mechanisms are extra important (Ramthun & Matkin, 2012).

3.4.2.1 Top-down and bottom-up processes

SMMs, or more specifically, a multiteam-interaction mental model (see section 3.3.2.1) , which describe the inter-team interactions, can be constructed in two ways, by using either top-down, or bottom-up processes. The usage of a bottom-up process suggests that SMMs is created through MTS members' long-term communication and interactions with one another. While the top-down process allows SMMs to be created through interventions (e.g., communication with team members) performed by the leaders (Arvidsson, 2012; Murase et al., 2014).

In MTSs, a top-down process is preferable, due to the leader's boundary-spanning role, which enables the leader to possess a better position which facilitates the overall understanding of the MTS functioning and the interactions between teams. However, a leader should be aware, and respect that each team member probably possesses a more adequate picture concerning their own team and their fellow team members (Ramthun & Matkin, 2012).

3.4.3 **Shared leadership**

In organizations who rely on *vertical leadership*, there are a clear decision-hierarchy, where several teams solely rely on one hierarchal leader (see Figure 18). These organizations rely on downward influence, where the focus is to enhance teamwork performance, by influencing team member's behaviors (Bienefeld & Grote, 2014; Murase et al., 2014; Shuffler & Carter, 2018).

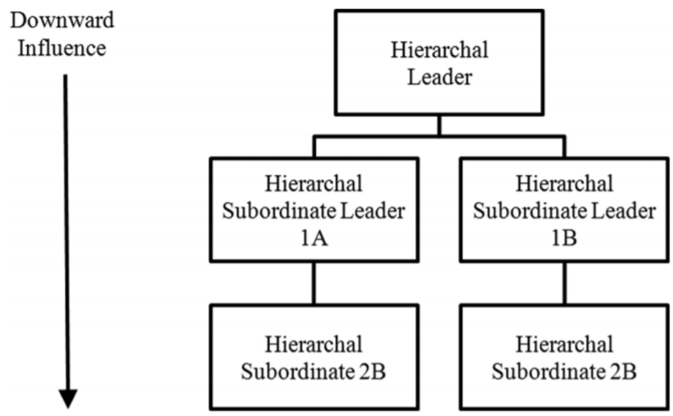

Figure 18 - Vertical leadership through downward influence (Ramthun & Matkin, 2012, p. 306)

However, the prevalent complexity and ambiguity in safety-critical MTSs makes it impossible for even the most competent leader to cope with all the necessary tasks that have to be performed (Fernandez et al., 2017). Time-critical situations, stressors and different geographical locations make it inefficient, safety-critical and inappropriate to rely on only one leader to manage all these aspects.

Instead, leadership in safety-critical MTSs should be shared between several persons, so called *shared leadership,* where personnel, in critical situations, are allowed to follow the colleague which possess the best knowledge given the prevailed situation, much in accordance with the principles of HROs and RE (see Figure 19), Shared leadership further suggests that power and influence should be shared among several individuals (Bienefeld & Grote, 2014; Fernandez et al., 2017; Murase et al., 2014).

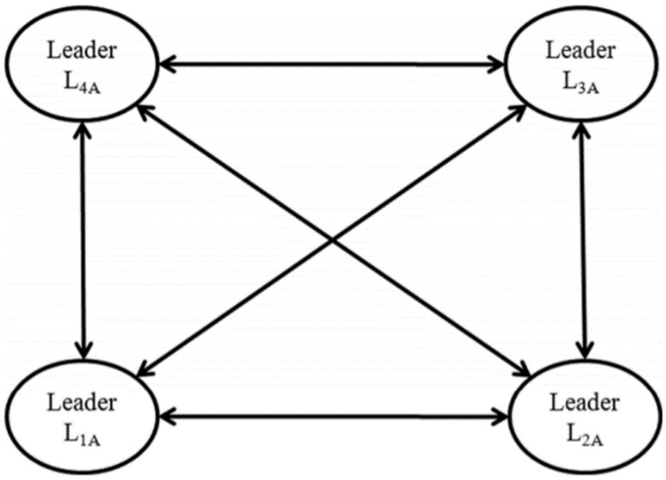

Figure 19 - Shared leadership within a component team (Ramthun & Matkin, 2012, p. 307)

Furthermore, the usage of vertical and shared leadership can vary between, and within organizations. The two type of leadership styles can though be used in combination with each other (see Figure 20), recall that this is an essential component in HROs, and the usage of shared leadership has been subject for research within fields such as aircrafts and military teams (Flin & Yule, 2004; Yukl, 2008).

