Effects of a systems approach in occurrence investigations

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Abstract

In 2017, a change (serendipity) in the philosophy of occurrence investigations took place at NS (Dutch Railways). It seems the investigations conducted and published before and after 2017 are different, both in the way the investigations are executed and in their effects on the organisation. This research has been carried out to find out if, in what way, and to what degree the two specific types of investigations are different with a special interest in the effects of the investigations on the organisation.

This research comprises two parts. In part 1 a comparative analysis is conducted on investigation reports — scrutinizing five reports pre-2017 and four reports post-2017. The analytical framework is derived from Hollnagel's categorization regarding incident investigation models, which delineates three models: sequential, epidemiological, and systemic.

The findings show that there are distinctions in both the nature and effects of the investigation reports. Investigations conducted pre-2017 exhibit characteristics of the sequential model due to a focus on what went wrong, (broken) components and measures that mostly aim at the sharp end operator (train drivers, conductors, train dispatcher) such as training and discussing specific findings of the investigations with those involved only. Investigations conducted post-2017 exhibit characteristics of the systemic model due to a focus on the central question 'why did it make sense to do what one did' (local rationality) implying a focus on work as done and understanding the functional characteristics on the level of the system as a whole, and measures that mostly aim at the system although measures that aim at individuals are still noticeable.

In Part 2 insights into the context and experiences of the effects of the investigations of nine individuals engaged in the investigation process are gathered through interviews. These experiences of the individuals support the conclusions of part 1 and in addition show that before 2017, the investigations were mandatory but did not seem to have a (positive) effect on the level of safety. The investigation process resulted in a feeling of blame and guilt by those involved. The measures of investigations focused mainly on fixing broken components with a focus on human operators (train drivers, conductors and train dispatchers) such as training and informing. After 2017, informants experience that the investigations are adding value to the organisation. Those involved feel a sense of being heard, understood, and recognized. Measures of investigations focus more on the system such as the visibility of trains with still an undertow of human focus regarding training.

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List of tables and figures

Glossary

This thesis starts with a glossary because ‘common’ definitions are not that common at all. To take it one step further, the author has his doubts about the usefulness of the word ‘common’. What is ‘common’ for the author, is not necessarily ‘common’ for the reader. Therefore, various definitions that are used in this theses are provided in Table 1 to align the perspective of the reader with the writer’s perspective. The definitions are further elaborated in the thesis.

Table 1

Glossary

Word	**Meaning**
Accident	A short, sudden, and unexpected event or occurrence that results in an unwanted and undesirable outcome. The short, sudden, and unexpected event must directly or indirectly be the result of human activity (Hollnagel, 2004, p. 5).
Cause(s)	The identification, after the fact, of a limited set constructed of aspects of the situation that are seen as the necessary and sufficient conditions for the observed effect(s) to have occurred (Hollnagel, 2004, p. 34).
Complexity	“Some properties of the system cannot be attributed to individual components but rather emerge from the whole system” (Hollnagel, 2004, p. 150). This definition is further explored in this thesis.
Incident	An unforeseen event or occurrence, which results in only minor injury or property damage (Hollnagel, 2004, p. 20).

Word	**Meaning**
Near-miss	An occurrence with potentially important safety-related effects which was prevented from developing into actual consequences (Hollnagel, 2004, p. 20).
Occurrence	Collective term for accidents, incidents and near-misses.
Safety	This definition is explored in this thesis.
SPAD	Signal passed at danger. A train passes a stop signal when it is not allowed to do so.
System	The deliberate arrangement of parts (e.g., components, people, functions, subsystems) that is instrumental in achieving specified and required goals (Hollnagel, 2004, p. 6).

Introduction to investigations at NS

This case study investigates the effects of a systems based occurrences investigation approach at the Nederlandse Spoorwegen (NS), the largest passenger rail service provider in the Netherlands. NS comprises five subsidiaries:

- NS Reizigers: manages passenger services.
- NedTrain: the maintenance division of NS handles the maintenance, repair, and overhaul of trains and train components within the NS fleet.
- NS Stations: manages railway stations nationwide and is therefore responsible for station facilities including commercial spaces, ticketing, and other amenities.
- NS International: offers international train services to destinations such as Brussels and Berlin.
- Abellio: operates train and bus services in various European countries, including the United Kingdom and Germany.

In addition to train services, NS also offers a range of travel products and services in The Netherlands, including bicycle rental and parking facilities at train stations, and mobile apps for travel planning and ticketing. This study focuses specifically on NS Reizigers. Other services are outside the scope of this research.

