A systems approach to accident investigation: Does it evoke systems thinking in organizations?

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Thesis work submitted in partial fulfilment of the requirements

for the MSc in Human Factors and System Safety.

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Lund 2023

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Number of pages: 78
Illustrations: 6

Keywords
Safety, Accident investigation, Systems approach, AcciMap

Abstract

As systems become increasingly more complex, it is doubtful that conventional models of accident investigation can provide insight into accidents which occur in these complex systems. In safety science this problem has been recognized, and accident models using a systems approach have been developed to illuminate these complex systems. However, they have not been widely applied in the railway sector, the focus of this research. This research considers if the introduction of a systems approach accident-investigation model to members of a rail-transport company changes perceptions of safety and accidents. This research shows that the exposure to a systems approach accident-investigation model, in this case the AcciMap (Rasmussen, 1997), led to some increased understanding among some of the participants of the research: they showed some increase of systems-perspective characteristics in their contributions. Due to the limitations of this research, the generalizability of these results is limited. There is a need for further research into the effects the introduction of a systems approach to accident investigation has on organizations.

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Acknowledgements

This thesis is the final component of the Master’s programme in Human Factors and System Safety at Lund University. This programme has provided me with new and valuable insights into(safety) science and expanded my worldview. Gaining a better understanding of the framework of safety science and its relationship with other scientific fields has been one of the most important benefits. I want to thank all involved in the development, organization, and facilitation of Lund’s Human Factors and System Safety programme, especially considering the challenges posed by the COVID-19 pandemic.

A special thanks to Mads Ragnvald Nielsen and all those involved in supervising and examining my thesis work; they deserve my gratitude for their valuable advice, critical questions, and overall contributions to my thesis work. Special thanks also go to Roel van Winsen for his moral support, valuable discussions and for commenting on earlier versions of my thesis.

Many thanks to my employer for the opportunity to participate in this programme and for facilitating my thesis research in my company. Special thanks to all colleagues who contributed enthusiastically to my research. This thesis would not have been possible without your contribution.

Finally, I want to thank my family for their support and patience during my participation in the programme, especially during the research and writing of my thesis.

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Introduction

From a historical perspective, Dutch Railways and the wider rail industry tend to persist with conventional approaches to accident investigation aiming to increase the safety levels of their operations. Such conventional perspectives generally focus on the prevention of component failures through both physical and procedural barriers. An example of such an approach in the rail industry is the addition of multiple, technical systems in train cabins to warn and assist train operators so they can stop when dangerous situations arise.

For this industry, adding or optimizing barriers is logical, as the rail industry has strong mechanical, electrical, and engineering roots. Above all, it could be argued that the optimization of the railway system in this conventional way has been successful in maximizing both operational performance and safety. For example, the number of signals passed at danger (SPADs), an important precursor of railway accidents, has shown a decreasing trend for almost two decades (ILT, 2019). This is even more impressive considering the risen demand and higher utilization of the available infrastructure, reflected by the increase in kilometres travelled by train passengers in the Netherlands over the same period (Compendium voor de Leefomgeving, 2020) and the increase of train kilometres by 15% between 2007 and 2019 (ProRail; 2013, 2020). However, after two decades, the data suggests a flattening of this positive trend. Should the rail industry continue to use the same methods to increase the level of safety? Or does this flattening trend show that the conventional approach has reached its limits?

During the past years, the railway system has become more efficient and better optimized. However, it has also become more complex. Increased levels of digitalization, busier lines, higher demand and new devices have led to increased interactions between system components in a relatively short time. To put it in other words, the system has become more tightly ‘coupled’, and its interactions have become more complex, in the way that Perrow conceptualises coupling in the interaction/coupling chart (1984, p. 97).

Can conventional models in safety cope with this increased complexity? Or is there a need for organizations to use other models that create a better understanding of the workings of complex systems and their environment? As Leveson (2011) eloquently notes:

> The most common accident causality models assume that accidents are caused by component failure and that making system components highly reliable or planning for their failure will prevent accidents. While this assumption is true in the relatively simple electromechanical systems of the past, it is no longer true for the types of complex sociotechnical systems we are building today. (p. XIX)

As conventional models tend to focus on failures of individual (system) components and barriers in a linear way, they are less, or not at all, suitable to analyse and identify systemic factors and dynamics in complex systems (Dekker, 2006). Models with a systems approach attempt to capture these features of complex systems may succeed in doing so because of their focus on the systems level (Leveson, 2011)

This tighter coupling of the railway system and the more complex interactions that occur in the railway system create the necessity for different or additional perspectives on safety investigations. Conventional approaches may not deliver understanding of this complexity, which may lead to marginal gains on safety investments.

Limits of the Conventional Approach to Safety

The bowtie diagram (Trbojevic & Carr, 2000), as an example of a conventional model, illustrates the limitations of conventional approaches to safety management in complex systems (Figure 1). The bowtie diagram is used by Dutch Railways as the basis of its risk management. These diagrams are built and visualized with BowtieXP (Wolters Kluwer, n.d.) Bowtie diagrams are not uncommon in the wider European rail industry: the bowtie example in Figure 1 originates from the UK Rail Safety and Standards Board (RSSB) website. Bowtie diagrams are used to assist organizations in recognizing multiple hazards and consequences relating to a specific safety scenario (called ‘Top Event’ in the diagram), such as a derailment. Usually, these hazards develop when a specific event occurs that enables the hazard to cause harm or damage. These events are to be avoided, according to this model, by implementing barriers. When accidents do occur, reoccurrence of these accidents is countered by adding new barriers or by improving the effectiveness of existing barriers.

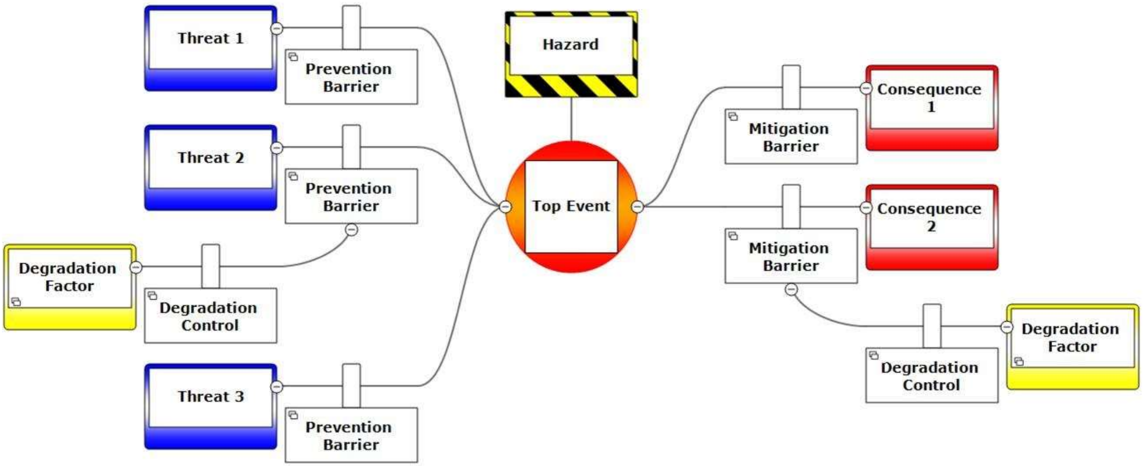
It is unclear where bowtie diagrams originated (de Ruijter & Guldenmund, 2016). However, this popular approach in the (Dutch) rail (and broader safety critical) industry has roots in the fault-tree method, cause–consequence diagrams, event tree analysis and barrier thinking (de Ruijter & Guldenmund, 2016).

One issue with the bowtie diagram in the context of complex systems is that it necessitates a precise identification of the hazard. This can only be achieved in relatively simple (parts of the) system(s). The defined system, as a result of this, must remain relatively small for the bowtie diagram to be useful. The diagram accentuates this with its focus on a single event. This focus suggests that the occurrence of the event and the effectiveness of the barriers intended to prevent it can be judged and measured in isolation from the rest of the system. It therefore assumes that the components related to the event and the barriers function in full isolation, that is, regardless of the functioning of (other components of) the system.

A second issue is that the model assumes a linear pathway from threat to top event. This is another sign that the bowtie diagram may fall short when creating safety in complex systems. A linear pathway may work for direct, causal, safety relationships. Powerline isolators, for instance, can effectively prevent energy from overhead electricity lines reaching unintended locations, such as passengers waiting for their trains or rail workers. In more complex systems, however, linear conventional models, such as the Bowtie model, may provide less insight, have less explanatory value. Such a model can be used to analyse linear barriers which prevent a train from passing a signal at danger: other signals, train-mounted automated-braking systems or the operator's basic understanding of train driving. However, it does not allow the incorporation of (non-linear) systemic factors. An example of such a factor is the formation of normal mental schemata by operators, which can lead to unintended interpretations of certain signals (Wilson & Rutherford, 1989; Klein, 2008). A systemic factor could be a policy change: pressure may be placed on the driver to arrive on time to cope with society's expectations of increased overall performance. This pressure sometimes leads to multiple goal trade-offs by train personnel during the train's departure. The bowtie model, in other words, is not fully capable of handling safety issues in larger and complex systems, in which events and accidents emerge from non-linear, internal interactions or the system interacts in complex ways with its environment, for example, society.

Figure 1

Bowtie Example

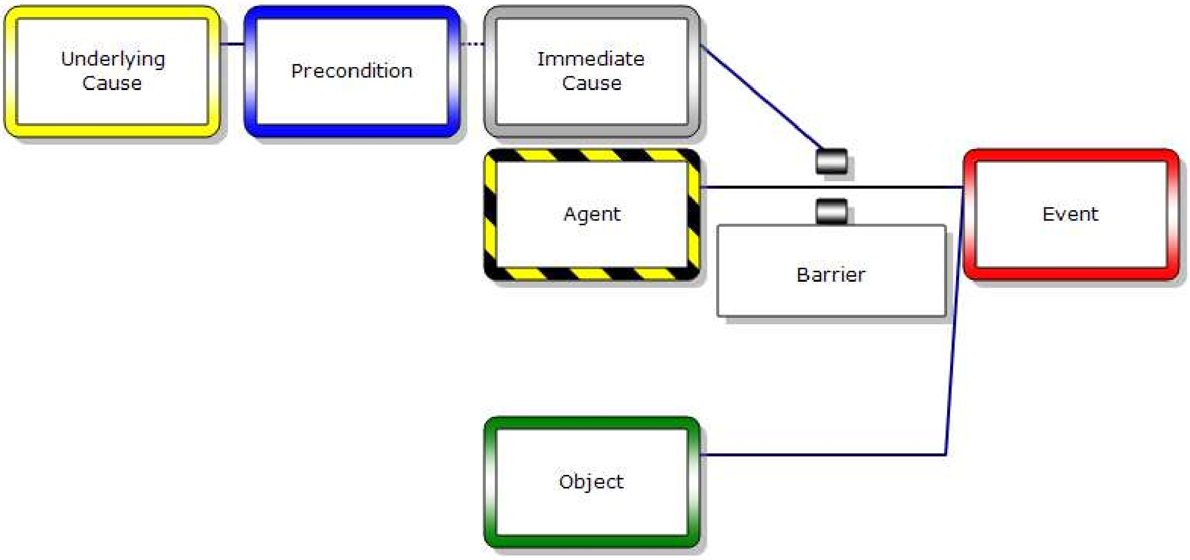


Note: From the introduction to bowties provided by the RSSB (https://www.rssb.co.uk/safety-and-health/guidance-and-good-practice/bowties).

The bowtie is not the only conventional model used in the railway industry. Conventional safety approaches also prevail in rail-accident investigations. Examples of these are root-cause analysis methods, Ishikawa or fishbone diagrams and the tripod beta model. Tripod beta (Groeneweg, 1998; Energy institute, 2004) is an investigation approach that is considered relevant and appropriate when a thorough investigation and analysis of an accident is required, and it has frequently been applied in investigations in the Dutch railway sector. A graphical representation of the model is provided in Figure 2.

Figure 2

Tripod beta example



Note: retrieved from tripod beta by Wolters Kluwer (https://www.wolterskluwer.com/en/solutions/enablon/bowtie/expert-insights/barrier-based-risk-management-knowledge-base/tripod-beta)

Although the tripod beta model can handle many different factors related to a particular accident, similarities with the bowtie model can be recognized from its visualization: as with the bowtie, the tripod beta model is based on linear relationships. Tripod beta applicants often claim that the model allows them to look beyond the more apparent causes to underlying organizational issues, and this may be the case. However, as the visualization shows, the model only permits the discovery of organizational issues that can directly be linked to failures.