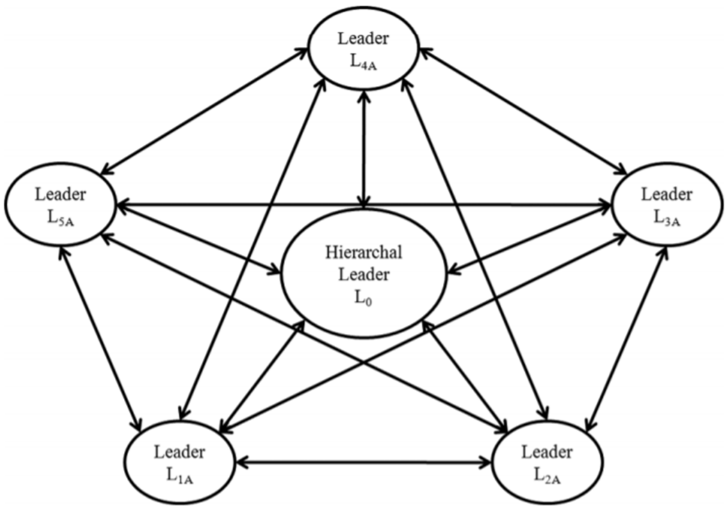

Figure 20 - Integrated vertical leadership and shared leadership (Ramthun & Matkin, 2012, p. 307)

3.4.4 **Leadership, behavioral characteristics**

The research conducted on leadership is vast and includes several studies, all of which contribute with different usable theories concerning what type of behavioral characteristics a leader should possess (Flin & Yule, 2004).

Leaders have both a *direct* and *indirect* effect on workers' behaviors and can thus affect the safety culture in several ways. The indirect effects constitute the establishment of rules, norms, procedures and practices. The direct effects relate to monitoring and control of subordinates' behaviors, which is carried out through direct interactions (e.g., training sessions, meetings) (Luke, 2018).

How effective this work is, is further not only constrained by *what* the leaders do, but also dependent on *how* they do it. Showing up on an oil platform in running shoes or to ignore wearing safety protection is two examples of harmful leadership behaviors that affect the subordinates' behavior, and thus the whole safety culture. Personnel do not do what they are told to do, they tend instead to mimic the leader's behavior (Yukl, 2008).

3.4.4.1 Leadership effectiveness

According to Yukl (2008), leadership effectiveness is defined in terms of several factors. One factor can be perceived as the followers' attitudes and perception of the leader, something that can be measured using questionnaires. These attitudes are further dependent on the subordinates' respect, admiration and trust in the leader, something that is determined by whether the leader has a successful career as leader, or was promoted rapidly, or under suspicious circumstances (Cooper, 2015).

Another factor that measures the effectiveness according to Yukl, is the leader contribution to the quality of team success. However, Yukl talks about definitions that apply to a general form of leadership. Instead, Cooper (2015) talks about the more current term, *effective safety leadership*.

According to Cooper (2015) an effective leader within a safety-critical system must establish a balance between caring and control. Important factors for effective safety leadership therefore consist of: the involvement of everyone in safety, showing appreciation, trusting the subordinates, listen to people and act on relevant information (Cooper, 2015; Rasmussen, 1997).

Furthermore, effective safety leadership positively impact employees' safety behaviors and attitudes by promoting the development of a good safety culture. By constantly challenging the status quo and questioning working patterns and safety work, a leader can drive corrective actions that are necessary in order to balance the work inside the safety margins (recall the model in Figure 4) (Ramthun & Matkin, 2012).

An effective safety leadership further helps to reduce injury rates and insurance premiums (Cooper, 2010, 2015).

3.4.4.2 Leadership styles

The different leadership styles are according to Cooper (2015): 1) transformational; 2) transactional; and 3) servant. These three types of styles all constitute different leadership behaviors and strategies that leaders use to shape and manage the safety culture (Cooper, 2015; Flin & Yule, 2004; Yukl, 2008).

According to Yukl (2008), *transformational leaders* are charismatic, inspiring stimulating and considerate. Transformational leaders further motivate team members by using a positive language (see Figure 17). They are observant and treat each colleague as an individual. To question traditional assumptions and encourage broad perspectives and diversity are also characteristics that belong to transformational leaders (Cooper, 2015).

Transactional leaders are more focused on performance monitoring and to promote consequence management. This leadership style considers team members to be responsible for their own work, and they set up clear goals concerning the desired outputs and the needed performance requirements. This form of leadership style is important to ensure compliance with safety rules and regulations, and this include leadership behaviors such as: safety observations, providing feedback to personnel, to take actions against arising safety issues (Sadeghi et al., 2012).

A critic against transactional leadership is the short-term focus which results from the reward-punishment system. This form of leadership can be advantageous during crisis and emergency states, but are not preferable in the long run, since it lack focus on the well-being among the personnel (Cooper, 2015; Sadeghi et al., 2012).

The last style described by Cooper (2015) is *servant leadership.* Leaders who use this style focus on building personal relationships by advocating open communication and a supportive environment, where team performance and engagement increases (Cooper, 2015). Safety behaviors according to this leadership style includes: being active in safety meetings and safety committees, listen to peoples' ideas and actions concerning how safety could be improved, and follow up on any corrections to ensure their completions (Cooper, 2015).

Which one of these three styles that are the best, depends on the prevalent situation, and leaders can use a combination of all three. However, servant leadership has been shown to have much stronger influence on safety culture, including personnel's' engagement, their safety behavior and a reduced incident rate. Yet, for a leader to engage in all these behaviors, the company must provide a supportive environment and sufficient resources to the leaders (Zenger et al., 2009).

3.4.4.3 Inspirational- and positional leaders

Inspirational leaders can help to develop peoples' knowledge, skills and their ability, enabling them to participate more wholeheartedly in safety efforts. They are devoted to safety and are driven by belief; they are genuinely passionate (Avolio & Bass, 2002; Cooper, 2015) and have the ability to motivate their colleagues to why it is important to follow the set guidelines. Personnel follow inspirational leaders because they want to, and because they are allowed to discover what feel right for themselves (Cooper, 2015).