The mission of NS is “to provide convenient, fast, safe and affordable travel and to ensure that people can reach their destinations in a sustainable manner” (NS, n.d.). ‘Safe’ (related to travel) is one of the adjectives in the mission statement and is the central part of this thesis. Although NS typically achieves positive outcomes, in rare cases, unwanted outcomes such as derailments and collisions happen resulting in safety concerns.

The natural reaction following such unwanted outcomes is ‘we want to know exactly what happened’ (NS, 2023; RTV Utrecht, 2023). An investigation tries to construct

understanding of what happened and how it happened. This may help to prevent similar occurrences in the future (Hollnagel, 2004).

The investigation process is an integral part of the Safety Management System (SMS) of NS. The European Union Agency for Railways (ERA) provides a SMS framework to enhance safety in the railway industry. Mandated by law, the SMS is a comprehensive framework encompassing policies, procedures, and practices to improve safety. It includes the identification, assessment, and mitigation of potential hazards, as well as continuous monitoring and improvement of safety performance. The SMS aims to establish consistent safety standards and promotes a safety culture across the European railway network (European Union Agency for Railways, n.d.).

The current investigation process

The ERA argues that "implementing all relevant elements of a SMS will provide an organisation with the necessary confidence that it controls and will continue to control all the risks associated with its activities, under all conditions" (European Union Agency for Railways, n.d.). One of the elements of the SMS is the emphasis on 'learning from accidents and incidents'. At NS, incident investigations are carried out with the ultimate aim to learn, especially when something 'bad' happens. The current investigation process is clarified along the 'OOG' model, an acronym for 'Onderzoek Ongewenste Gebeurtenissen', which translates to 'Investigation unwanted occurrences'. The OOG model comprises six steps. The six steps are hereafter explained.

Before initiating the investigation process, the unwanted occurrence needs to be reported. Anyone within or outside the organisation can report events¸ particularly those events with the potential to result in unwanted occurrences.

For safety occurrences with the potential to harm, individuals involved are temporarily removed from the operational process in the context of caring for those involved. Essential

information, such as witness statements, are documented. Depending on the severity, personnel may resume their duties if they feel capable and are willing to do so. In cases of uncertainty about employability (for example when the occurrence was very fierce and may have had an emotional impact on those involved), a Safety Advice Commission is convened to identify necessary support for the individual's return to duties. This support may be for example accompaniment by the team manager during the first shifts after the occurrence. The Safety Advice Commission consists of at least two line managers, an HSE advisor and an individual with the same function as the one involved and functions independently of the investigation but may inform subsequent inquiries.

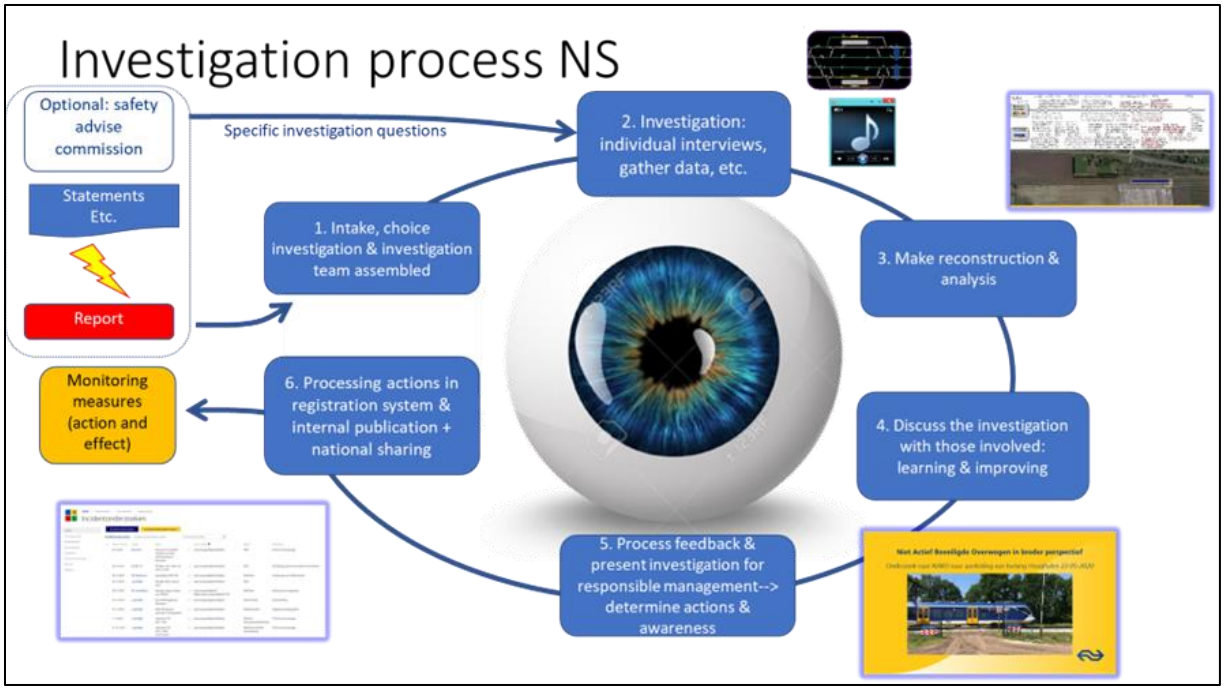
The six steps belonging to the investigation process that follows a report of an unwanted occurrence are:

1. Intake;
2. Investigation;
3. Reconstruction and analysis;
4. Feedback with those involved;
5. Presentation to responsible management;
6. Processing actions and publication.

This structured approach ensures a comprehensive and systematic understanding of unwanted occurrences with a strong focus on understanding what happened seen from the eyes of those involved, learning, improvement, and preventative measures. The six steps of the OOG model, visualised in Figure 1, are hereafter elucidated.

Figure 1

The current investigation process of NS.



First, an intake takes place. Every Monday morning a digital bulletin is circulated, summarizing occurrences from the past week. The main focus is on accidents and incidents although near misses are covered as well. Subsequently, a cross-departmental meeting convenes to discuss reported incidents. These incidents are assessed based on factors like learning potential, thematic interest for future cases, or management requests. If an incident is deemed worthy for further investigation, a dedicated team is assembled.

The second step encompasses the investigation itself. Relevant information next to the statements of those involved is gathered such as individual interviews, examination of camera images, and analysis of voicelogs between train dispatchers and train drivers. This data guides the team to the third step, the reconstruction of the incident and the construction of a timeline. This timeline represents the (non-)events leading to the occurrence seen from the perspectives of those involved.

In the fourth step, the investigation findings are presented to those directly involved in the incident. This phase is crucial for ensuring that the constructed timeline and analysis of the occurrence accurately represent the perspectives of those involved. Those involved are asked to provide their perspectives regarding potential improvement measures to prevent recurrence of the occurrence. It is assumed that those involved knows best how to prevent recurrence because those involved generally work daily in the circumstances potentially leading to the occurrence. The feedback is integrated into the timeline and analysis. The potential improvement measures are described in a separate chapter at the end of the presentation.

The fifth step involves the presentation of the investigation to local or company management, depending on the scope of the investigation. The investigation and possible improvement measures are discussed. The responsible management may adopt or reject the measures suggested by those involved based on a risk assessment and may come with other measures.

In the sixth step the measures are documented, and monitored in a registration system. The investigation report may be shared internally depending on the size of the investigation and the business needs (what is the central message of the investigation and what is the learning potential for all sharp end operators). Small investigations are relatively easy to share because those investigations are presented in “one-pager” form, one sheet on which the investigation is shared. The “one-pagers” are both digitally and physically shared. For larger investigations, the “one-pager” is not suitable because the information does not fit on one page. Thereby more context is required to interpret the investigation. Those investigations are shared digitally.

This comprehensive process may apply to all occurrences, including occupational health occurrences and railway-related occurrences such as train derailments, collisions, and

incidents involving road traffic and trains. Near misses are also investigated when resources permit and learning potential may be significant.

Notably, there is a growing trend to exclude the outcome from the decision-making process for investigating occurrences. NS generally has minimal influence on the outcome, therefore the outcome is considered a distraction from the occurrence itself and provides limited information about the occurrence's nature. For example, on 17 October 2022 a train collided with a bus that broke down on a level crossing (NOS, 2022). Luckily, the bus was empty and the bus driver had left the vehicle in time. There was (major) material damage to the bus, train and railway crossing. If there was someone injured in the bus or train the outcome would be different but the occurrence would be the same. In general, this changes the perspective of the occurrence unjustly because someone got hurt. To address this, the term "occurrence" is used in this study instead of more specific terms like incident, accident, or near miss unless specifically noted. The investigation process remains consistent across all types of occurrences.

Pre 2017, approximately seven years ago, the investigation process differed from the current (OOG) approach. The approach before 2017 is called SIM (Simple Incident analysis Method) because the reports were called this way.

Transformation of occurrence investigations

Before 2017, investigations at NS followed a structured approach known as SIM, the Simple Incident analysis Method.