For example, in 2010, a train failed to stop at the end of the track, which led to the train crashing into a water-sports shop positioned beyond the end of the line. Fortunately, no one was seriously injured. This accident was investigated by the Dutch Safety Board. The investigation (Dutch Safety Board, 2011) used the tripod beta model for its accident analysis and concluded that the main causes were that the train driver failed to break (failed barrier) and there was no automatic train control (ATB) at this location (missing barrier). With a focus on the (in)actions of the train driver, underlying factors were identified: an organizational failure to appropriately assess risks, too many occupants in the cabin, and a lack of oversight. Recommendations were made to strengthen or improve these failing and missing barriers. Systematically, many factors were addressed, but these factors were limited considered in a systemic manner: in relation to each other or to seemingly unrelated, non-linear, distant factors. The model, therefore, like the bowtie, tends to focus on isolated system parts, on the failings of barriers and on the linear causality of incidents. This limited scope of the Tripod beta model has been recognized, which led to new tripod models to be proposed (Groeneweg et al. 2007) While tripod beta may consider many different causes and factors, it does not make it possible to sufficiently address or consider the complexity, interactions and dynamics of a system in which many accidents occur.

As examples of conventional approaches to safety, the Tripod beta and Bowtie models seen as insufficient to analyse and cope with complex systems. These models are rooted in analytical reduction, reflected in their focus on finding broken components; this approach neglects factors which interact on a systems level. This highlights the need for a different approach towards safety, a systems approach.

A Systems Approach to Safety

The limitations of a conventional safety approach – and, more generally, of analytical reduction in safety – has been identified by many in safety science (Perrow, 1984; Rasmussen, 1997; Dekker, 2006; Leveson, 2011). In contrast, systems approaches to safety aim to counter these limitations. However, there are multiple definitions and perspectives on what a system approach consists of. Some of these are explored in the literature review. For this thesis an important perspective on a systems approach originates from Rasmussen, who captured some his ideas into the AcciMap model (1997).

In complex systems, components interact in non-linear ways, both in the system and with their environment (Leveson, 2011). This usually leads to desired results but can also occasionally lead to negative results, such as accidents. Accidents in complex systems, therefore, usually cannot be sufficiently explained by focusing solely on direct causes. These accidents are the result of the workings of interacting components as a system that interacts with its environment. Such system behaviour requires models that transcend cause-and-effect relationships.

Research Question

Systems-approach models in accident investigation are considered to be more suited for gaining insight into the (complex) systems in which accidents occur (Underwood & Waterson, 2014). Application of these may create opportunities for organizations to improve safety further, while the effects of the conventional models may have stagnated. Systems-approach models for accident investigation, such as AcciMap (Rasmussen, 1997) are developed for gaining, or attempt to gain, an understanding of (complex) systems in which accidents occur. Such an approach is opportune and increasingly necessary as today's systems and their environments become increasingly complex. In light of the issues and opportunities presented above, this thesis develops a case study to research the following:

> *Does the introduction of one systems-approach model (AcciMap) for accident investigation to members of a Dutch rail-transport company change their perception of safety and accidents and, if so, how could this affect the organization?*

Literature Review

The primary aim of this thesis is to investigate if and how members of an organization change their perception of safety when introduced to a tool that uses a systems approach to accident investigation. Therefore, it is relevant to consider where models with a systems approach are rooted in the safety-science literature and the broader body of scientific knowledge. After all, to consider what effect a model with a systems approach can have, it is important to define what a systems approach is.

Furthermore, systems-approach features need to be identified to determine if members of the organization show aspects of a systems approach when exposed to a systems-approach investigation. To that end, this chapter discusses a systems approaches, what that means in safety, and which features constitute a systems approach. Further, a number of systems-approach models are explored, and a description and review of the AcciMap model are included.

Systems Approaches?

As touched upon in the Introduction, the limits of analytical reductionism – the tendency to ascribe the behaviour of a system or phenomenon to isolated constituent parts – have been frequently noted in safety science (Perrow, 1984; Rasmussen, 1997; Dekker, 2006; Leveson, 2011). For complex systems, a systems approach is required, which perceives the behaviour of systems to emerge from the interactions between their parts (Leveson, 2004). Since its introduction in safety science, the systems approach (sometimes referred to as a systems-thinking approach) has gained a significant position in the safety domain, especially in relation to accident analysis (Underwood & Waterson, 2014; Salmon, 2020; Hulme et al., 2019).

Definitions of 'System'

The word 'system' is frequently used in daily life and can be found in scientific literature concerning safety and accident analysis. However, what is deemed a 'system' appears to differ in practice. A 'system' is defined according to the Oxford English Dictionary as 'an organized or connected group of things' or 'a group or set of related or associated things perceived or thought of as a unity or complex whole' (n.d.). Chapanis defined a system as follows: 'A system is an interacting combination, at any level of complexity, of people, materials, tools, machines, software, facilities, and procedures designed to work together for some common purpose' (1996, p. 20). Meadows, in turn, applied a somewhat broader definition: 'A set of elements or parts that is coherently organized and interconnected in a pattern or structure that produces a characteristic set of behaviours, often classified as its "function" or "purpose"' (2008, p.188). Despite differences, these definitions agree that systems consist of components or elements that work together leading to outcomes that can only be achieved as a system rather than as individual components or parts.

What is outside the system is defined as the system's surroundings or environment (Meadows, 2008). It is important to note, however, that what is seen as the system and where its environment begins is relative to the observer's viewpoint, as is where this boundary is drawn (Meadows, 2008). Meadows (2008) explains this eloquently:

> There is no clearly determinable boundary between the sea and the land, between sociology and anthropology, between an automobile's exhaust and your nose. There are only boundaries of word, thought, perception, and social agreement—artificial, mental-model boundaries. (p. 95)

Systems, in other words, cannot be found but are defined, or rather constructed, with a certain perspective in mind. As Meadows further explains: 'It's a great art to remember that boundaries are of our own making, and that they can and should be reconsidered for each new discussion, problem, or purpose' (2008, p. 99). This means a systems approach should be seen as a perspective, not as the perspective. As Dekker et al. (2011) write while considering the value of multiple 'revisionists' accident analysis: '[they] have offered various audiences the opportunity to embrace a greater richness of voices and interpretations. Together, they better acknowledge the complexity of the events, and the systems in which they happened, than any single account could' (p. 6).

Systems Approach

Turning to what a systems approach could encompass, a good metaphor is provided by Richmond: 'People employing systems thinking position themselves so that they can see both the forest and the trees; (one eye on each)' (1994, p. 140). Systems thinking argues for the relevance of adopting a perspective that makes it possible to see both the generic(system), and the specific parts simultaneously and in relation to each other. In behavioural terms, the observer sees both the pattern and the specific event (Richmond, 1994). As Bertalanffy (1950) likewise argues, from a biological standpoint, the existence and behaviour of complex systems (such as organisms) cannot be understood by merely analysing their constituent parts. A living system – with its will, intentions and character – is more than the sum of its parts. Bertalanffy argues, therefore, that the parts of an organism, or of any complex system, are interrelated and influence each other, resulting in a whole, such as life (1950).

In scientific literature, terms such as 'systems thinking' (Dekker et al., 2011), a 'systems approach' (Salmon et al., 2012) and 'systemic analysis' (Waterson et al., 2017) are used interchangeably (Leveson, 2011). The term 'systems thinking', according to Richmond, refers to 'the art and science of making reliable inferences about behaviour by developing an increasingly deep understanding of underlying structure [system]' (1994). A 'systems approach' is defined by Leveson (2011) as follows:

> The systems approach focuses on systems taken as a whole, not on the parts taken separately. It assumes that some properties of systems can be treated adequately only in their entirety, taking into account all facets relating the social to the technical aspects. (p. 63)

Both terms are rooted in systems theory, which ‘dates from the 1930s and 1940s and was a response to limitations of the classic analysis techniques in coping with the increasingly complex systems starting to be built at that time’ (Leveson, 2011, p. 61). During that time, Bertalanffy (1956) produced, preceded by work on holism by Smuts (1926). foundational work for his general systems theory and related work on cybernetics (Wiener, 1948). Cybernetics is defined as ‘the study of the underlying logic of the control of systems of any kind’ (Checkland, 1985).

These concepts may be interpreted by others as strongly related but not equivalent. However, for the purpose of this thesis, these multiple concepts are considered to refer to the same principle. Therefore, the term ‘systems approach’ is used to refer to all these concepts.

Based on his work on organisms, Bertalanffy (1950) developed his open-systems theory. Open-systems theory not only studies systems in terms of wholes, functions and relationships, it studies the whole system as it interacts with the environment.

To be able to generalize from the open-systems concept to other sciences, Bertalanffy introduced a general systems theory (1956), from which the field of systems thinking emerged. This discipline found its way into many different fields and domains, such as organizational science (Flood, 2010), management science (Jackson, 2009) and safety science (Rasmussen, 1997; Hollnagel, 2004; Hollnagel & Woods, 2005; Dekker et al., 2011).

Systems Thinking in Safety Science

Bertalanffy (1950, 1956) highlights that complex systems can only be understood as whole systems and not by studying the elements from a reductionistic perspective. This has been acknowledged in safety science by multiple contributors (Dekker et al., 2011; Hollnagel, 2004; Leveson, 2004; Rasmussen, 1997; Svedung & Rasmussen, 2002). Accidents in complex systems emerge from complex interactions, multiple factors and various dynamics rather than from a single-point failure or a few causal aspects, sometimes referred to as Safety I (Dekker, 2006)

To advocate for a different approach to safety, conventional safety is labelled by Hollnagel as ‘Safety I’ (2014; Dekker, 2006). In contrast to ‘Safety I’, Hollnagel proposes a focus in safety (science) on (work) processes, suggesting that this is where the most (system) safety improvement may be made: this is labelled ‘Safety II’ (Hollnagel, 2014).

Although Hollnagel’s clear aversion to what he labelled as ‘Safety I’ is shared by others in safety science, his strong critique of Safety I has attracted sharp criticism of its own from Leveson (2020). Leveson argues that Hollnagel made a caricature of the past actions of safety science and the practitioner field. She argues that much has been accomplished to understand the systems in which accidents occur, stating that Hollnagel is either ‘uninformed about safety engineering or he has created a strawman to make Safety-II look better’ (Leveson, 2020, p. 104). Furthermore, Leveson criticizes Hollnagel’s Safety II as leading to a strong focus on the behaviour and decisions of people in the system: Safety II ‘Concentrates almost entirely on the human operator’ (Leveson, 2020, p. 104). She further states that ‘Safety-II is the opposite of a systems approach (or a sociotechnical approach) as the technical seems to be excluded from playing any important role in safety’ (Leveson, 2020, p. 104).

As interesting as these discussions in safety science are, they seem to lead to polarization in the community: ‘The theorists bicker whilst the empiricists, who should be adjudicating these arguments, are instead trapped within closed theoretical frameworks’ (Rae et al., 2020, p. 2). Rae et al. argue that these discussions do not advance safety science, and they therefore advocate reality-based safety science. They state: ‘Reality-Based Safety

Science is based on a virtuous cycle of studying current practice in order to advance theory and applying theory to advance current practice' (2020, p. 5). This thesis research attempts to follow this lead, applying a safety-science model that uses a systems approach to accident investigation and researching the effect on accident investigation in a typical organization.

Features of Systems Approaches in Safety Science

Three features (or elements) of a systems approach surface in the safety science, or systems safety, discourse: emergence, complexity and interactions. These are considered in this section. These features are relevant for this study as they can indicate whether participants display a systems view of safety in their comments and notes on the case study.

Emergence

Emergence in safety science has a direct link with Bertalanffy's (1956) description of the emergent behaviour of organisms. From a systems perspective, safety is an outcome of the behaviour of the whole system and the system's interactions with its environment. It cannot directly be explained by considering the behaviour of the system's constituent parts alone. Safety emerges at the system level and is the outcome (and therefore resultant) of the many interactions and dynamics that exist both within the system and between the system (components) and its environment (Leveson, 2011).