According to Cooper (2015), inspirational leaders can be recognized on their body language, tone and spoken words. They have a clear vision and might say something like, “Regardless of down-time cost, if our operations create a hazard to our workers, we will immediately stop that activity and eliminate any threat before someone gets hurt. If you believe we are not living up to this ideal, phone me and we will work to get the matter resolved" (Cooper, 2015, p. 50).

In contrast, *positional leaders* operate more clearly under the virtue of power, since they tend to tell people what they want them to do, and people follow not necessary because they want to, but rather because they have to (O’Reilly & Roberts, 1976; Shuffler & Carter, 2018).

3.4.5 **Maintain and enhance the safety culture for safety participation**

A positive safety culture has a positive impact on communication and learning, meaning it has an indirect impact on SMMs, which in turn enhances the team’s coordination and thus the team performance and effectiveness. A leader should therefore shape and drive an organization’s safety culture (Arvidsson, 2012). The previously described factors so far concerning safety leadership, are all together, equally important for safety culture, and can help to enhance its status.

Additionally, in MTSs, as have been mentioned earlier, a leader should be aware of both individual’s and teams’ attitudes and perception toward safety, since individuals and teams together have an enormous influence on the overall safety culture in MTSs. These attitudes and perceptions among the members in MTSs, are transient in nature and constitute an organizations safety *climate.* The safety culture has been described in earlier sections, but to recall, it is a more lasting phenomena that constitutes shared values, believes and perspectives (Reason, 1997; Reiman & Oedewald, 2009). Safety climate can therefore be seen as a snapshot of the safety culture (Whitmeyer & Wilcutt, 2013).

Together, safety culture and safety climate have positive implications for *safety participation,* which is enabled through each team member’s safety-related knowledge and motivation. Safety participation further describes the activities that employees engage in, and whose actions contributes to the overall, organizational safety, rather than safety of the self. An example to this is when an employee reminds his or her coworkers of using helmets or participate in safety workshops and feedback sessions (Salas et al., 2005; Shuffler & Carter, 2018).

Motivation and safety knowledge can be enhanced through training and SMMs, where the leader can facilitate training by providing the coordination control mechanisms. This further facilitates the usage of the previously described concepts of backup-behavior, performance monitoring, mutual trust and adaptability (Ramthun & Matkin, 2012). Important components for effective leadership related to the “Big-Five”-framework can be seen in Table 4 below.

Table 4 - Important components of effective leadership and their behavioral markers, (Schipper, 2017, p. 449)

Component	Description	Behavioural markers
Communication	Managing communications about team actions and goal progress across all component teams	The leader teams gather information about the MTS’s performance environment to create a ‘big picture’ understanding The leader teams manage the flows of information between component teams to facilitate the timely and accurate exchange of information
Performance monitoring	The ability to develop a shared awareness of the teams’ environment and the strategies used to maintain an awareness of component teams’ performance	Leader teams monitor goal progress and goal blockages Feedback regarding component team actions is provided to facilitate self-correction
Backup behaviour	Knowing how and when to back up teams and team members. This includes the ability to shift workload among teams to achieve balance during periods of high workload	Leader teams recognize that there is a workload distribution problem within component teams Leader teams prompt component teams to provide back up and helping behaviour to other teams and to shift work to underutilized teams Leader teams proactively assist component teams with task work
Decision making	Decision making refers to the leader team’s ability to determine goals; develop plans and strategies for task accomplishment; identify contingencies, and to alter/update a course of action in response to changing conditions	Leader teams develop and share alternative plans for collective action in response to anticipated changes in the performance environment Leader teams remain vigilant to changes in the internal and external environment Strategies and plans are adjusted to unanticipated changes in the performance environment

4 Examples of how today's safety-critical organizations perform

Based on the information and the theoretical framework provided in earlier chapters, the purpose with this chapter is to provide the reader with information regarding how some safety-critical systems in Sweden work with system safety, leadership and teamwork, and their perspective on the same.

Furthermore, the aim is to investigate if, and how their organizational, practical work, differ from the previously described theory concerning the teamwork, leadership and system-safety.

In this chapter, one report from the Swedish Safety Radiation Authority, together with two interviews that have been conducted with leaders from two different safety-critical systems will be presented. The focus has, again, been on the leadership and teamwork.

4.1 A report from the Swedish Safety Radiation Authority

A report from 2012 conducted by the Swedish Safety Radiation Authority, investigated the prevailing conditions within the Swedish healthcare, with the aim to analyze the organizational work concerning their incidents reporting and investigational work concerning these incidents.

The result showed there were several inconsistencies and differences between the different wards (radiation therapy, nuclear medicine and X-ray), regarding established routines and working processes. The safety culture was further characterized by stigmatization, hierarchical structures between different professions and attribution of guilt among the personnel. Additionally, the effects from changes within the organization was not followed up, since the investigational resources were insufficient (Arvidsson, 2012).

The relatively low frequency of incident reporting among physicians was also explained by the shortcomings in the safety culture, which had also impaired the transparency and experience exchange within the organization (Arvidsson, 2012).