Nedtrain, the maintenance division of NS, primarily conducted investigations related to occupational health and safety. The investigator at Nedtrain utilized a specific visualization method by using PowerPoint and animations to visualise occurrences coupled with the question 'why did it make sense to do what one did?'. According to individuals involved in the investigation process at Nedtrain, this approach resulted in more meaningful outcomes than

the SIM. NS Reizigers, being larger than Nedtrain, primarily conducted investigations related to railway safety using SIMs. Those investigations were carried out by HSE advisors. Investigations were a small part of their job and were time consuming. This resulted in relatively simple investigations that took a long time to execute. If there were any measures, these were determined by the HSE advisor. Those measures did not have an unambiguously term. They were called recommendations and further specified under the term ‘learning action’. In response to the need for more in-depth investigations and quicker learning from occurences, NS Reizigers introduced a new role particular for those investigations: (central) investigator. This individual collaborated with Nedtrain's investigator, establishing a foundation for more profound investigations within NS Reizigers based on the experience of the investigator at Nedtrain. It may be argued that this change fits in the thought about the mechanism of serendipity, a discovery in which observation, sagacity and chance are brought together within a certain context (Merton & Barber, 2004).

The central question, 'why did it make sense to do what one did?' stems from the local rationality principle, asserting that people's actions make sense to them at that time, given their goals, attentional focus, and knowledge (Dekker, 2014). It would go too far for this thesis to delve further into local rationality.

This study is driven by a fascination with the investigation process(es) at NS and aims to examine the differences in the nature and foremost the effects of the investigations before and after 2017. While the two types of investigations appear distinct, this study seeks to explore whether and in what ways they differ on the basis of the analytical framework presented in the following chapter. The year 2017 serves as a pivotal point, marking a shift in the philosophy of incident investigations at NS. The thesis question is constructed to delve into the characteristics and outcomes of both types of investigations.

What effects did the implementation of a systems approach in incident investigation have? A case study at NS: towards a systems incident investigation approach.

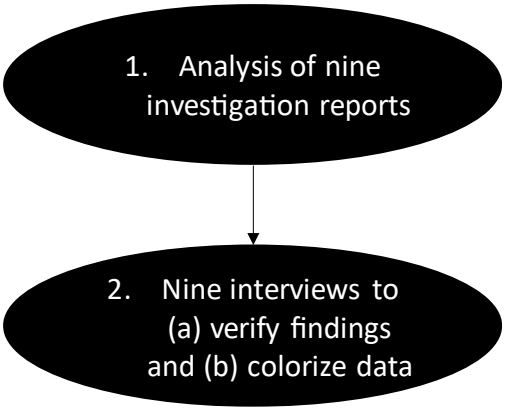
1. What main incident investigation models exist in the field of safety (including their philosophy and characteristics)?
2. (How) did the philosophy of incident investigations change at NS?
3. What characterizes the investigations of NS, historically and after the introduction of the new approach?
4. What are the effects of the change in incident investigation at NS?

Research design

This research is grounded in a case study conducted at NS, aiming for "an in-depth exploration of intricate phenomena within some specific context" (Rashid et al., 2019, p. 1). Employing two lenses, as outlined in Figure 2, the study delves into the multiple facets of a phenomenon (Baxter & Jack, 2008). The initial phase involves the examination of nine incident investigation reports divided into five reports written and published before 2017 and four reports written and published after 2017. The nine reports are analysed and it is argued what characteristics the reports have in the light of the framework outlined further in this thesis. Subsequently, the second phase encompasses nine interviews, serving the dual purpose of (a) validating the initial findings and (b) providing a nuanced perspective to enrich the data regarding the effects of investigation (reports).

Figure 2

Research structure.



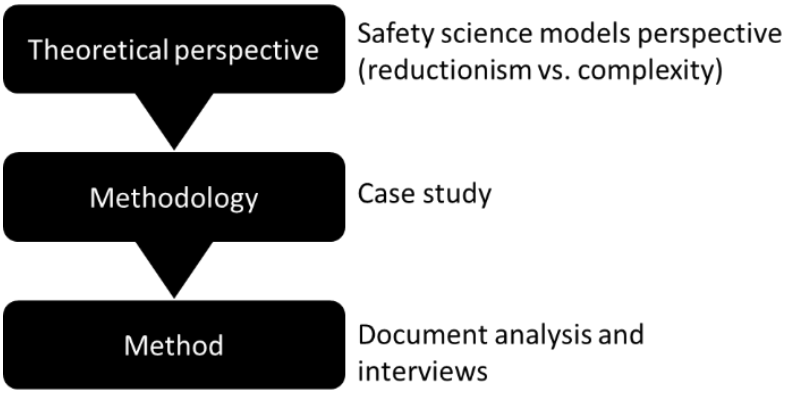
In this thesis, the application of deductive reasoning is deemed appropriate because the qualitative data is compared with an existing theoretical framework, as described in the subsequent paragraph. The primary objective is to ascertain the alignment of the data (comprising accident investigation report analysis, and interviews) with the theoretical

underpinnings of accident investigation models. The interviews, in this context, are anticipated to gain additional insights, contextual depth and to provide information about the effects of the investigations on the organisation.