However, not everything that can be contributed to a system is emergent. Simple or more complex systems can generate deliberate and expected processes and outcomes. The researcher understands emergence in the context of unintentional processes and states. In line with how Lintern & Kugler define emergence: 'Emergence is a non-intentional consequence of relational interactions between system processes. Crucially, this claim asserts that the function or form of an emergent state as established by interactions between system processes is not specified by an intentional agent' (2022, p. 2).

Systems, in safety science, include all kinds of social (or organizational) dynamics that must be considered (Rasmussen, 1997). The accidents that safety science generally address emerge from these system dynamics. Organizational accidents, therefore, should not only be investigated to search for the broken element, but predominantly analysed as an outcome of a whole system; an accident has emerged from the system's interactions because the system had become increasingly complex (Dekker et al., 2011). Consequently, the investigations into these accidents should have a systems approach because 'the acknowledgment of complexity in safety work can lead to a richer understanding, and thus it holds the potential to improve safety' (Dekker et al., 2011, p. 944).

Complexity

Systems thinking has a strong relationship to complexity thinking (Dekker et al., 2011). Defining complexity has been difficult (Hollnagel, 2011). Hollnagel (2011) defines it in a formal sense as follows:

> A measure of the number of possible states a system can take, or as the condition of a system, situation, or organization that is integrated with some degree of order, but with too many elements and relationships to be understood in [a] simple analytic or logical way. (p. 200)

Flach (2012), based on Hollnagel, defines complexity with a focus on what he sees as the problem: 'the term complexity refers to the number of possibilities in the problem space – the greater the number of possibilities, the greater the complexity of the problem' (2012, p. 188). Both definitions of complexity focus on the scale or number of interactions and relationships between system parts, which can lead to different states of the system at the system level.

Complex systems can never be fully understood; nonetheless, people do function in complex systems (Dekker et al., 2011). According to Dekker, they behave in a manner that makes sense from their perspective in the system: they do what seems rational from their local view of the system and their place and function in it. This is sometimes referred to as 'local rationality'. Local rationality refers to the idea that people act reasonably from their perspective in a system, from the goals they are pursuing and the knowledge and resources that they have available at that moment (Dekker, 2006).

A scholar who linked complexity and safety explicitly is Perrow. In his book *Normal Accidents* (1984), he introduces the notion of interactive complexity and coupling as the two axes on which systems may be plotted to determine whether these systems have the potential of experiencing a normal accident. A 'normal accident' refers to an accident that inherently occurs because of the nature of the system; it is not an accident because it is certain to happen. Perrow explains that if 'interactive complexity and tight coupling – system characteristics – inevitably will produce an accident, I believe we are justified in calling it a normal accident, or a system accident' (Perrow, 1984, p. 5). In other words, systems with these characteristics are setup for accidents: hence the term 'normal accidents'. In these systems, accidents will inevitability occur. Perrow refers to normal accidents "or, as we will generally call them, system accidents" (1984, p. 12); so, he uses both terms interchangeably.

'Tight coupling' refers in Perrow's work to the characteristic of system components being closely packed together in proximity or time, making it difficult or impossible to interrupt or stop an evolving accident. In Perrow's own words, 'what happens in one [item] directly affects what happens in the other' (1984, p. 90). If systems only have linear interactions, or act in a linear fashion, this is unproblematic. Linear interactions make systems comprehensible, which allows timely interventions to prevent unwanted outcomes even if components are tightly coupled. However, if the system has a high degree of non-linear interactions – that is, complexity – it becomes challenging to predict or analyse where events will occur in the system. This complicates any intervention; it becomes less possible to control all the components (Perrow, 1984).

According to Perrow (1984), interactive complexity, with its non-linear interactions, can lead to normal accidents when combined with tight coupling. Today's socio-technical systems – systems in which technical and social aspects are connected and interact – are becoming increasingly complex (Rasmussen, 1997; Dekker, 2006). Accident analyses, and the analysis models used, should therefore be capable of capturing some of this complexity.

Interactions

A focus on interactions (between components in the system and between the system and its environment), rather than on the isolated components in the system, is also a crucial foundation of systems thinking (Rasmussen, 1997).

The value of interactions should thus be considered another feature of system-safety thinking and should be considered when studying a system in which an accident has occurred (Dekker et al., 2011; Perrow, 1984). Neglecting these interactions in accident analysis would result in an analysis of the system, such as an accident investigation, that did not reveal the (complex) interactions that were involved in making the accident possible. As Dekker writes, 'The processes of erosion of constraints, of attrition of safety, of drift towards margins, cannot be captured because reductive approaches are static metaphors for resulting forms, not dynamic models oriented at processes of the formation, the evolution of relationships' (Dekker, et al., 2011, p. 4).

The systems-approach characteristics discussed in this section have been introduced to safety science through a number of models. These are discussed below.

Systems-Approach Accident-Analysis Models in Safety Science

Introducing a systems approach in safety science has resulted in a number of methods and models for analysing accidents. Among the most well-known and applied models in safety science (Waterson et al., 2017; Underwood & Waterson, 2014) are the systems theoretic accident model and process, mostly referred to as STAMP (Leveson, 2004) and the AcciMap (Rasmussen 1997).

STAMP was developed by Leveson (2004) and is created around the three concepts of ‘safety constraints, hierarchical control structures, and process models’ (Leveson, 2011, p. 73). According to Leveson, this leads to seeing safety as a control problem instead of a reliability issue (2011). The STAMP model shows relationships and interactions between system parts – such as components, employees and subsystems – in hierarchical order, focusing on the controls required to prevent accidents (Leveson, 2011).

AcciMap was developed by Rasmussen (1997) and developed further by Rasmussen and Svedung (2000, 2002). It is based on the theory of the socio-technical system in which accidents occur (discussed further in the origins of AcciMap section) that Rasmussen developed in the late 1980s and 1990s. (1992, 1997). The AcciMap aims to map or analyse an accident by perceiving not only direct related factors, such as actions by operators or machinery, but also the context of the socio-technical system in which the accident occurred. The AcciMap model considers this context, such as events and decisions, at six interacting levels of the socio-technical system (Figure 4). The authors perceive this as a characteristic which differentiates the model from its predecessors:

> In contrast to the conventional cause–consequence chart, the analysis for development of an AcciMap should not only include events and acts in the direct dynamic flow of events. It should also serve to identify *all decisionmakers at the higher level* in the socio-technical system that have influenced the conditions leading to [an] accident through their *normal work* activities. (Svedung & Rasmussen, 2002, pp. 406–407)

Comparisons have been made between these models. For example, Underwood and Waterson (2014) compare systems-thinking models (STAMP and AcciMap) with a reason-inspired (1990) Swiss-cheese-based model (ATSB) in application to the Grayrigg train derailment. They conclude that the STAMP model 'more clearly embodied the concepts of systems theory' (Underwood & Waterson, 2014, p. 93), However, the AcciMap (and ATSB) models presented their findings in a graphically more concise way. Underwood and Waterson therefore conclude that 'the AcciMap method may more easily meet the needs of both [practitioner and research] parties' (Underwood & Waterson, 2014, p. 93).

Salmon et al. (2012) compare STAMP, AcciMap and the Human Factors Analysis and Classification System (HFACS) when applied to the Mangatepopo gorge-walking tragedy. This research shows that both AcciMap and STAMP can provide a comprehensive coverage of the overall socio-technical system in which the Mangatepopo tragedy happened. However, they also find important differences between the models. They find the STAMP model can potentially provide a deeper understanding of the system under analysis, but to achieve such insight an in-depth knowledge of the system is required. Understanding the STAMP taxonomy and STAMP-specific language is also necessary (Salmon et al., 2012). This means considerable resources are needed to perform an analysis based on the STAMP model. Therefore, Salmon et al. (2012) conclude their research by choosing AcciMap as the preferred model:

> Analysis suggests that the AcciMap method is the most suitable. The entire system can be considered, and the analyst is not restricted by taxonomies of failure modes, making the approach the most comprehensive and easy to use … Further, the ability to consider failures, decisions and actions generally is likely to be simpler for safety practitioners and accident investigators not familiar with control theory and systems dynamics. (p. 1169)

AcciMap

As a result of the arguments by Salmon et al. (2012) and Underwood & Waterson (2014) in the previous section, for this thesis research, the AcciMap was used as a systems-approach model to accident investigation. Therefore, it is relevant to explore further the origin of AcciMap and how it is perceived and has been used in research.

Origin of AcciMap

AcciMap was developed by Jens Rasmussen in the context of his concept of the socio-technical system. He proposed a model of a socio-technical system, a system in which technical aspects and social dynamics (e.g., human, organizational and institutional dynamics) are tightly connected and intertwined.

Rasmussen introduced the first theory of the socio-technical system in safety science with his social-technical system in the late 1980s (Le Coze, 2015). This was followed by an alternative version in 1992 that includes scientific disciplines associated with a specific level of the model and then by his most complete version (Figure 3) which adds environmental constraints (1997).

Rasmussen perceived that the propagation of a course of events leading to an accident is shaped by the activity of people (at any level of the system) triggering an unintentional flow or diverting the normal (safe) flow in work processes. Safety is therefore achieved through the control of work processes (Rasmussen, 1997). Such control is, or can be, striven for throughout all levels of the social-technical system. This control, Rasmussen argues, can only be effectively applied with a sufficient understanding of the whole problem space, the socio-technical system and how it functions. This may only be achieved by studying all six hierarchical levels (Figure 3) in conjunction, ranging from the government level (top level) to the activities in operations (bottom level). It is also necessary to study the feedback loops between the levels (information of systems parts which is related back to other system parts on different levels) and other interactions.

The AcciMap was developed as an applicable framework of the socio-technical system (Le Coze, 2015). It has been applied by Rasmussen (1997) in the context of the capsizing of the MS *Herald of Free Enterprise* in 1987 at Zeebrugge to gain an insight into the problem space.

The AcciMap model is intended to provide users with a comprehensive systems perspective. It includes an integral analysis of interactions across hierarchal levels rather than the apparent, linear, causal explanations provided by conventional approaches to safety.

Figure 3

The socio-technical system involved in risk management (Rasmussen, 1997)