The personnel together with leaders had deficient knowledge regarding system-safety, risk management and other questions concerning the organization's safety work. The leaders' commitment was also questioned (Arvidsson, 2012).

However, among the persons who got interviewed, the safety culture was perceived as just and open (Arvidsson, 2012).

4.2 Leaders' experience from two different safety-critical systems

This chapter provides discussion concerning two different and separate interviews that have been conducted with one person within the nuclear power industry, and one physician with profound leadership experience within healthcare.

The results show how two different safety-critical systems manage their safety work, as well as their respective view and perspective on leadership and teamwork, concerning opportunities and challenges. A summary regarding their answers and how these relates to recent theories is provided in the discussion.

4.2.1 **Operations manager, a university hospital**

The last 15-20 years, the view and perspectives on leadership within the university hospital has changed. Prior working environment at the university hospital was characterized by hierarchical and transactional leadership structures, but today, the focus has rather been shifted towards the models of shared leadership and transformational behaviors, a shift that the respondent encourages. The driving force behind this "paradigm shift" can be derived from the increased complexity, where personnel groups have become increasingly larger and the technological equipment have become more and more integrated within the working environment.

To cope with the inherent complexity and ambiguity, and at the same time be able to carry out critical lifesaving interventions and operations within an environment comprised of time pressure and financial constraints, the leadership and teamwork have to function properly. One of the most important components which allows personnel to learn to handle these situations, is simulation exercises, as well as management courses for the leaders. This type of training interventions are a well-established form which is widely used today.

The importance of flexibility, redundancy and dynamical decision hierarchies became especially evident with the outbreak of the Covid-19 pandemic, which highlighted the need for the organization's ability to tackle this crisis as a resilient organization.

Acute and critical situations, like the pandemic, often require a transactional leadership, which is also often used by leaders closer to the personnel, under normal circumstances. In turn, transformational leadership behaviors are often more used by administrative leaders, which operates indirectly, and further away from the personnel. However, the seriousness of situations decides whether a transformational or transactional leadership behavior is used, and whether a vertical or shared leadership is utilized. To quickly redirect resources and shift focus is an essential component to successfully handle these types of situations, something that personnel at the hospital continually practice through simulation exercises.

One of the most critical aspects according to the respondent is communication, where a lack of communication, often due to time pressure, cause the majority of the reported incidents within the organization. The prevailing safety culture provides a safety climate where personnel feel free to communicate and report incidents, even though this opportunity vary throughout different infirmaries.

The organization is good at following up incidents, but the respondent admits that perhaps too much focus is spent on investigating *why things went wrong* (safety-I), instead of highlight positive things that have went right (safety- II). However, during feedback sessions, both negative and positive feedback is given.

Further work includes the study on whether further interventions concerning shared leadership is possible.

4.2.2 **Nuclear power industry**

The safety work within the nuclear power industry is characterized by carefulness and systematics. The workflows regarding critical operations is intended to follow carefully evaluated instructions, where several independent instances, internal as external, have established and reviewed safety documents systematically before any interventions can be initiated. This documentation is aimed to function as a tool of coordination and communications, which will ensure that the planned work can be conducted and achieved in a safe way, and that everyone involved are well aware of the prevailing conditions and circumstances. Safety-critical work is further conducted according to a “friend-review” principle, where two persons work together in order for them to check up on each other’s work.

The last instance is the Swedish Radiation Safety Authority (SSM), which has the function to analyze the previously established documents by the different instances, where the SSM should approve or reject the intended working plans.

Additionally, tasks are often divided into several subtasks, where each team, highly specialized in their specific fields, can provide their support. In this way, large and complex tasks are handled through the usage of multiple specialized teams, where the safety is constantly checked upon by an appointed safety officer, a person who is qualified enough and who has together with the organization decided to play the role.

Since several divisions and teams always cooperate within the organization, before, during and after a safety-critical operation, it is therefore essential that the communication works. The functioning of the communication is further secured through physical meetings and closed-loop communication.

The greatest challenge within the organization is however related to the communication. The challenge is to ensure that everyone has understood the prevailed conditions, and what has to be done in order to avoid misunderstandings (i.e., in what order should the work be done, what safety measures need to be considered, how should we prepare, how should the work be conducted etc.).

The leadership behaviors can further be categorized as inspirational leadership, even though the organization is managed through the usage of vertical, hierarchical leadership. One of the most important qualities for a leader according to the interviewee, is to "lead others, by first leading oneself". That is further characterized by some of the concepts behind inspirational and transformational leadership, that is, *reflection*, *serve as a responsible example*, *listen* and to *inspire others*.

Since the organization cannot, under any circumstances, allow some specific type of failures to happen, the organization is highly focusing on engineering approaches regarding how to calculate and evaluate risks.

Since the organization is immense and includes over thousand employees, it is important that everyone takes their responsibility. Before any new employees can enter the working area, they must participate in safety training. The organization have also more specific courses, that aim to ensure continuous learning even for the more experienced workers.

5 Answers to the thesis' objectives

In this chapter, each research question stated in section 1.2.1, will be answered.