Within the realm of social research, the work of Crotty (1998) may serve as a guiding framework providing direction for exploring the intricacies of the research domain. Crotty's (1998) four elements —epistemology, theoretical perspective, methodology, and methods — are used as guiding principles that mutually inform one another throughout the research process. These elements, foundational to any research undertaking, collectively contribute to ensuring the soundness and robustness of the research and the persuasiveness of its outcomes (Crotty, 1998). Figure 3 offers a visual representation of the research guiding principles. For this thesis, the theoretical perspective, methodology and method are explored and explained hereafter.

Figure 3

Research guiding principles



In this research the worldview constructionism is used. Constructionism is about the making or construction of meaning (Crotty, 1998), exactly the aim of this thesis. Crotty (1998) defines constructionism as “all knowledge, and therefore all meaningful reality as such, is contingent upon human practices, being constructed in and out of interaction between

human beings and their world, and developed and transmitted within an essentially social context" (p. 42). This thesis is a story about the change in incident investigation philosophy and searches for perspectives, opinions, ideas and authenticity thereby making meaning of the change. It must be said that this is not about finding or constructing one truth.

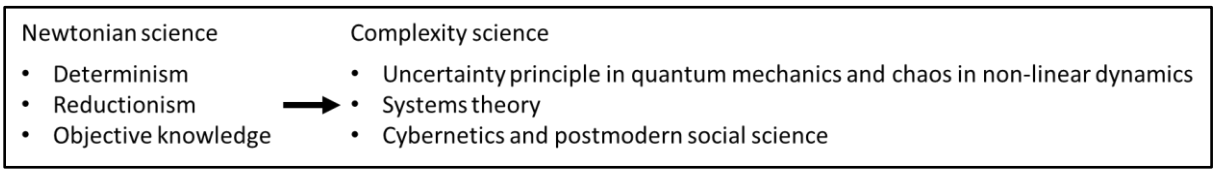
Theoretical perspective refers to the philosophical stance informing the methodology and thus providing a context for the process and grounding its logic and criteria (Crotty, 1998). In this research, the theoretical perspective is reductionism versus systems theory as part of the science of complexity. This perspective is based on the different investigation models that provides the theoretical framework for the study of effects of the investigation reports. The characterisation of investigation models as constructed by Hollnagel is used. This framework is further explored in the thesis. Hereafter both reductionism and systems theory is shortly touched.

Reductionism is a philosophical approach that seeks to understand systems by breaking these systems down into separate components. The underlying science is Newtonian science where reductionism, determinism and objective knowledge are proposed (Heylighen et al, 2007). This traditional scientific method, based on analysis, isolation and the gathering of complete information seemed to be incapable to deal with complex interdependencies.

Determinism was challenged by Heisenberg's uncertainty principle in quantum mechanics and the notion of chaos in non-linear dynamics. Objective knowledge was challenged by cybernetics and postmodern science resulting in the idea that knowledge is intrinsically subjective. "Systems theory replaced reductionism by a scientifically based holism" (Heylighen et al, 2007). These three developments are now named under the header of 'complexity science' (Heylighen et al, 2007). This development is visualised in Figure 4.

Figure 4

The shift from Newtonian to complexity science.



Note: Determinism, reductionism and objective knowledge is based on Newtonian science and is gradually replaced by respectively uncertainty and chaos, systems theory and cybernetics and postmodern social science named under the header of 'complexity science' (Heylighen et al, 2007).

For this thesis the focus is on reductionism as part of Newtonian science and it's replacer systems theory as part of complexity science.

Systems theory developed from a scientifically based holism. Holism is a philosophical concept that emphasizes the idea that the whole is greater than the sum of its parts (Heylighen et al, 2007). Or even more precise, dating back to Aristotle, "the totality is not, as it were, a mere heap, but the whole is something besides the parts" (Ross, 1924). This suggests that the whole cannot be (fully) understood by studying the parts and the other way around that the parts cannot be (fully) understood by studying the whole. But what is it that the whole has more? Nowadays one may say that a whole has emergent properties. Properties that the individual parts do not have (Heylighen et al, 2007). The whole and parts are interconnected, interdependent and constant in motion.

Holism represents a perspective that encourages a broad understanding of complex systems, emphasizing the importance of the relationships and interactions between their different components. According to Heylighen et al (2007), science has ignored holism so far because "the Newtonian approach was so successful compared to its non-scientific

predecessors that it seemed that its strategy of reductionism would sooner or later overcome all remaining obstacles" and secondly because "holism or emergentism seemed to lack any serious scientific foundation, referring more to mystical traditions than to mathematical or experimental methods the Newtonian approach was" (p. 6).