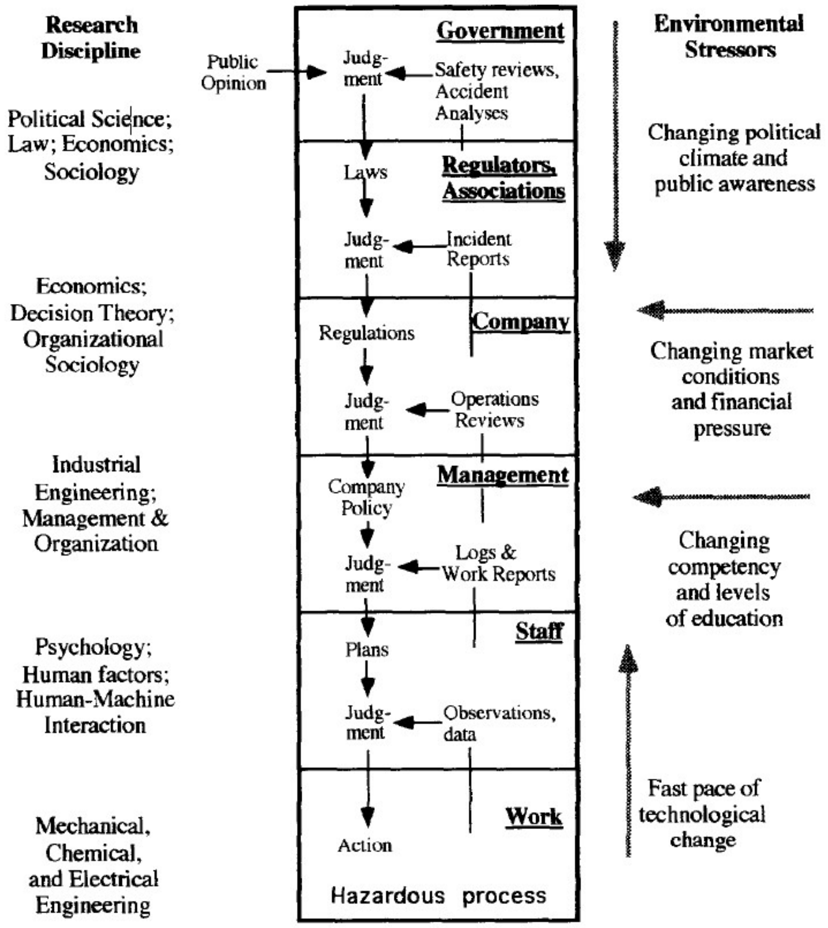
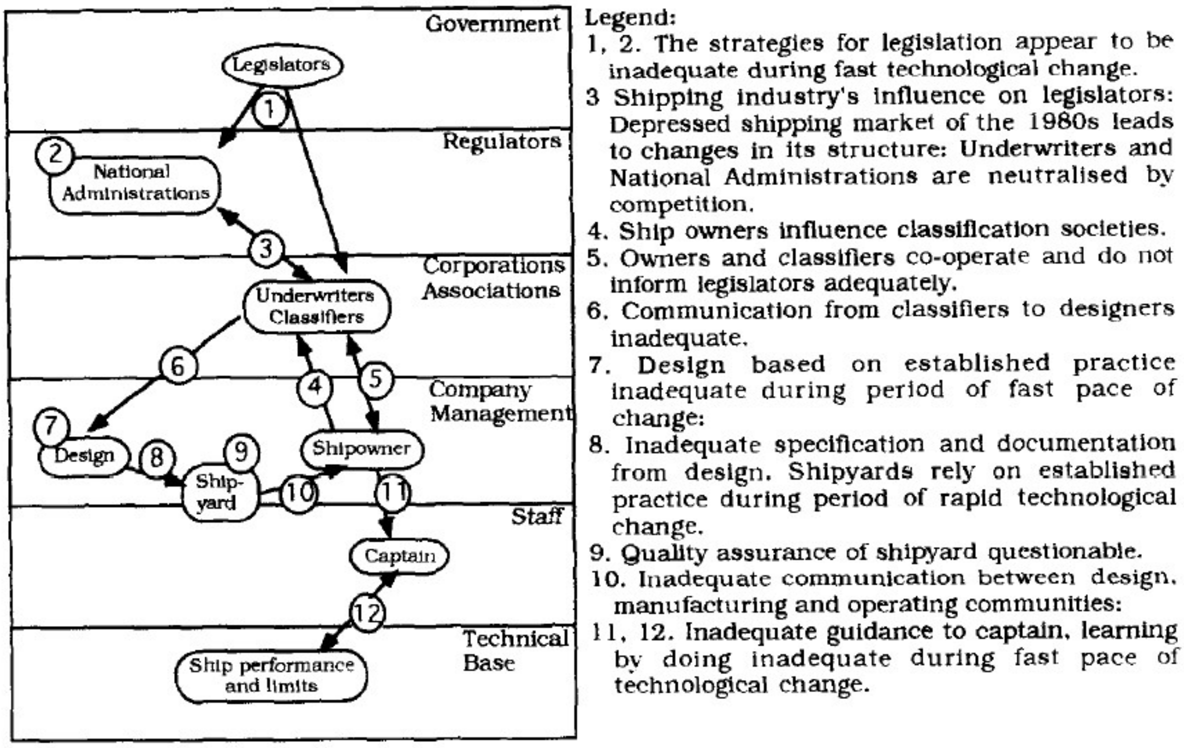


Figure 3 represents Rasmussen's most complete version of the socio-technical system, although versions and elements are present in his earlier work (Le Coze, 2015). Rasmussen's work on the modelling problem of socio-technical systems led to his later AcciMap model for risk and accident analysis (Figure 4).

Figure 4

A simplified AcciMap of the Zeebrugge accident (Rasmussen, 1997)



Legend:
1, 2. The strategies for legislation appear to be inadequate during fast technological change.
3 Shipping industry's influence on legislators: Depressed shipping market of the 1980s leads to changes in its structure: Underwriters and National Administrations are neutralised by competition.
4. Ship owners influence classification societies.
5. Owners and classifiers co-operate and do not inform legislators adequately.
6. Communication from classifiers to designers inadequate.
7. Design based on established practice inadequate during period of fast pace of change:
8. Inadequate specification and documentation from design. Shipyards rely on established practice during period of rapid technological change.
9. Quality assurance of shipyard questionable.
10. Inadequate communication between design, manufacturing and operating communities:
11, 12. Inadequate guidance to captain, learning by doing inadequate during fast pace of technological change.

AcciMap was not initially developed purely as an accident-analysis technique, as Le Coze explains: 'AcciMap is initially a tool designed for mapping the distributed nature of decision-making shared by actors located at different moments in time and geographical positions in the daily operation of socio-technical systems' (Le Coze, 2015 p. 134). Nevertheless, it has been widely applied to provide a systems approach to accident analysis (Waterson et al., 2017; Salmon et al., 2020). The popularity of this approach started with

Rasmussen's application of his model to the capsizing of the MS *Herald of Free Enterprise* (Rasmussen & Svedung, 2000). Other researchers have altered the AcciMap, (Parnell et al., 2017) or combined it with other models (Salmon et al., 2013), reflecting the popularity of the AcciMap's ideas and visualizations. In the safety-science literature, the AcciMap is most often applied to a case for which formal investigation reports are available as source material (Hopkins, 2000; Jenkins et al., 2010; Salmon et al., 2013; Lee et al., 2017).

Practitioners' Views of AcciMap

Systems models of safety have gained popularity in safety science. However, they seem to have had little impact outside academia (Underwood & Waterson, 2013). This may be related to the wider issue of the gap between academia and practice (Shorrock, 2019). There are a few exceptions, however, such as EUROCONTROL's 'Systems Thinking for Safety' whitepaper, which attempts to promote systems thinking by suggesting 10 practical principles (EUROCONTROL, 2014). Nevertheless, in safety-critical industries, reductionist models dominate practice and system approaches to accident investigation analysis seem to be less popular (Underwood & Waterson, 2013).

Underwood and Waterson (2012) studied possible reasons why systems-approach models, such as AcciMap, are less frequently used. They identify the following: 'Model validation, usability, analyst bias and the implications of not apportioning blame for an accident were identified as the key issues which may influence the use of the systems approach within industry' (p. 1717). First, systemic models lack sufficient validation, which impedes practitioners from applying these models and favours established, conventional models. The usability of systems models of safety, moreover, is limited due to the lack of clear user guidelines. The usability could also be influenced by the higher effort (and cost) needed to implement systemic tools and even by regulations in certain industries that prescribe more conventional approaches. Furthermore, many practitioners may have prior experience with sequential techniques and models using the individual cognitive style. Therefore, they may have developed a preference for this type of analysis, which may inhibit their use of systemic models. Last, systemic models tend to promote the avoidance of apportioning blame to individuals, while industry practitioners often feel a need to identify the responsible individuals. This possibly adds to the incentive to use non-systemic models to be able to more easily identify culpable personnel (Underwood & Waterson, 2012).

More recent research on this issue has been performed. Igene et al. (2021), for instance, recently studied ‘patient safety practitioners’ perception of the use of Branford’s formalised AcciMap approach for incident/accident analysis’ (p. 4).. They used a case-study methodology with practitioner focus groups. The aim of their research was threefold: (1) to obtain the participants’ perceptions of the application of the formalized AcciMap approach, (2) to perform a qualitative evaluation of the AcciMap approach and (3) to explore whether there are benefits in using this approach as part of an adverse-event analysis for health and social care (Igene et al., 2021).

Three focus groups were held, in which the participants created their own AcciMap after an instruction session. Thereafter, the focus-group participants completed a survey. The participants’ perceptions of the AcciMap approach were derived by comparing usage characteristics (Underwood & Waterson, 2014). Characteristics included the data requirements (validity, reliability, and usability) and the graphical representation of the accident. The researchers wanted to determine if an AcciMap would work in practice. The results show that the AcciMap approach was perceived as generally intuitive and relevant for incident investigations in a healthcare setting. However, the participants expressed concerns about its usability in comparison to conventional root-cause-analysis (RCA) techniques (participants suggested it was time-consuming and demanding to understand the AcciMap model). Although Igene et al.'s research delivered valuable insights, they did not study explicitly to what extent and in what ways organizations would be affected.

Research Design

Most research into system-approach investigation models in safety science has compared models (Sklet, 2004; Salmon et al., 2012; Underwood & Paterson, 2014) or applied a model to a case (Hollnagel et al., 2008; Jenkins et al., 2010; Stanton et al., 2019b). For this research, the effect of a systems approach investigation model is researched by gaining data from first exposing participants to a conventional investigation and then a systems approach investigation model, the AcciMap. As these participants are a representation of the target audience, Dutch Railways, this data collection aims to provide insight as to whether the perspectives of members of this organization change their perception of safety and accidents when systems-approach models are incorporated into its investigation process.

To ascertain the participants' experiences and perspectives, a case-study approach was chosen. A case-study approach is well suited for generating data from people's experiences and practices, and it allows the researcher to reflect the complexity of organizational life (Blaxter et al., 2006). The case study was performed in the researcher's own organization, a Dutch train operator. This improved access to participants and the potential relevance of the research to the organization.

As part of the research design, respondents were a multi-hierarchal representation of the departments of the target (operational) organization. The operational parts of the organization were represented in two focus groups. First, they were briefed about an accident and subsequent actions based on a formal investigation report that represents a safety-board perspective on accidents: that of the National Transportation Safety Board (NSTB), an institution held in high regard (Malmquist et al., n.d.). Participants were then asked to write and share their perspectives on the case and the report, after which there was a plenary group discussion. During the second part of the focus group, the participants were briefed on the same accident, but now from a systems-approach model: the AcciMap model (Rasmussen, 1997). Thereafter, participants were asked what their perspective on the accident was now, with the aim of understanding the effects of being exposed to the AcciMap's systems perspective. The participants' perspectives (the data) was collected through recordings and a survey. Through an analysis of this data, this research investigates how the participants were affected when exposed to a systems-approach model.

Selection of Participants

Accident-investigation reports are usually written by safety professionals (Dutch Safety Board, 2010; US Chemical Safety and Hazard Investigation Board, 2014). However, accident-investigation reports target audiences such as the general public, stakeholders and organizations who were (indirectly) involved or related to the accident. As seen in the literature review, other researchers have studied safety professionals; however, this research does not focus on solely safety professionals but a broader target audience.

Therefore, participants were selected to represent a target audience, the Dutch railways (operational) organization. To that end, members of major departments, staff and decision-makers were selected (Table 1). Due to the range of these informants, the data is considered representative of the wider organization. Having two focus groups of informants makes it possible to validate the data, from each focus group by comparing it with one another. Each participant in each focus group was selected so that their position in the organization was comparable or strongly related to a functional counterpart in the other group. Table 1 provides an overview of all the selected (18) and participating (16) participants of both focus groups.

Table 1

Focus group participants' backgrounds

	Focus group 1	Focus group 2
1.	Logistical department representative	Logistical department representative
2.	Train drivers team manager	Train drivers team manager
3.	Quality advisor	Quality advisor
4.	Technical helpdesk representative.	Technical helpdesk representative
5.	Fleet management representative**	Fleet management representative*
6.	Managing director**	Managing director**
7.	Maintenance department representative*	Maintenance department representative
8.	Train staff management representative**	Train staff management representative.
9.	QHSE*** advisor	QHSE*** advisor**
Number of participants:	8	8
Total number of participants:	16	

Note: * Due to circumstances, these participants could not attend the focus group session. ** These participants indicated, when asked, that they had seen a AcciMap model before and estimated that they could work with such a model individually. *** Quality Health Safety Environment (QHSE)

The focus-group sessions were held in Dutch, the native language of all the participants. All the information provided during the session was therefore in Dutch. Information that originated from English texts was translated from English to Dutch using Google Translate and then crosschecked and modified to correct the Dutch where necessary by the researcher.

To create an open and safe environment for the participants, they were given a brief description of the session, what was expected of them, the rules during the session and the importance of respect for each other's opinions and stances towards the accident. As the focus groups included respondents from more than one hierarchical level, it was stressed that each contribution to this research was equally valuable.

The Accident Used in the Case Study

The research used an accident that occurred in Tempe, Arizona, USA, on 18 March 2018. A pedestrian who was walking alongside her bicycle was hit by a Volvo CX90 that was modified to test Uber's automated driving system (NTSB, 2019). In the modified Volvo CX90, an operator was present to monitor the autonomous driving system and to intervene if necessary. The vehicle collided with the pedestrian when she was crossing the street, which resulted in her death. The incident generated a great deal of attention in the (international) media due to the unique features of the incident, largely because the accident involved a (semi-) autonomous vehicle.