5.1 Question 1 - What factors constitute good leadership in safety-critical contexts?

The definition of *leadership* has varied throughout the history, so in order to determine the characteristics of *good leadership,* one should probably be more specific about the context in which the leadership is subject to be analyzed in.

In the early 1900s, a *good* leader would probably be a dominant person who had the ability to control others. Since the goal was to "control workers" and to streamline the work without any long-term focus on the workers' well-being, a transactional leadership behavior with strong vertical leadership styles would probably be determined as *good leadership.*

In today's society, the working environment is analyzed in a more long-term, holistic perspective, where the workers' mental and physical health have been shown to have a strong impact on the overall working environment and the organizations' ability to cope with the increasing environmental complexity.

In order for an organization to survive in today's environment, everyone in an organization must be identified as an important asset that needs to be valued and carefully taken care off.

A good leader in today's safety-critical context, is probably a charismatic person that focuses on every subordinates' well-being, and someone who has a long-term focus. A good leader is eager to *build*, *maintain* and *develop* a good safety culture in which communication and coordination are key factors for success. The long-term communication should also be positive and unambiguous.

Leadership should promote *curiosity*, *devotion* and *fellowship,* which further enables shared mental models to develop, which increase the overall performance and ensure that challenges and unexpected events are managed in the most appropriate way.

Good leadership should also be preceded with inspiring leaders who is open-minded and aware of how accidents occur and how the corresponding proactive work, which constantly needs to be evaluated and questioned, can prevent disasters from happening.

5.2 Question 2 - What factors constitute good teamwork in safety-critical contexts?

Good teamwork would probably be characterized by an *awareness* that ensures that the team is heading in a right direction. A team's awareness should be founded on a framework that provides common and shared values for how the team adapts, learns and communicates. In good teamwork, the coordination mechanisms are utilized, together with the components in the "Big-Five"-framework. Everyone is further equally engaged in the safety culture and its different building blocks.

Good teamwork in MTSs is probably characterized by team's devotion and positive attitude towards their own team members and the team's success. However, good teamwork should also include an interest in other teams' performance and their constellations, since teamwork in MTSs constitute collaborations not only within teams, but also between teams.

Good teamwork is not only characterized by team performance, but rather team effectiveness. Since the world is constantly changing and the environmental complexity increases in parallel, a good teamwork should be preceded by team members who value knowledge and training. This is especially important in shared leadership constellations, or in contexts where team members are expected to monitor fellow co-worker's performance and provide backup.

5.3 Question 3 - How can good leadership improve teamwork within safety-critical systems?

By promoting a good safety culture where everyone feels free to communicate, and where information exchange is backed up with closed-loop communication, a leader could improve coordination and thereby the teamwork.

By advocating the importance of safety courses and common training and simulation sessions, a leader could improve the functioning of mental models and thereby enable the development of shared mental models, which further facilitates the pursue for team effectiveness. This can be done by ensuring that new personnel are being well integrated from start, and that personnel are constantly offered further education and training, to let them recall previously learned information, or to cope with new working tasks and new equipment. In this way, the teams' adaptability is enhanced.

In MTSs a leader should be responsible of updating the team regarding objectives and to ensure that everyone, each team members within every teams, are updated with the latest information. In complex, ambiguous and stressing environments, the usage of shared leadership, can facilitate the dissemination of information. The leadership styles should vary in situations where it is necessary, allowing the best method to be applied. In safety-critical situations, the best method might for example be vertical – and transactional leadership. But as soon as possible, the leadership styles should go over to a transformational style.

The important aspects of mutual trust, back-up behaviors, monitoring and adaptability, further insinuate that team members must feel comfortable to perform these steps. Good leadership must therefore enable teams to interact with each other, allowing team members to get to know their fellow colleagues and get a perspective on how their own work relates to other teams' and team members' work.

5.4 Question 4 - How can leadership within safety-critical systems improve and preserve system safety?

The preservation of system safety, that is to prevent severe accidents and preserve a climate where a long-term focus on safety work in maintained, demands a good safety culture. This term safety culture holds several invaluable concepts, and in order for a good safety culture to arise and remain, each team member of an organization is a key factor.

System safety in today's context includes the well-being among personnel. A leader should therefore focus on building teams and organizations where each team member feels unique, important and valuable. In this way, personnel can keep their motivation. Team members should further be equally devoted to safety, and a good safety culture should not be taken for granted.

Building highly adaptive teams, where shared mental models constitute the teams' cognition, creates resilient organizations. Focusing on the "Big-Five"-framework, together with the coordination control mechanisms and coordination mechanisms, a leader have several tools which altogether can both improve and preserve system safety.

The leadership style should be dynamic, and leaders should constantly monitor safety culture. Best practice of safety leadership is further to lead by example.

6 Discussion

In this chapter, the thesis results are discussed and reflected upon.

6.1 Could the described historical accidents have been prevented?

The described historical accidents described in this thesis could for sure have been prevented. At least in theory. Many mistakes were made, including several violations among people at different hierarchic levels within the organizations, which triggered active failures from latent conditions.

In the example with the Piper Alpha catastrophe, a first glance at the accident report might lead one to think that the accident was caused by the failure of the pump B, or the failure of being able to adequately communicate the conditions with pump A among the different teams.