Holism in itself may be seen as reductionist too. Like reductionism, holism has boundaries because one is probably not able to grab the whole (system). After all, what is the 'whole system'? Despite this critique, holism may be a way to refer to a richer and broader perspective than reductionism is able to offer. Later in this thesis the reductionist and systems perspective are explored further.

Methodology refers to the strategy, plan of action, process or design lying behind the choice and use of methods to the desired outcomes (Crotty, 1998). This research will be based on a case study. A case study provides "an in-depth exploration of intricate phenomena within some specific context" (Rashid et al., 2019, p. 1). In this research, two lenses (as framed in the method section) are used to reveal multiple facets of the phenomenon (Baxter & Jack, 2008). The research is exploratory and tries to find out under what conditions a change from 'reductionist' investigations to 'systemic' investigations was possible and more important what the effects of this change are.

Methods refer to the techniques or procedures used to gather and analyse data (Crotty, 1998). This thesis consist of two complementary methods. A content analysis and interviews.

The literature review is followed by a *content analysis*. This analysis focuses on nine investigations carried out in the between 2011 and 2021 at NS. Five investigations are written and published before 2017 and four investigations are written and published after 2017. These reports are published internally with the purpose to inform and learn. This content analysis may be seen as secondary research because the investigation reports are in this research used for other purposes than the original purpose of the investigation report (Baxter et al, 2008).

The nine reports (artefacts), specified in the research, are picked randomly based on foremost availability. A preliminary assessment indicated that few reports are available and that the investigation reports before 2017 are generally similar, making the specific selection less critical. For the investigation reports after 2017 the same holds true for similarity although more reports are available. The chosen reports may therefore be seen as representative of the period.

The number of nine reports is arbitrary. On the one hand it is important to keep the research narrow, on the other hand this decreases the validity of findings because other reports not included in the preliminary assessment may differ. For this qualitative research nine reports seems to be doable and above all representative. The data derived is qualitative because the content will be interpreted, assessed and judged with a special focus on the process and the effects of the investigation on the organisation especially in terms of measures. To what degree a particular report may be plotted in the characterisation of accident models (which is part of the literature review) is qualitative as well. Based on the accident model framework where Hollnagel distinguishes three stereotypical ways of thinking about how an accident occurs (Hollnagel, 2007), the content of the reports will be coupled to this framework (specifically the characteristics of the three models). The data may eventually result in conclusions about the ratio of reductionism and complexity characteristics in the investigation reports. This content analysis will show how the investigation reports at NS changed over time.

The investigation reports used are only published internally (within the organisation). In general, for most reports there is no incentive or need to publish externally (outside the organisation). This also means that the reports are not available for the reader. Therefore this specific research is not repeatable by ’outsiders’ in one way or another.

Qualitative interviews will complement the content analysis. The structured interview method is used because it offers the possibility to conduct naturalistic and in-depth conversations to collect data (Baxter et al, 2008). The results of these interviews will qualitatively answer the question ‘What are the changes in effects of the incident investigations at NS as executed before and after 2017?’. The individuals involved in the incident investigation process and the receivers of the incident investigation reports are probably the best informants to inform the researcher on this topic. Therefore, eight interviews are conducted with informants that represent three different functions with the aim to identify their view on incident investigations carried out at NS and how these investigations changed over the years:

- two HSE managers with experience of both investigations pre and post 2017;
- three HSE advisors with experience of both investigations pre and post 2017;
- three (senior) managers with experience of both investigations pre and post 2017.

’Experience of both investigations pre and post 2017’ means that these informants have working experience with both types of investigations because the informants were active in this function before and after 2017. It is important to note that during the interviews questions are asked about the period before 2017. In other words, a part of this research looks back at a period approximately seven years ago. This may be tricky because the period after 2017 may influence the informants perspective on the period before 2017. Therefore the results regarding the investigations before 2017 needs to be carefully considered.

I expect the HSE advisors and HSE managers are able to inform about the investigation processes as well as the results and the effects of these processes and investigation reports. The three managers are probably able to share their perspectives on both the investigation process and the results of the investigations. The informants all work at NS. I have access to them and I expect the informants to be available during the research.

The eight informants cover three functions – HSE managers, HSE advisors and managers - that are thought to be representative for the aim of this part of the thesis. I expect the informants are able to share their views and experiences. If there is a variety in outcomes, it will be possible to conduct additional interviews.