The tragic accident in Tempe was selected for the case study because there are two accounts of the case publicly available. The case was investigated by the NTSB, and their report can be seen as representative of a typical, conventional, safety investigation by a safety board. The other account appears in a scientific publication, where the accident was analysed using the AcciMap systems model (Stanton et al., 2019a).

The NTSB is a respected organization with authority regarding safety investigations. The NTSB report (2019) can therefore be seen as representative of how the NTSB, and similar safety boards in other (Western) countries, investigate and report (major) accidents.

Another consideration for using this particular accident for the case study is that the preliminary NTSB report (2018) was a primary source for the AcciMap analysis in the scientific publication (Stanton et al., 2019a). Therefore, both reflections of the case share broadly the same level of information. The two accounts, moreover, can be regarded as more bias-free, as the researcher had no hand in converting the NTSB accident analysis into an AcciMap systems approach. Preventing that any researchers' biases were included, due to the researcher being an accident investigator himself. This does not mean the NTSB and AcciMap representation of the case are completely bias-free. The investigators of the NTSB and Stanton et al. had to accommodate their own biases in the process of the investigation and the research. Moreover, Stanton et al. (2019a) faced further challenges due to working with secondary data, which may be altered or influenced in comparison to primary data.

Nonetheless, for this research, the advantage of utilizing the NTSB and scientific report (Stanton et al., 2019a) are deemed to outweigh the potential risks of their use. Although the NTSB and Stanton's report might have been subject to the biases of the authors, these biases were minimised through the review process prior to their publication. There use has its advantages in comparison to the risk of introducing the researchers' own biases by using a self-created AcciMap.

Design of the Focus Groups

Two focus groups were held, one with each participant group. The focus groups were divided into two parts. The focus group design can be found in Table 2. In the first part of each focus group, the group was briefed on the accident based on the NTSB's findings. After this, the respondents were asked to fill in a form that asked (1) what they thought of the NTSB's findings, (2) what learning point they saw relating to the case study and (3) what three measures they would implement in order of importance. A 20-minute plenary group discussion followed, during which the participants discussed their answers to these three questions, exchanged views and reactions and discussed their views.

In the second part of each focus group, the group was briefed on the accident based on the AcciMap. After the presentation of the AcciMap analysis of the accident, the respondents were asked to fill in a form answering (1) what they thought of the AcciMap analysis, (2) what learning point they saw relating to the accident from the AcciMap and (3) what three measures they would implement in order of importance. Two additional questions were asked in this part of the focus group: (4) what they thought of the NTSB's findings having seen the AcciMap and (5) if they thought the AcciMap added value to the NTSB investigation. As in the first part, the briefing and survey was followed by a 20-minute plenary group discussion, which included an exchange of views and reactions and a discussion.

Table 2

The focus-group design

	Focus group 1	**Focus group 2**
Introduction to the accident		
Part 1: NTSB findings briefing	Individually fill in Form 1	Individually fill in Form 1
	Group discussion	Group discussion
Part 2: AcciMap analysis briefing	Individually fill in Form 2	Individually fill in Form 2
	Group discussion	Group discussion

Part 1: NTSB Findings Briefing

Part 1 started with a PowerPoint presentation by the researcher. This presentation was based on the executive summary from the NTSB's investigation report (NTSB, 2019). The sections concerning the crash summary, probable cause and findings were translated and used in the presentation. The sections concerning the safety issues and recommendations were deliberately left out the presentation. Also NTSB's findings concerning measures after the incident were omitted from the presentation. These sections and findings were left out to avoid overly influencing the participants and to enable them to devise their own measures and form their own opinions.

Images from the formal report (NTSB, 2019) were added to help the participants understand what happened. For similar reasons, a short video recording (VentureBeat, 2018) was included which shows internal and external footage of the Volvo CX90 a few seconds prior to the accident. After the presentation, the participants received the presentation on paper.

Part 2: AcciMap Analysis Briefing

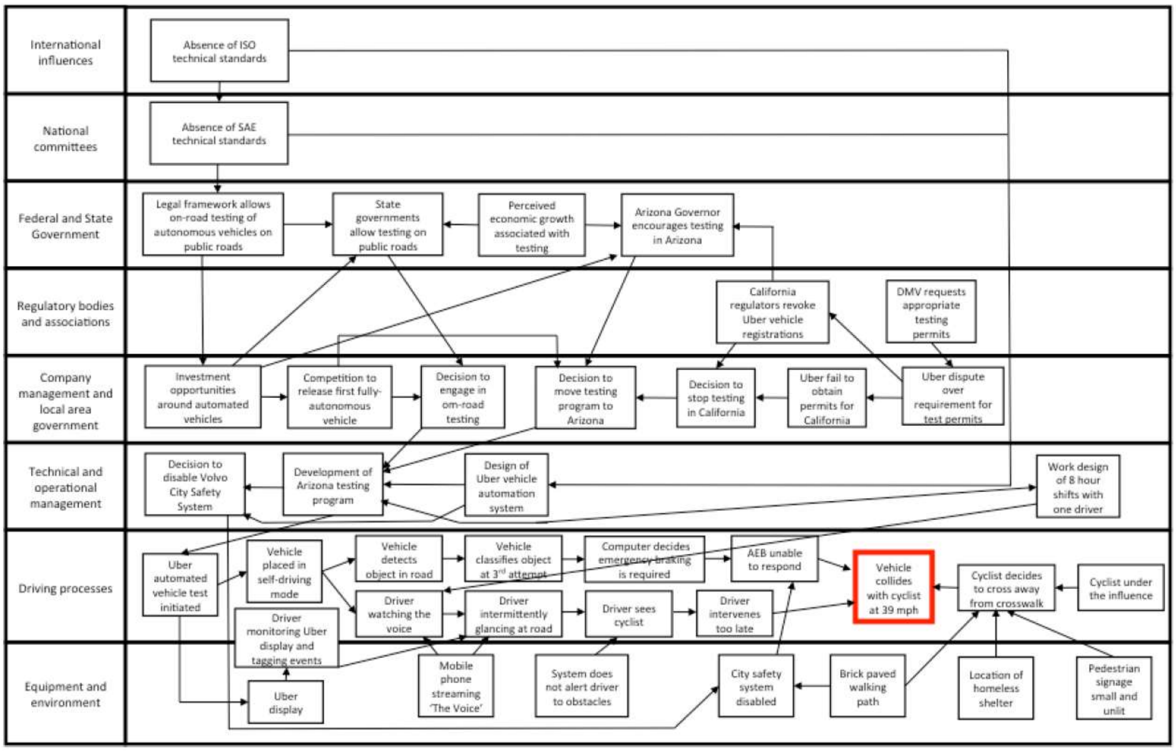
The AcciMap presentation started with a brief introduction of the AcciMap in general terms, referencing Rasmussen (1997). Participants were also shown a few examples of applied AcciMaps, to familiarize them with the model, so they would have some idea of what the eventual AcciMap of the accident would look like. This step was included because an AcciMap can be somewhat overwhelming sometimes at first glance as one participant of the second focus group noted, and was acknowledged by others, during a group discussion:

> Of course, you can just sit and work this out yourself with those arrows and which way they point, but like you say. It takes time. By including us in it, you save time. But in the end, I think we'd all get it, but you might be staring at it for an hour.

Minor changes were made to Stanton's AcciMap, moreover, to assist the participants to gain an understanding of the AcciMap in the limited timeframe available. The adapted version of Stanton's AcciMap figure is shown as Figure 6. The first change was that the AcciMap analysis was recreated in PowerPoint so that it could be animated to prevent participants becoming overwhelmed. Rather than all at once, the AcciMap was visually built in the PowerPoint presentation as each box and line was added. The order in which these elements were added was based on Stanton's description of the accident to be as true as possible to Stanton's AcciMap narrative (Stanton & Salmon, 2020).

Figure 5

Stanton's AcciMap of the Uber collision with a pedestrian

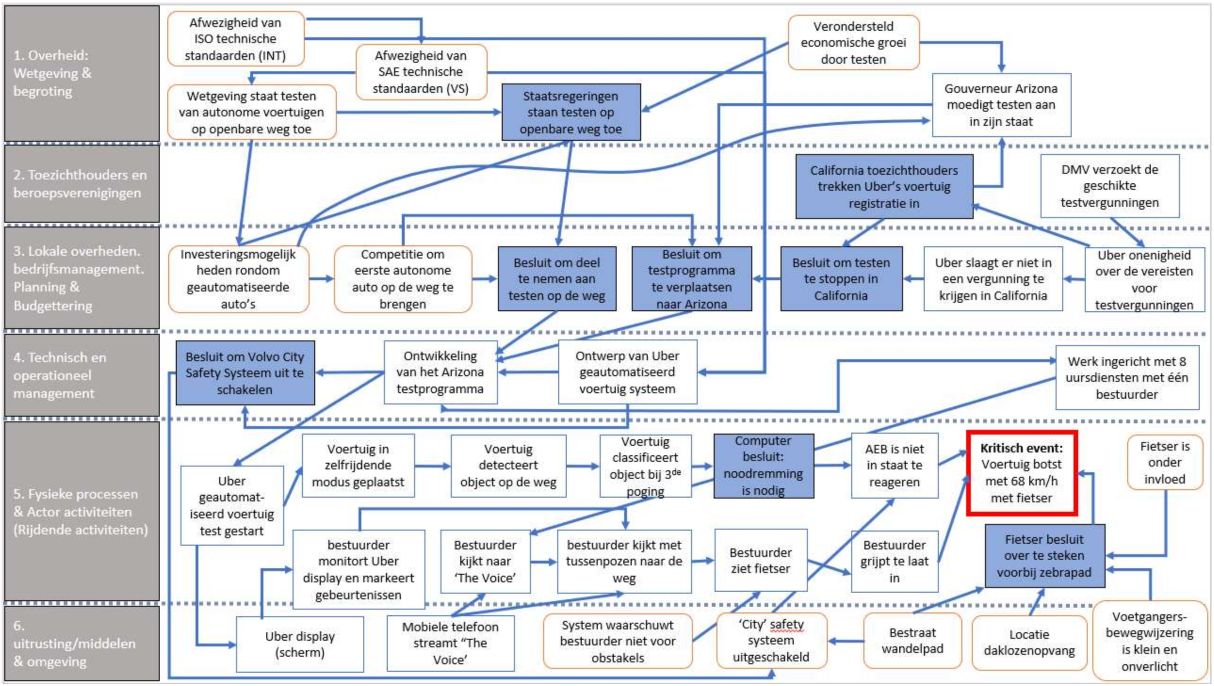


The second change was that, for the purpose of providing clarity, Rasmussen's original AcciMap layout and visualization was used (Rasmussen & Svedung, 2000), while Stanton's AcciMap was based on an interpretation of the AcciMap (Parnell et al., 2017). The top two levels of Stanton's AcciMap ('International Influences' and 'National Committees') were therefore removed and integrated with the third level ('Federal and State Government'). The AcciMap presented thus comprised Rasmussen's (original) six levels. It also used shapes as originally proposed by Rasmussen and Svedung (2000), which were applied in accordance with the texts of Stanton's AcciMap. For instance, Stanton explicitly used the word 'decision' in certain boxes, which were visually altered in the recreated AcciMap. After the presentation, the participants received the presentation on paper.

For most participants, the AcciMap used as the systems-approach investigation model in this research was the first AcciMap they had seen. Five participants indicated they had have seen an AcciMap before.

Figure 6

Adapted version of Stanton's AcciMap of the Uber collision with a pedestrian



Analytical Approach

The first data set consisted of the audio of the focus groups. This audio was recorded using a voice recorder, and a back-up recording was made on a mobile phone. The recordings were transcribed into Word files (one for each focus group). The transcriptions were processed into an Excel file, where the discussions following each question from both focus groups were combined. These transcriptions are in Dutch and are available on request from the researcher.

The second data set is the results of the survey consisting of two forms that were filled in during the focus-group sessions. Each participant of a focus group filled in two forms, one after they were briefed about the accident based on the NTSB's findings, the second after they were briefed with the AcciMap version of the accident. The answers from these forms were processed into a (second) Excel matrix, with all the answers ordered by question and participant.