However, the oil platform's sprinkler system had further corroded, which highlights that the Piper Alpha accident was not a result from single, isolated event or active failure. The accident was a result of several, relatively small, failures, that together lined up, allowing the accident to occur.

In the example with the Boeing 737 MAX accidents, one problem might have been too much redundancy and overlap in the pilots SMMs, since none of pilots had any clue what was going on when the MCAS took over the control of the plane. As have been described in this thesis, the functioning of SMMs are further dependent on the leadership as well as the functioning of each of the five components in the "Big Five" framework. It is further tempting to blame the leadership in this specific case and point at how badly the communication was handled between the pilots and the leaders.

How come no one in the crew nor in the flight control center had any idea about the MCAS? But which leaders should be blamed? Who was responsible for the information not being delivered properly? Was it the leadership within the Boeing Company or was it lack of leadership within the Ethiopian Airline or the Indonesian owned Lion Air? Or maybe all of these three? Perhaps, it was the communication *between*, and not within, the different organizations that failed, the so-called inter-team communication? In that case, the teams' *multiteam interaction models* could probably provide some useful information.

Apparently, several Boeing 737 MAX planes were perfectly operating in several areas around the world, before the first crash occurred. How come these planes did not crash? It would have been interesting to compare the teamwork and leadership between the planes that actually worked, and the planes that crashed.

In today's complex systems, no one should put their faith in someone else, everyone should be on guard and continuously question rules, procedures and decisions. This is important since the world is constantly changing, and without a compelling safety culture where personnel and leaders are awake and question these concerns, the organization's safety culture will be underpinned and will most likely fail to be resilient, and hence fail to be prepared on sudden, critical events.

Something that is crystal clear however, is that all of these accidents were no results from *one* specific event. There were, as was mentioned before, several violations, made. To in a more concrete way, point out which factors that resulted in these accidents, one should probably (after have read this thesis) say something about bad teamwork and leadership, or more specifically: *bad decision-making* (when the night shift decided to restart pump A), *pressure towards safety margins due to external forces* (for example NASA's strive towards the accomplishment of sending 24 spacecrafts into space each year), *faulty inter-, as well as intra-team communication* (the day shift's failure to adequately communicate the conditions concerning pump A at the Piper Alpha), *poor coordination, deficient mental models as a result of poor training and communication*, and *failure in quick adaptive actions* (i.e., being resilient). The scrupulous reader probably notices that all of these factors to various extent, further relates to the organization's safety culture, which insinuates that safety culture is extremely important, since it sets some sort of standard in regard to how the organization acts and functions.

It would be interesting to further investigate, on a more concrete level, how these teams and organizations should have acted instead.

6.2 Can the factors concerning leadership and teamwork be concretized?

As one probably has been noticing throughout the reading of this thesis, the theories concerning leadership and teamwork are varied.

To try to determine what *good* leadership or teamwork consist of, therefore emerges as a rather diffuse task. Something that constitute *good* leadership in one specific context, may be defined as the opposite in another context. An example is the usage of vertical or shared leadership, as well as the usage of different leadership styles (e.g., transactional, transformational). Vertical leadership together with transactional behaviors may be more preferable during crisis but should not be used as a standard form of practice since this combination undermines the safety culture and thus the safety work. This became evident during the interviews, were participant strengthened this assumption. The different interviewees had different perspectives on what constitutes a *good* leadership and teamwork. However, one common important and concrete success factor can be extracted from this noise. That is, the leaders have the primary responsibility to create a good safety culture, since this affects several other aspects in the organization.

How this safety culture in practice looks like, may however differ from organization to organization, but the overall positive impact it has on the organization, remains the same.

A complex system therefore requires a complex form of managemental system, meaning that the leadership styles and behaviors must vary together with the system itself. This is further a statement that the theories of RE and HRO would argue for as well.

A challenge with shared leadership is though that this put great demands on specific persons and their personal attributes and skills.

6.2.1 **Recurring concepts**

Some concepts have recurred frequently in different context, so the interpretation could be that these concepts are more essential than others, regardless of the context. These concepts can be identified as: *communication*, *shared mental models* and *safety culture*. The importance of these components has been confirmed throughout the interviews. All three participants agreed on the positive influence that communication and training had on safety culture, and they further emphasized the importance of a good safety culture and how the leaders' main responsibility was to ensure that safety culture was maintained and respected.

Even though, mental models were not explicitly mentioned and emphasized, the interviewees talked about many of the factors that this concept cover, for example, they mentioned that it is important that everyone is aware of prevailing conditions and what has to be done (i.e., the common tasks and goals).

The best concretization of factors positively influencing the teamwork could probably be the "Big-Five"- framework. Each of these components was further highlighted by several, external and independent authors, who also confirmed their importance.

6.3 Comments on the conducted interviews

In this section, some comments and discussion regarding the conducted interviews will be presented.

6.3.1 **University hospital**

During the interview with the physician, it was mentioned that multiteam (or more specifically, interdisciplinary teams, which is composed of healthcare professions from several disciplines) could divide the safety culture, meaning that several different teams, at different wards, would have their own specific safety culture. This was something that was more common back in time, and a problem that leaders within this hospital constantly worked hard on to make sure that only one, common safety culture prevails.