It would be very valuable to also include sharp end operators such as train drivers and conductors. The chances are very small that specific sharp end workers were involved in incidents both before and after 2017. Thereby it would be a difficult search to look for those sharp end workers if possible at all. Therefore sharp end workers are excluded from the interview part of this thesis.

The interviews will be conducted in a ‘closed’ setting with one participant and one interviewer. The interviews will be structured because I want to have a conversation covering the change in incident investigation methods at NS with a specific set of questions. In the conversations, I want to pick up aspects that are relevant for the research. The interview questions are provided in Appendix 1. Interview questions.

Informed consent is required to inform participants about the study and how the data will be stored and used. The informed consent form is included in Appendix 2. Informed consent for interviews. An ethical review is not required because there is no personal data concerned as mentioned on the research ethics part of the website of Lund University (2023).

The interviews will focus on the incident investigation process as was executed before and after 2017. I expect the informants to be able to tell about both the investigations conducted before 2017 and after 2017 and the change the organisation has made based on the differences between the two types of investigations. The investigations were part of the core business of the HSE managers and advisors. Therefore I expect both types of informants to be able to tell and explain their perspectives. For the line managers this is different because their role in the investigation process was and still is limited. While the investigation process has a

massive influence on those involved, I expect the line managers to have their own perspectives on the investigation process before and after 2017 as well, although their focus may be more on those involved. This data is qualitative and will be used to validate the findings of the document analysis.

The recorded interviews are manually written down on digital paper. In the texts, relevant passages for the research are highlighted. In another document, the highlighted text is plotted per interview. This results in an overview of relevant passages per interview. The passages are compared and themes are constructed wherein those passages are plotted. The results of the interviews as described in this thesis are based on these themes.

Previous research and relevant literature

This section of the thesis covers the literature review. The literature review provides background information and justifies the proposed research. For this research a systematic literature review is carried out. The systematic review tries to gain insights in the research already carried out in the field of incident investigation methods in all domains. Incident investigation is part of the safety science domain. Therefore the starting point is the safety (science) domain.

Safety and incident investigations

Safety lacks an "unequivocal definition" (Hollnagel, 2009, p. 8). It seems there are two opposite worldviews on safety. The first worldview emphasizes safety as "a condition where nothing goes wrong or more cautiously as a condition where the number of things that go wrong is acceptably small" (Hollnagel 2014, p. 37). This indirect definition sees safety as an epiphenomena, an incidental product of some process(es) that has no effects of its own (Hollnagel, 2013). The second worldview emphasizes safety as a phenomenon where as many things as possible go right (Dekker, 2014a).

There is little attention given to the history of safety, probably because safety is seen as a combination of various sciences such as engineering, psychology, sociology (Guarnieri, 1992). Despite this perspective, Guarnieri (1992) argues safety has its own unique history because safety "is more than a by-product of progress in other sciences" (p. 151). The history of incident investigations, as part of the safety science discourse, has even attracted less attention. There is probably one recent book titled 'From safety to safety science' that filled this gap (Swuste et all, 2022).

Accidents may be seen as disruptive events challenging "existing believes, worldviews and assumptions about the nature, location and distribution of risk" (Dekker, 2014b, p. 202). Incident investigation is a way in which an organisation creates feedback in order to prevent

accidents (Kjellén & Albrechtsen, 2017) and thereby increasing safety. Hollnagel (2004) challenges this perspective and argues that although we may think that we are looking for explanations of the accident, we are probably more often looking for certainty in the form of a cause thereby concluding that finding an acceptable cause is more important than what really happened. Hyatt (2006) agrees with the perspective of Kjellén & Albrechtsen and sees preventing accidents as one of the main purposes of incident investigations, next to find out what happened and why it happened. Harvey (1985) mentions five different reasons for accident investigation:

1. Legal: to satisfy legal requirements, and to document any violations of the safety code;
2. Describe: to describe the events and circumstances surrounding the accident;
3. Cause: to identify the probable cause or causes of the accident;
4. Prevention: to recommend what changes could be made to the safety code or work side in order to decrease the probability of a similar accident in the future;
5. Research: to gather accident information for use in accident research programs and safety programs.

Kletz (2001) challenges the use of the word cause because (1) there may be a temptation to list causes we can little or nothing do about them, (2) cause implies finality leading to ending investigations without further investigation, (3) the word cause may be experienced as blame resulting in people becoming defensive and (4) causes may be abstractions that which can be done nothing about. In 2014, Dekker suggests that “accident investigation is a psychological exercise in epistemological, preventive, moral and existential meaning-making”. Dekker (2014b, p. 202-203) explains these four psychological purposes of accident investigation as follows:

- Epistemological: explain what happened;
- Preventive: explain how to avoid recurrence;

- Moral: explain deviance;
- Existential: explain suffering.