The analysis was inspired by a thematic analysis approach. Thematic analysis is 'a method for identifying, analysing, and reporting patterns (themes) within data' (Braun & Clarke, 2006). Braun & Clark distinguish six phases of a thematic analysis: 1) becoming familiar with the data, 2) generating initial codes, 3) searching for themes, 4) reviewing themes, 5) defining and naming themes and 6) producing the report (2006).

For the purpose of analysis, the (second) Excel file, containing all the answers from the forms, was used as a starting point: all the answers were read from this matrix to determine the preliminary themes. This process was performed inductively (looking for whatever emerges from the data) and deductively (attempting to find elements that support assumptions and theories). On the one hand, the data was reviewed with a broad idea of what could be relevant from a systems-approach perspective, based on the literature review. On the other hand, the data was read with the aim of discerning prominent points. Therefore, both open coding (breaking the data into parts and labelling them) and selective coding (combining the identified codes into core categories) were used, which led to the preliminary themes (Creswell, 2014).

For clarity, the steps in this thematic inspired analysis will now be explained with a number of examples.

To start with, the researcher familiarized himself with the data by reading and transcribing it (Phase 1). The survey data was placed in an Excel sheet, and the transcriptions of the group discussions were entered into a second Excel sheet divided into multiple tabs, each tab concerning a single question.

The(second) Excel file containing all the survey data was read to search for words or elements that appeared frequently and for traces of a systems approach, as discussed in the literature review (Phase 2). An example of this is the frequent use of words such as ‘factual’ and ‘complete’ in response to the question: ‘What do you think of this NTSB investigation?’ after the Tempe case was presented in its NTSB form (Part 1). Another example is the frequent use of words such as ‘more context’, ‘more complete’, ‘overview’, and ‘circumstances’ in response to the question, ‘What do you think of this AcciMap investigation?’ after the Tempe case was presented in its AcciMap form (Part 2).

These codes were then grouped into the preliminary themes (Phase 3). Due to the research design, similar questions were asked after the NTSB briefing (Part 1) and the AcciMap briefing (Part 2): the first three questions were asked twice, after the NTSB’s findings and after the AcciMap analysis. Preliminary themes emerged in relation to the answers given after Part 1 (NTSB’s findings), such as ‘Complete and factual’, and after Part 2, such as ‘AcciMap gives more context and insight into circumstances.

With these preliminary themes in hand, the researcher reviewed the transcripts in the second Excel sheet (a combination of Phases 4 and 5). By doing so, the preliminary themes could be validated with the data from the transcription or dismissed if they were not substantiated in the transcription data. Second, in this stage of the analysis, preliminary themes from Part 1 and Part 2 were combined. For instance, the Part 1 theme ‘Complete and factual’ and the Part 2 theme ‘AcciMap gives more context and insight in circumstances’ were combined into the overarching theme ‘Context and circumstances. Third, in reviewing the transcription data, additional words and codes became prominent, which led to additional themes: for instance, ‘Cause-and-effect perspectives’. In effect, Braun and Cralke’s (2006) Phases 2 and 3 were repeated. An overview of the codes and themes that emerged can be found in Appendix B.

Although all phases of Braun and Clarke’s process are mentioned above, a number of phases were conducted simultaneously or overlapped. This was particularly the case for searching for and defining themes (Phase 4 and 5) and for defining themes and writing the report (Phases 5 and 6). This stems from the process of going back and forth through the data and themes, as recognized by Braun and Clarke (2006).

The (second) Excel matrix, with all the survey answers, was also used for a second purpose: namely, to discern possible changes in the participants’ safety perspectives on the case study (conventional vs. systems). The data was reviewed for changes after the AcciMap-based briefing in comparison to the participants’ earlier perspectives, which developed after the NTSB findings–based briefing. These perceived changes were then checked to see if they were also recognizable in the transcript of the group discussion. A search for these changes was also conducted in the opposite direction. After comparing the group-discussion transcripts of the participants’ perspectives after the AcciMap briefing with the perspectives in the transcripts of the discussions after the NTSB briefing, the changes were checked to see if they were also distinguishable in the survey data.

Quality Aspects

This research was performed as part of the Human Factor and System Safety Master’s programme at the University of Lund. The supervision, interaction and feedback provided by the tutors, from the thesis proposal to the writing of this final version, has assured the quality of this thesis.

However, the generalizability of the results is still limited. This research was conducted in one organization, a public-transport organization, and was performed with the participation of a small number of members of this organization. Due to this directed approach, the outcome of this research cannot be directly declared applicable for other organizations or companies in other countries or sectors. Even for similar organizations, caution is advised.

Furthermore, although this research could be reproduced following the research design with different informants and researchers, the results may differ due to biases, focus-group dynamics and dominant informants in the focus groups.

The researcher is an accident investigator at the organization where this thesis research was conducted. This background has been helpful in communicating with the informants. Furthermore, some examples or remarks made by informants could be understood by the researcher, as the informants and the researcher share, to some degree, a common work environment and context. However, this could also mean that the researcher shares the same potential bias as the informants given their similar normal work environment.

Another source of potential bias is the researcher's own views, employed as an accident investigator, regarding the topic of this research: a systems approach to accident investigation. Before conducting this research, the researcher held the view that a systems approach in accident analysis can provide additional insight into the workings of systems in which accidents occur. However, how informants, representing the researcher's own organization, would react when exposed to the case study from a systems-approach perspective was unknown.

During the research, the researcher kept these potential biases in mind. By keeping an open mind towards the data gathered, linking the results with knowledge gained from the literature review and following the research design as described above, the researcher attempted to minimize the effect of these potential biases.

Research Findings and Analysis

The results of this research are discussed in this chapter. It is structured by the themes that emerged from the analysis regarding whether changes could be identified in the respondents' perspectives, as representatives of the organization. Any changes would appear after exposure to the AcciMap systems-approach analysis of the Tempe accident and would contrast to their earlier perspectives after the analysis based on the NTSB report.

The themes that emerged from the thematic inspired analysis are 1) 'Context and circumstances', 2) 'Moving from few to many causes', 3) 'Shifting focus from the sharp- to the blunt end', 4) 'Interactions and relationships' and 5) 'Cause-and-effect perspectives'. For clarification, additional information is provided where necessary, based on Table 2. Therefore, '(Part 1)' is added when data from the group discussions and survey information after the NTSB's findings is discussed and '(Part 2)' is added when data from the group discussions and survey information after the AcciMap analysis is discussed.

Can Exposure to an AcciMap Analysis of an Accident Add Context to Accident Analyses?

After the presentation based on the NTSB's findings (Part 1) two opinions could be identified among the respondents regarding the context and completeness of the NTSB report in both the individual surveys and the plenary group discussions. The first opinion was that the participants had the impression that the NTSB's findings were factual and complete. In the words of one of the participants during the group discussion after the NTSB briefing, 'I think they have collected a lot of necessary facts here'. This opinion was also seen in the forms filled in individually after the presentation of the case during the first part of both focus groups (Part 1). Seven out of the sixteen participants wrote that they recognised the NTSB's findings as factual and complete, or words to that effect.

The second opinion started to emerge during the first group discussion. Here, the participants discussed what they thought was missing in the NTSB's findings: 'As I read those findings, I wrote down "This is pretty complete fact finding". But I kind of miss the follow-up: why did that happen…' Another participant aired the following: 'I thought it was indeed quite extensive research. Everything is included. But I really miss a bit of depth in research into the technology of the car'.

During Part 2 of the focus groups, when the participants were exposed to the same accident from the perspective of the AcciMap analysis, the participants were asked again how they perceived the NTSB's findings. The individual surveys showed mixed views. Ten out of the sixteen participants maintained a similar attitude towards the NTSB's findings: they remained either negative or positive. However, six out of the sixteen participants changed their opinion. Initially, these six participants recognised the NTSB's findings as factual and comprehensive. However, after they had been briefed on the AcciMap version of the case, they changed their attitude about the NTSB's findings to 'incomplete' or 'lacking context'.

New elements or different perceptions of the case surprised these six participants themselves, as one of them explained during the second group discussion: 'In the first part, with this [NTSB] report, I already said, it maps out the entire chain or system. But because of that AcciMap, you see that you are actually secretly missing some links'. Another participant added: 'I now find the NTSB much more incomplete, I'm more aware of that now than when I hadn't seen the AcciMap yet. And certainly, those dependencies – I missed those [the first time]'. Later, this participant added why they thought the AcciMap had changed their position towards the NTSB's findings: 'The focus is more on the systemic whole, rather than the incident.' Other participants agreed, stating the following when asked what they thought of the AcciMap analysis: 'Circumstances and decisions are better worded'. Another added: 'It gives me a lot more context about how this incident could have happened'. Apparently, the exposure to an AcciMap made six of the participants change their perspectives on the NTSB's findings from 'factual' and 'compete' to 'incomplete' and 'lacking context'.

Can Exposure to an AcciMap Analysis of an Accident Change Understanding of What Elements Can Be Considered as Causally Related?

After being briefed with the NTSB's findings (Part 1), the participants of both focus groups were asked for what they thought to be the learning points regarding the accident. Both the individual surveys and contributions during the first group discussion were predominantly focussed on the design and the organization of the Uber test programme and how actors in the accident behaved in relation to the accident. One participant stated: 'Especially in this system [Uber's vehicle automation system], man remains the crucial factor. The system doesn't seem very set up for it. That console sits very low there [looking at the design of the test vehicle]'.

Other contributions to the first group discussion were more directed towards the role of the operator, as one participant explains: 'But this person [Uber's operator] is there with a function, you would think. I had exactly the same thought as you [agreeing with another participant of the focus group]: is there sufficient supervision?' This participant seemed to relate the behaviour of the operator to the level of supervision, whereas another participant aired their surprise that the design of Uber's test apparently did not take human factors into account: 'For instance, that Automation Complacency: you have to assume that people actually go into a kind of automatic mode'. Some remarks were made regarding the seeming lack of regulations or the overall attitude of Uber in this case, as one participant stated:

> The safety culture. How is that set up? What standards do you set for it? If someone can just use their phone? Huh? Assuming she [Uber's operator] was looking at that phone. Then, you could also put rules there: that is not allowed during the test phase.

In conclusion, the focus of participants' contributions after having been briefed with the NTSB-based findings predominantly related to the design and organization of the test and to the behaviour of the operator. This changed during the second group discussion, after the participants had been exposed to the AcciMap model.

The participants of both focus groups were asked again, during the second part of the focus groups, what they thought to be the learning points, after having been briefed with the AcciMap analysis of the accident. When analysing the individual surveys, no significant changes were identified when this was compared with their answers after having been briefed with the NTSB's findings (Part 1). The participants generally reported the same number of learning points or causes in the case study after the AcciMap analysis. A plot of all the answers did not show a significant change after having been briefed with the AcciMap analysis, as Table 3 reflects.

Table 3

Comparison of number of learning points

	FOCUS GROUP 1								**FOCUS GROUP 2**								**TOTAL**
PARTICIPANT	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	**(16)**
AFTER PART 1	2	3	3	3	1	0	3	3	3	1	1	2	3	3	2	3	
AFTER PART 2	2	3	2	2	3	2	2	3	3	5	2	3	3	2	3	3	
CHANGE	=	=	−	−	+	+	−	=	=	+	+	+	=	−	+	=	**=**

Note: This table represents to what extent each individual participant increased or decreased in the number of learning points they wrote down after Part 1 and Part 2. The change from Part 1 to Part 2 is represented by = (no change), − (decrease) and + (increase). There was no significant change when all the participants were combined.

However, during the second group discussion in both focus groups, a change seemed to have emerged, visible in light of what was expressed and discussed. This supposed change mainly concerned the breadth of the recognised learning points and causes. While the focus in the first group discussion was mainly on the actors, technical issues and the design of the Uber test, the discussions after having been briefed with the AcciMap analysis had a different focus. All levels of the AcciMap analysis of the case study were discussed, showing a general broadening of the participants' scope. This is illustrated by the following contribution to the second group discussion:

> But the AcciMap helps me a lot. First, we talked purely about the company, which was allowed to do everything. But actually, due to the lack of national regulations, it is even worse. Where a Democratic governor in California doesn't allow something, the Republican governor in Arizona thinks it's okay, because he weighs the company's interests differently. And I didn't get that from that other [NTSB] report.