The contrast between leadership within a hospital environment and nuclear power industry becomes evident when looking at the components of resilience and HRO. It seems that hospital settings are more suitable for the adaptability and flexibility behaviors concerning the dynamical decision hierarchies. Working with a safety-I, perspective, that is focusing on the errors, works within the field of health care, even though it in the long term is more preferable to have a safety-II (focus on the success). The hospital setting seemed better suited for testing different leadership and teamwork strategies, since the wards, compared to nuclear power industry, are more adaptable and flexible, and not as tight coupled as the nuclear power industry.

However, as today's working environments constantly change and hospitals environments are no exception, there are no "golden rule" for how an organization should function. This further means that the best practice may be to combine safety-I and safety-II and let them both contribute to the overall safety culture, as long as this approach does not have an evident negative effect on the organization. One should further have a vigilant attitude and constantly evaluate the safety culture, but to focus too hard on trying to supplant things without further contemplation, will do more harm than good.

6.3.2 **Nuclear power industry**

Since the consequences resulting from a failure within the nuclear power industry can affect millions of people and several countries, the safety work in this kind of fields require a systematic and profound proactive work. In these settings, the hole organization must constantly be on guard and cannot afford any severe failures. From the interview it was noticed that the organization is far more rigid and tight coupled than the hospital wards. Even though nuclear power still utilizes several of the mathematical and engineering approaches from the 60s, these organizations also apply some of the more modern concepts of safety culture.

The prevailing safety perspective within the nuclear power industry reminds of those theories that was first established in the beginning of the 1900s. That include Taylor's and Heinrich's views that every task can be divided into several subtasks, and that each working steps should be carefully evaluated and managed. Many of the used analytic and mathematical tools used to evaluate risk and maintain safety within this organizations, originate from the mid-1900s, even though today's work has been more digitalized.

It was evident that the nuclear power industry obeys several rules, laws and regulations that authorities have established for them. They are carefully supervised, and all work has to be carefully evaluated and analyzed, before, during and after a task. Since these setting are far more rigid and tight coupled than those in the hospitals, the leadership and safety culture might be extra crucial within nuclear power industry, due to the absence of the ability to test different strategies and use shared leadership.

The principle of "friend-review" also reminds of the concept behind "mutual performance monitoring" described in the "Big-Five"-framework.

A common theme among the two interviewees, were the view on which behavioral characteristics a leader should possess. They both promoted a transformational and inspirational leadership. However, the two organizations both used transactional leadership in crucial situations.

6.4 Overall discussion

Even though the thesis' subject is a relatively new research field, the field is extremely broad and includes numerous aspects. As have been illustrated through the historical review in chapter 3.1, the view on leadership, teamwork and system safety have evolved throughout the years, meaning that the most recent research and theories have only existed for a limited amount of time. This became evident when searching for literature within the subject, where the most "modern" terms such as *multiteam systems* gave limited numbers of search results prior to the 2000s.

The tremendous amount of interest within the field of multiteam systems could not be foreseen. The majority of articles discussing leadership and teamwork also mentioned MTSs to some extent, which was motivating enough to also include these aspects into this thesis and dedicate a whole section solely to this.

However, as was mentioned previously, most studies found within the subject of leadership and teamwork have focused on single teams, since the term multiteam systems was coined relatively recently.

Additionally, many of the studies conducted on MTSs have been performed in laboratory environments, while those studies that specifically have analyzed leadership and teamwork in real-world settings, have done so in more specific working environments, like the energy or railway sector. But even though these studies had been conducted in different settings, many of them had concluded the same thing (i.e., they identified the same success factors), probably because these systems share some similarities regarding the organization's safety focus, and the prevailing conditions where several teams worked together (MTSs).

A fair reason behind the numerous recent articles mentioning MTSs should be due to more extensive use of information technology and internet, as well as globalization and outsourcing. The majority of today's organizations therefore consists of different teams, working together across nations and time zones, whether the organization is categorized as a safety-critical organization or not. These aspects make it necessary to further direct the future research to the field of MTSs, since the majority of today's and future organizations undoubtedly are, or will be, composed of a multiteam system and virtual teams.

Additionally, recent years accidents further highlight the need for future research within the field of safety-critical systems. The intricate network of socio-technical systems, consisting of multiple actors, can creates a division of the safety culture, creating so-called *subcultures,* something that seems to breed a culture where actors avoid their responsibility, even though everyone are well aware of the inherent risks.

An example is the devastating explosion in Beirut, the capital of Lebanon, which occurred the 4th of August 2020, at the same time as this thesis work was conducted. Only hours after the horrific explosion, news agencies and organizations all over the world, including CNN and Reuters, reported that the Prime Minister of Lebanon had assured that whoever are responsible for this catastrophe, they will pay the price. However, at the same time, the authorities of Lebanon quickly admitted that the government was well-aware of the highly explosive compounds, consisting of tons of ammonium nitrate, that had been stored at the harbor since 2013, without any safety-measures. The decision to store all of these hazardous compounds at the dock, turned the otherwise harmless facility into a safety-critical storage. This further highlight that it is not just *someone* who needs to take responsibility, but *everyone* must take their responsibility, including governments, agencies and leaders.

At the same time, comments on several social-medias and news sites, shows how incapable and narrow-minded the public, including authorities, are, and how quickly everyone want *one* or *some* scapegoat(s). However, after having read this thesis, one should probably be careful to quickly put the blame on a few individuals. If one embraces a more holistic perspective, which is necessary, one might find out a more accurate and horrifying truth that can explain the cause behind this devastating accident. However, even though it might take some time to investigate this accident, one can probably say that one thing is certain; this was not an accident caused by a single "mechanical" failure or an "unsafe act".

6.5 Conclusion

The literature uniformly point out the organizational challenges related to an increased complexity within today's society. Globalization, technological advancements and demands for efficiency and sustainability, altogether highlight the new era, where complex multiteam systems constitute the new normality for safety-critical systems.

This new constellation puts higher demands on the teamwork and leadership, which further means that prior safety theories that have dominated throughout the early and mid-1900s, must be put into perspective and evaluated in regard to todays' organizational constellations and their challenges.

The short-term focus on single teams, must, to a greater extent, be replaced with a focus that requires a more long-term, holistic approach, where organizational and sociological factors constitute the foundation of how these complex organizations should be understood. However, the characteristics of multiteam systems seems to spur actors to avoid their responsibility.

The categorization of *good* leadership and teamwork is not trivial, and highly influenced by the context in which these concepts are intended to be analyzed in. From a safety-critical perspective, these concepts need to be evaluated in regard to a long-term, cross-border perspective. A good leadership and teamwork have a positive impact on the safety culture and should further facilitate the dynamical operations inside the system, allowing the entire organization to cope with unexpected, contemporary as well as future, hazardous events. How well this works in practice is determined by several factors, such as communication, coordination, performance monitoring, backup behaviors etc., many of which are included in the concept of shared mental models, something that can be developed and enhanced through education and throughout cross-border training and simulation sessions. A good leader should promote the development of mental models and have a humble attitude towards team constellations, allowing strong, alert and curios teams to develop.

In today's socio-technical multiteam systems, humans, both as individuals and as teams, play an important role in the work for safety. From historical disasters, we have learned important lessons, and several devastating accidents in the 2000s further highlights that this endeavor must be a continuous work.

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Appendix

Below is the guide that was used during the interviews

Intervju-guide

1. **Berätta om dig själv och din erfarenhet från ledning**
    a. Dina ledarskapserfarenheter? Från vilka jobb?
    b. Vad gör du i jobbet idag? Vart jobbar du? Din roll?
    c.
2. **Snabba frågor – Vet du vad följande begrepp är? (Liten kort motivering + definition)**
    1. HRO
    2. RE
    3. Säkerhetskritisk verksamhet
    4. Multiteam och multiteam system
    5. Säkerhetskultur
    6. Säkerhet 1 och säkerhet 2

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3. **TEMA: Ledarskap**
    1. Hur definierar du ledarskap (vad är det för dig?)
    2. Framgångsfaktorer för ett bra ledarskap (Vad karakteriserar ett bra ledarskap, vad är de tre viktigaste komponenterna? Hur ska en bra ledare vara, (3 attribut))
    3. Den viktigaste uppgiften för en ledare?
    4. Vilka förutsättningar krävs för att du/andra ska kunna utföra ett bra ledarskap?
    5. Svårigheter och utmaningar med ledarskap? (under vilka omständigheter är det svårt att utföra ett bra ledarskap? Och när det är svårt, hur gör ni då?)
    6. Enligt dig, hur bör man utveckla ledarskapet inom er organisation? (vad ska man fokusera på, vad funkar/vad funkar inte?)
    7. Hur gör ni idag? Skiljer det sig mot hur du tycker att det borde vara? Om det skiljer sig, varför tror du det gör det?

8. Anser du att synen på ledarskap (ex vad som ska fokuseras på osv) har förändrats under din tid som yrkesverksam?

4. Vet du vad följande begrepp med tema på ledarskap är?

1. Vertikalt ledarskap/vertical leadership
2. Delat ledarskap (shared leadership)
3. Direkt vs indirekt ledarskap
4. Transaktionellt vs transformativt
5. Inspirationsikt vs positionellt ledarskap
6. Mentala modeller

5. Hur ser du på följande?

1. Kommunikationen (hur ska den gå till? Svårigheter/utmaningar? Hur går den till i er organisation vid stressade och kritiska situationer? Ge exempel på dålig/bra kommunikation)
2. Feedback
3. Koordination
4. Säkerhet (vad är det enligt dig? Hur upprätthåller man en god säkerhet? Vad är tecken på god säkerhet enligt dig?)
5. Hur uppstår olyckor enligt dig?
6. När olyckor uppstår hur hanteras det.
7.

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6. TEMA: Teamwork

1. Hur definierar du teamwork? (vad är det för dig?)
2. Vad är ett ”bra” teamwork? (Framgångsfaktorer, nämn 3 faktorer)
3. Vilka förutsättningar krävs?

a. Svårigheter/utmaningar? (när fungerar teamwork, när fungerar det inte? Och när det är svårt hur gör ni då?)
b. Enligt dig, hur tycker du man bör utveckla teamwork?
c. Hur gör ni idag? Skiljer det sig mot hur du tycker att det borde vara? Om det skiljer sig, varför tror du det gör det?
d. Var är en bra säkerhetskultur?