Other participants had similar perspectives on how the AcciMap analysis had helped them to add learning points, stating: 'I actually had two additional ones [measures], so it's quite different here [AcciMap] from there [NTSB's findings], but I think it's something extra'. For others, the AcciMap analysis added not only a few but many possible learning points: 'It [the AcciMap analysis] has given me much more, the learning points for me are on all these [AcciMap] levels'. This participant added later: 'I didn't have one clear cause with part one, but I do have more now'. The following comment implicitly shows the large number of potential causes recognised by the participant, although, at the same time, it displays a potential legal concern with such a broad view of causality:

> I think that AcciMap, from a legal point of view, I'm not a lawyer, but I think that's still a problem because there are thirty boxes: you don't have thirty guilty parties. So, I think if you submit this as evidence, I wonder if it can contribute to that.

Apparently, the exposure to an AcciMap made some participants of the focus groups broaden their perspectives on what kind of learning points or causes they recognised. This was visible when comparing the first and second group discussions. During the latter, the respondents identified broader causes and learning points compared to the first discussion. Could this mean that between the two discussions, some participants have developed a wider perspective of the system and its environment, and thus of what could be causal to the accident? Interestingly though, this finding was only observed in the group discussions, not in the individual surveys.

Can Exposure to an AcciMap Analysis of an Accident Shift Focus from a Sharp-end to a Blunt-end Perspective in Accident Analyses?

During the first and the second parts of the focus groups, the respondents were asked to write in the surveys what they thought were the three most sensible measures to be taken in relation to the accident, in order of importance. When discussing these measures during the first group discussions, after having been briefed with the NTSB's findings (Part 1), nine out of the sixteen participants tended to focus primarily on the sharp end of the system. The 'sharp end' refers to the front line, where operators – such as pilots, train drivers or in this case an Uber operator – usually work. Actions and events at the sharp end usually tend to have an immediate effect upon the system (Reason, 1990). The participants frequently mentioned the operator of the car and to some degree the role of the pedestrian in their discussion of potential measures during the first part as if these people could best be related to the accident in a causal relationship. One participant said: 'I have as my most important measure making the driver responsible. If you are still in such a test phase, then, I guess an assumption, but if she had paid attention, she would have seen that pedestrian too'. Further into the discussion, this participant added: 'I mean, there are millions of drivers driving around, they continuously have a responsibility for their actions.

The participants in this first group discussion did not only consider issues at the sharp end in relation to the accident though: they also mentioned a (lack of) regulatory oversight and a potentially deficient test-program design. As an example, one participant stated: ‘I don’t think they [Uber] have set up a system which convinces you they can really, safely test if the system works’. Nonetheless, the measures discussed during the first part mainly concerned elements close to the sharp end, including the physical surroundings of the accident. For example: ‘Such a dark grey XC90 in dark weather you don’t see it, of course. If you make the visibility of that car somehow attention-grabbing in the test phase, fellow road users become more alert’. Another participant stated, ‘The overall road situation should be evaluated. I wrote that down as a measure’.

During the discussion of the measures in the second group discussions (Part 2), when the participants had been briefed on the AcciMap analysis, some participants voiced a change in their stance towards the (AcciMap hierarchical) level at which mitigation should be directed. One participant in the first focus group described this in the following manner:

> I wrote down that I now [having seen the AcciMap perspective] pay more attention to what is pre-agreed, determined and regulated. That’s kind of a summary of what’s written here [on the form]. Indeed, less focus on the woman who crossed the street and the one [operator] who was behind the wheel.

Rather than focusing on sharp-end issues, the participants’ contributions had shifted towards contextual, higher-order, blunt-end issues. ‘Blunt end’ refers to those parts and people in the system that can influence the system indirectly but operate at a certain distance from its direct activities (Reason, 1990) This change in focus could be seen in the surveys also.

Therefore, for further analysis of the proposed recommendations, each measure that was suggested by the participants in the surveys was labelled according to one of the systems levels of Rasmussen’s AcciMap (1997). By doing so, a comparison could be made between the measures that were written after the NTSB section and the measures written after the AcciMap section.

Table 4

Comparison of measures proposed by their level on Rasmussen’s AcciMap

	FOCUS GROUP 1								FOCUS GROUP 2								TOTAL
PARTICIPANT	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8	
AVERAGE OF PART 1	D	D	E	E	B	D	E	C	C	C	B	D	D/E	D/E	D	D	
AVERAGE OF PART 2	C	C	E	C	C	D	C	C	B	C	D	E	D	D	D	C	
CHANGE	+	+	=	+	−	=	+	=	+	=	−	−	+	+	−	+	=/+

Note: ‘A’ stands for the highest (Government) level, ‘F’ for the lowest (Equipment and surroundings).

On average, as Table 3 shows, the participants in the focus groups tended to lean towards measures higher in the system in which the accident occurred after having been exposed to the AcciMap of the accident.

In Focus Group 1, this tendency was stronger than in the other focus group. Nevertheless, this tendency can be observed in both sessions, which suggests that a particular accident model can influence, the breadth of the measures that people consider when reviewing an accident. It also suggests that exposure to an AcciMap systems-approach model, to some degree and for some individuals, might leads people to consider features of a systems approach to accidents. Rather than solely considering the micro-level and its direct surroundings (i.e. the sharp end), some participants considered micro and macro perspectives on the accident more (i.e. the blunt end) after exposure to the AcciMap perspective. This reflects a wider understanding, by some of the participants, of the system in which the accident occurred, leading to the inclusion of more distant factors at the blunt end of the system as playing a vital role in the creation of the circumstances that made the accident possible.

Can Exposure to an AcciMap Analysis of an Accident Help Make Relationships and Interactions More Explicit in Accident Analysis?

In the second part of the focus groups, the participants were asked what they thought of the NTSB's findings after having seen the AcciMap of the accident. Furthermore, they were asked if they thought the AcciMap added value to their understanding of the accident. During the following group discussions, in both respondent groups, five participants shared the perspective that the NTSB's findings lacked connections and interactions. One participant stated in this regard: 'definitely those dependencies, I miss them [in the NTSB's findings]'. Another one stated: 'Like I already said, [the NTSB's findings are] a summary of facts, without connections or relationships becoming clear. Those relationships [in the AcciMap] really add something'. Another agreed: 'I think there are too few relationships between the events [in the NTSB's findings]. One leads to the next. And then the next one. The other one [the AcciMap] gives more insight'.

This apparent ability to draw attention to interactions seem to be an effect related to the perception of an AcciMap analysis by some in this research. Such models generally emphasize the connections and interactions of the system in which the accident occurred.

The participants agreed with the increased emphasis that the AcciMap places on interactions and relationships, as one participant said: 'When I see both like this, Part 1 [NTSB's findings] feels like a summary of facts, it requires you to make connections, and Part 2 here [the AcciMap] – the connections become clearer'. Another participant added: 'Through the lines you can see more of what has an impact on the decision. The interaction'. This participant added later: 'dependencies are explicitly mentioned. That's a big advantage'.

The AcciMap model seemed to help some of the participants to see connections more clearly. They also expressed a seemingly better understanding of the effects of these connections or the interactions between elements: ‘And the relationship it has when you turn one knob doesn’t just affect that one cell [box], it actually has a snowball effect. And you can see that connection very well in an AcciMap’.

Can Exposure to an AcciMap Analysis of an Accident Influence Cause-and-effect Perspectives in Accident Analysis?

As the results of this research suggests, exposure to the AcciMap analysis made some of the participants show a broader perspective on what kind of learning points or causes they recognised. However, during the group discussions, the causal relationships were also discussed beyond the content of the case, not as factual, but as potentially subjective.

During the first part of the focus groups, after the NTSB’s findings were presented, cause–effect chains were not a topic reflected in the participants’ answers on the forms or during the group discussions. However, after the AcciMap analysis was presented, the participants in both focus groups reflected during the group discussion on the clearer cause–effect relationships they saw: ‘Well, the first impression is that it paints a clearer picture for me. From head to tail’. The phrase ‘head to tail’ in the quotation refers to the logical order and completeness of the story from the perspective of the participant: a narrative rather than a collection of seemingly isolated elements. Others aired similar comments: ‘I also find this [AcciMap] very pleasant to read, you can clearly see what the cause and the effect is’; ‘It simply provides insight how something arises from start to finish and how that risk ultimately unfolds into the actual incident’. Eight out of sixteen participants remarked that they found the AcciMap presentation helpful in gaining a clearer understanding of the causes and effects in the case study. There was no trace of less positivistic perspectives.

However, the sequence in which the AcciMap analysis was read is an interesting result from the second group discussions. One participant related a sequence she found in the AcciMap analysis as follows:

> I read it from the red square. I read it back. I think yes, that was what happened. I recognize that. Because that's what we were going to talk about. And from there you read the arrows back to see on which levels things have happened, decisions have been made, that led to this. I don't know if that's the way to read it, but that's how it worked for me.

This participant recognised a sequence in the AcciMap which led to reading it from the eventual accident backwards towards the prior events and decisions, deconstructing the accident backwards in time, as is common in reductionist approaches. However, others saw different sequences in the AcciMap, as the following discussion amongst participants shows:

Participant 1: 'The only thing I still miss is the sequence: where does something start? I didn't get that very quickly. You really have to look for it.'

Participant 2: 'Actually just the one at the top, that's where it starts.'

Participant 1: 'Absence of supervision? Or top left, or…?'

Participant 3: 'Oh yes, if you look at the picture that way. When I look at those six different layers, for me it starts at 1 [highest level].'

Participant 1: 'It starts of course that someone wants to perform a test. Or that there is a crash. But that takes a bit of searching. It's complete though.'

This discussion shows that the AcciMap apparently did not provoke a single, logical chain of events; instead, it led to recognising chains of events for some participants, which were different from each other.

These results show that the AcciMap visualization helped some participants to create a richer understanding of how events and decisions throughout the system were related. These relationships were interpreted as clear(er) cause and effects relationships in the case study. Although these cause-and-effect relationships can be perceived through a typical, linear perspective, the multiple sequences seen in the AcciMap suggest an exposure to an AcciMap can create appreciation, to some degree, of the complexity of the accident.

Discussion

In this chapter, the research findings and analysis are systematically explored in relation to the characteristics of a systems approach in safety science – complexity, emergence and interactions –identified in the Literature Review chapter. Thereafter, findings of this research are discussed in relation to conventional traces; then, the limitations of this research are explained.

Characteristics of a Systems Approach to Safety

Complexity

Once the respondents had been exposed to the systems approach accident investigation model, the data suggests, some participants mentioned they now saw more clearly the contextual elements and circumstances of the accident in the case study than after the first (NTSB-based) briefing. What was observed, was that after the second briefing, some of the respondents defined and recognised the system around the accident as wider and perceived more context. This is illustrated by the finding that six out of sixteen participants changed their perception of the NTSB's findings after being exposed to the systems-approach analysis of the accident from 'factual' and 'comprehensive' to 'incomplete' and 'lacking context'. For instance, they noted more distant actors influenced the outcome of the case, which is illustrated by the learning points and causal relationships identified by the participants (after the systems-approach analysis) at the inspectorate, governmental and legislative hierarchical levels visualized in the AcciMap. This led to respondents foreseeing measures higher up, at the blunt end of the system.

Systems elements in this perceived larger system and its environment were also seen as (more) related to each other after exposure to the systems-approach perspective, as commented by a participant: 'The focus is more on the systemic whole, rather than the incident'.

These indications by some of the participants – the increased perception of context, the breadth of potential causes recognised , the shift in focus towards the more distant blunt end and the participants' understanding of the actors'– seem to relate to how Hollnagel (2011) and Flach (2012) define complexity: as the number of possibilities increase in the problem space, the complexity increases. In essence, the exposure to the systems-approach model may have evoked insight into the system's complexity among some of the participants in their evaluation of the accident. This insight was not present when the respondents were exposed to a more conventional safety approach, based on NTSB's findings.

Emergent Dynamics

An important element of a systems-approach to safety investigations is the understanding that safety emerges from the interacting system as a whole rather than from isolated failing components (Leveson, 20011 p. 64). Safety is therefore seen as an emergent characteristic of the whole system (Dekker, 2006). However, this is contested within safety science, illustrated by Holnagel's current position, arguing safety is not emergent at all (Hollnagel, 2015). This continuing debate in safety science is further illustrated by Lintern & Kugler who noted: 'What constitutes emergence may seem intuitively obvious, but it has been a challenging concept to pin down' (2022).

It may therefore be understandable that emergence is not a concept the participants are familiar with. The participants never explicitly referred to emergent dynamics in the accident presented to them.

At best, the findings suggest that after the respondents had been exposed to the systems-approach analysis, some of them recognized elements (preconditions) for potentially understanding such dynamics. For instance, the research findings and analysis show that what some participants saw as the system and its environment, or both seem to have been augmented by exposure to the systems-approach analysis. This was demonstrated, for example, by an increase in the breadth of the learning points and causal relationships that the participants mentioned. Furthermore, after exposure to the systems-approach model, for instance, the participants repeatedly mentioned the term ‘causes’, even when they pointed towards blunt-end issues with no direct link to the accident. Understanding of emergent dynamics starts with an appreciation of the wider system and the consideration of multiple contributing factors, instead of a single cause. This was recognized by some of the participants.

However, the findings do not suggest emergence was recognised by the participants. This supports what Lintern & Kugler already noted, it is not only challenging to pin down the concept of emergence but even harder to ‘determine’ or 'find’ it in field research.

Further education in organizations on the characteristics of (complex) systems could improve understanding of the concept of seeing safety as emerging from systems.

System Interactions

An understanding of interactions in and with systems has also been identified in the focal theory for this research as an important element of a systems approach to safety. It has been argued that there is a need to use a systems-approach model for investigations to analyse accidents on the basis of the interactions between system components instead of components in isolation (Hollnagel & Woods, 2005; Dekker, 2011; Dekker et al., 2011). The findings suggest that, after having been exposed to the systems-approach analysis of the accident, some respondents’ understanding of system interactions in accident analysis rose. These respondents may have quickly developed a richer understanding of how events and decisions throughout the system were related. For example, after the briefing with the systems-approach analysis, they mentioned multiple chains of events and how these were related to each other rather than only the most apparent cause or unrelated contributing factors.

Understanding Developed

The findings suggest that some of the respondents, after exposure to a systems-approach model of an accident, developed a degree of understanding of the complexity, conditions for the understanding of emergent dynamics and interactions that occur in a system in which an accident happens. In the Literature Review, it was shown that such characteristics can be regarded as features of a systems view of safety. An example is the reduction in judgmental language demonstrated by the study: During the first group discussions based on the NTSB report (Part 1), several participants directly or indirectly questioned the driver's (lack of) actions. One participant, for instance, stated the following: 'I guess, although it is an assumption, if she had paid attention, she would have seen that [victim] too'. Other participants emphasized the driver's responsibility: 'As a person, as a driver, you have a super-responsible task. And you really have to be aware of that. I don't know, maybe she was, that lady [operator], I don't know, but I think that's very important'. Another participant stated: 'This is still a test driver. If you're going to bring that [system] to market, great. But this person is there with a function, you would think?'

However, after the participants had been exposed to the AcciMap analysis, the judgmental language that accompanied these issues in the first group discussions was absent. Instead, contextual views were provided in much more nuanced ways, such as, 'I think if you set up such a system, in which humans are also a part, humans will remain the crucial factor. The system doesn't look like it has been designed to cope with that risk very much'.

Dekker (2006) refers to judgmental language as often fuelled by conventional, hindsight thinking. Dekker argues, moreover, that judgmental attitudes in accident analysis can be countered by developing an appreciation of the circumstances for the operators. This was also seen in this study: some participants acknowledged and showed a better understanding of the context of the operator in the autonomous car.

The findings from this thesis, in short, suggest that exposure to a systems-approach model of an accident can evoke an increased appreciation for and recognition of system complexity in accident investigation. Appreciation also seemed to increase for related concepts, such as emergence, and interactions. Although these concepts are difficult to grasp, there is a suggestion in this research that AcciMap might help. Further research on this topic is needed, which is consistent with other research (Igene,et al.,2021) .

Conventional Traces

It could be argued that the data from this research does not necessarily point towards appreciation of a systems approach in an investigation model. This ambiguity arises because interactions seem to have been interpreted by the respondents, from a more or less conventional, linear perspective. The AcciMap visualization made the relationships clearer, and the participants expressed appreciation for the AcciMap due to the clearer cause-and-effect connections they recognised. This recognised clearer cause-and-effect sequence could be seen as an expression of a more reductionist, conventional approach to accident investigations (Dekker, 2006). This might be related to the visualization features of the AcciMap: although the AcciMap is considered a true systems model, the model is ultimately founded on traditional cause–effect models (Le Coze, 2015).

However, there might be a different explanation. For instance, it may be that the respondents, after having been exposed to another viewpoint and its language only once, did not have sufficient knowledge of concepts such as emergence and complex non-linear causality to refer to them. These concepts were not yet included in their mental library and vocabulary, and thus not there to use. Exposing members of the organization more often to these concepts, and educating them in their meaning, could increase the likelihood of their application.

It is also noteworthy that the increased variety in the chain of events leading to the accident that some of the respondents saw after exposure to a systems-approach model of the accident started a debate on how the AcciMap visualization should be read. After the NTSB-based briefing, there was hardly any discussion about the cause of the accident. After the AcciMap-based briefing, discussions did arise for instance, in what direction or sequence to read the AcciMap would be correct. In both focus groups, the respondents were unable to bring this debate to a conclusion, but they also did not seem to consider this a problem. Exposure to the AcciMap analysis, while it tended to evoke multiple perspectives, may have encouraged respondents to accept that multiple views of an accident can easily co-exist.

Limitations

Several limitations of the study are relevant, as they demonstrate that it is only possible to draw tentative and cautious conclusions from findings in this research.

A first limitation concerns the environment in which this research was conducted. The research was conducted in a single organization, a public-transport organization, and a small number of members of this organization participated. Due to this directed approach, the outcome of this research cannot be declared directly applicable for other organizations or companies in other countries or sectors. Even for similar organizations, caution is advised.

Another limitation of the research relates to the setup of the focus groups. The participants were not informed in advance of the accident that was used for this research. This lowered the risk that participants would have prior knowledge of the case, creating as equal a starting position as possible for each participant. However, by the time the respondents arrived at the first group discussion, they may have already formed their views of the accident and discussed their views among themselves during the break after they had individually completed the survey.

The informants of this research were asked to participate for a limited amount of time. Each session had a duration of two and a half hours. This meant in some stages of this research, such as filling out of the surveys or interpreting the information provided, time pressure was a limiting factor. This has also been noted by Igene et al. (2021) in their research that was discussed in the literature review. The results of this research could therefore be different when time would be less of a limiting factor.

The setup of the focus group sessions may have introduced a second limitation. Both the NTSB's as Stanton's perspective has been presented by the researcher. During these presentations the researcher was vigilant to be as neutral as possible, staying on the narrative as reported by the NTSB, and as written by Stanton. However, it cannot be ruled out the researcher unconsciously showed his preference towards a systems approach through body language or certain choice of words.

Moreover, during the second part of the focus group, the AcciMap representation, the participants were presented with the accident for a second time. This could have resulted in their perceiving more details of the case instead of being influenced by being shown a systems-approach model of the case. During the second group discussion, one participant aired this limitation: 'I do have a side note. Hearing this case for the second time, you already heard it once. Now I'm hearing it for a second time. Then of course there will be more details'. He added later, 'that might affect [my perception of] the [AcciMap] model'. It could be questioned, therefore, whether it can be concluded that the change in focus identified in this research was actually caused by exposure to a systems model.

For most of the participants, as far the researcher was aware, the exposure to the AcciMap of the accident was their first encounter with that model; only a few had seen an AcciMap before. When exposed more frequently or for a longer duration to an investigation model using a systems-approach, the perception of accidents or safety as emergent properties of a system might be increased. There is also the possibility that other systems-approach models, such as STAMP (Leveson, 2004) or the Functional Resonance Analysis Method (Hollnagel, 2004), would better evoke the perception of safety as an emergent property of systems.

Conclusion

The research written up in this thesis explored how an organization, represented by a multi-hierarchical cross section from a rail-transport company, reacted to the introduction of an accident investigation based on AcciMap alongside the official, more conventional, report on the same accident.

Interesting findings arose from the research, and some of the participants indicated that the introduction of the AcciMap report provided (as a representative model of a systems approach) 1) a wider understanding of the context of the accident, 2) a potential for a broader range of potential causes or contributing factors, 3) a change in focus from the sharp to the blunt end and 4) insight into more explicit relationships and interactions in what preceded the accident.

Furthermore, some participants' reflections also showed signs (rather than significant changes) that the exposure to a systems approach accident investigation model created a clearer understanding of cause–effect relationships and the ability to recognise multiple sequences.

However, the findings, were not consistent among the participants. Therefore, the study was unable to determine if and how the organization would be affected by changing its own approach to accident investigations, for example, by switching to or adding AcciMap or a similar systemic-investigation model. Further research and testing would be needed to answer this emerging question. A possible direction of this further research could be: What makes participants *not* change their ideas when exposed to a systems approach investigation model?

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Appendices

Appendix A: Letter of Consent

Letter of Consent

Research Project Title:

Introducing a safety science model into accident investigations.

Student Researcher:

Tomas Onstenk
Email:
Phone:

Purpose:

This focus group is for the purpose of gathering experiences and perceptions from members of the (operational) organization regarding an accident investigation model from safety science.

Investigation models in general help in understanding and explaining accidents and the factors which contributed to its occurrence. Accident investigation models have their foundations in different branches in safety science. Therefore, the use of a model influences the direction, the outcome and usefulness of an accident investigation.

For this research an accident, which has happened in 2018, is used as a case study.

In conducting focus groups, the hope is to gain an understanding of what the accident investigation model researched here, invokes in terms of learning from and understanding of accidents

The research is being conducted as part of the fulfillment of the requirements for a master's degree.

Confidentiality:

The identities of the individuals that contribute to this study will have full anonymity in the final thesis. During the focus group I will audio record the conversations and take notes. The data collected for the research will only be available to the researcher and the data will be handled according to prevailing legislation. The recordings will be transcribed and anonymized. This data will only be used for the purpose of this research. This data can only be used for other purposes with the consent of the participant. Once the research is complete all notes and audio/video recordings will be erased.

Risks/Benefits:

There are no known risks or benefits in participating in this research.

Consent:

Your participation in this research is entirely voluntary. You may refuse to participate or withdraw from the research at any time. Your signature indicates that you have received a copy of this consent form for your own records and that you consent to participate in the research.

Date:

Time:

Name:

Participants Signature

Researchers Signature

Appendix B: Codes and Themes

Codes	(sub)-Themes	Themes
Words used or sentences pointing out "factual' 'complete' in perceiving the NTSB findings	Complete and factual	1) context and circumstances
Words used or sentences pointing out 'more context', 'more complete', 'overview', and 'circumstances' in perceiving the AcciMap Analysis	AcciMap gives more context and insight in circumstances	
Words used or sentences pointing out: 'automation system', 'design of the driver interface', 'operator's function', 'operator's phone use' 'designed for complacency', 'men-machine interface'.	Learning points focussed on design of the test programme/ organisation and actors.	2) moving from few to many causes
Words used or sentences pointing out: 'automation system', 'design of the driver interface', 'men-machine interface', 'missing regulation', 'no standards', 'risk management'.	Learning points focussed on technical considerations, the organisation, and actors, regulation, governmental oversight. More learning point perceived	
Words used or sentences pointing out: 'multiple causes',	Increase of number of learning points	
Words used or sentences pointing out measures concerning: 'operator actions and training', operator task execution', 'oversight' 'technical support for operator',	Focus on sharp-end measures	4) shifting focus from the sharp- to the blunt end
Words used or sentences pointing out measures concerning: 'regulatory oversight', 'governmental decisions', 'sectoral guidelines'	Focus on blunt-end measures	
Words used or sentences pointing out: 'connections', relation', 'what impacts decisions'.	Relations and connections	5) interactions and relations

Words used or sentences pointing out: ‘interactions’, turning one knob effects all’, ‘dependencies’	Interactions	
Words used or sentences pointing out: ‘head to tail’, clear cause and effect’, ‘start to finish’.	Clear causal relationships between system components	6) cause-and-effect perspectives
Words used or sentences pointing out: ‘’sequence’, ‘starting points’, multiple perspectives	Different perspectives possible n the story line	