Investigations may serve one or more of the purposes. Those purposes may be sometimes in conflict with each other. For example an investigation may serve epistemological purposes but may not be able to serve existential purposes. Following these purposes, Dekker takes his analysis one step further and describes accident investigation as "exercises in political sensemaking" and even "an exercise in power" (Dekker, 2014b, p. 203). Dekker (2014b) argues that this perspective may be an explanation for how two different investigators looking at the same sources from a case present divergent stories and conclusions because interest, purposes and motives to investigate may differ.

The underlying practices and principles that explain how accidents happen, are called incident and / or accident models (Hollnagel & Speziali, 2008).

The use of incident (investigation) models

In executing incident investigations, incident investigation methods are used to guide the researcher through the process by providing a sequence of steps for applying the model (Ahmadi Rad, 2022). Therefore methods provide a means to apply the theory (Underwood & Waterson, 2013). These methods are very diverse and specific and therefore not suitable to use in this research. Here, a mere broad and generic characterisation type of accident models offers an alternative, name it the underlying theory. The characterisation type of accident models may be seen as a conceptual structure or representation based on a stereotypical way of thinking about how accidents occur (Ahmadi Rad, 2022; Hollnagel, 2002; Underwood & Waterson, 2013). The models support the investigators by (Kjellén & Albrechtsen, 2017, p. 25):

- Creating a mental picture of the accident sequence;
- Asking the 'right' questions and defining the types of data to collect;

- Establishing stop rules (i.e. rules for when to terminate the search for new causes further away from the accidental event);
- Checking that all relevant data have been collected;
- Evaluating, structuring, and summarising the data into meaningful information;
- Analysing relations among pieces of information and seeing interrelations;
- Identifying and assessing remedial actions;
- Communication among people by providing a common frame of reference.

The investigation models provide a basic framework for this thesis. The knowledge gained in the first year of the human factors and systems safety master in combination with a search in Scopus is used to find available frameworks. This resulted in the existence of at least five characterisation types of accident models. Four types - types defined by Hollnagel (2002), Kjellén & Albrechtsen (2017), Van Alphen et al. (2012) and types defined by the human factors and systems safety course (not particular accident models but are mentioned as well because these types are also used to explain accidents) are distinguished, explored and judged.

According to Kjellén & Albrechtsen (2017), accident models help the investigator to:

> create a mental picture of the accident sequence, asking the ‘right’ questions and defining the types of data to collect, establishing stop rules (i.e. rules for when to terminate the search for new causes further away from the accidental event), checking that all relevant data have been collected, evaluating, structuring, and summarising the data into meaningful information, analysing relations among pieces of information and seeing interrelations, identifying and assessing remedial actions, communication among people by providing a common frame of reference. (p. 25)

Lundberg et al. (2009) describe in their study that “the causes found during an investigation reflect the assumptions of the accident model, following the ‘What You Look For Is What You Find’ principle” (p. 2). The identified causes may result in specific problems to be fixed during an implementation of solutions, following the ‘What You Find Is What You Fix’ principle (Lundberg et al., 2009).

The results are presented in the overview in Table 2. The grey marked lines are the four different characterisation types of accident models. Under these lines, additional literature is provided with a relation to the main characterisation types.

This literature review distinguishes four sets of assumptions of what the underlying mechanisms of individual accident investigation methods are (Hollnagel, 2002). These sets are provided in Figure 5.

Table 2

Prioritisation list of the types of literature relevant for my thesis.

Author	Type	Title	Year
E. Hollnagel	Paper	Understanding accidents - From Root Causes to Performance Variability	2002
E. Hollnagel	Book	Barriers and Accident prevention	2004
Z. H. Qureshi	Paper	A Review of Accident Modelling Approaches for Complex Critical Sociotechnical Systems	2008
Z. H. Qureshi & A. Campbell	Paper	Systemic Safety and Accident Modelling of Complex Socio-technical Systems	2009
P. Underwood & Waterson, P.	Paper	Accident Analysis Models and Methods: Guidance for Safety Professionals	2013
S. Sklet	Paper	Comparison of some selected methods for accident investigation	2014
DOE Handbook	Book	Accident and Operational Safety Analysis	2012
E. Hollnagel	Paper	Accident Analysis and barrier functions	1999
Kjellén	Book	Prevention of Accidents Through Experience Feedback	2000
Kjellén & Albrechtsen	Book	Prevention of accidents and unwanted occurrences.	2017
Van Alphen et al	Book	Leren van ongevallen (learning from accidents)	2012
Human factors and systems safety course	Various	Various	

Figure 5

Four sets of underlying mechanisms of individual accident investigation methods.

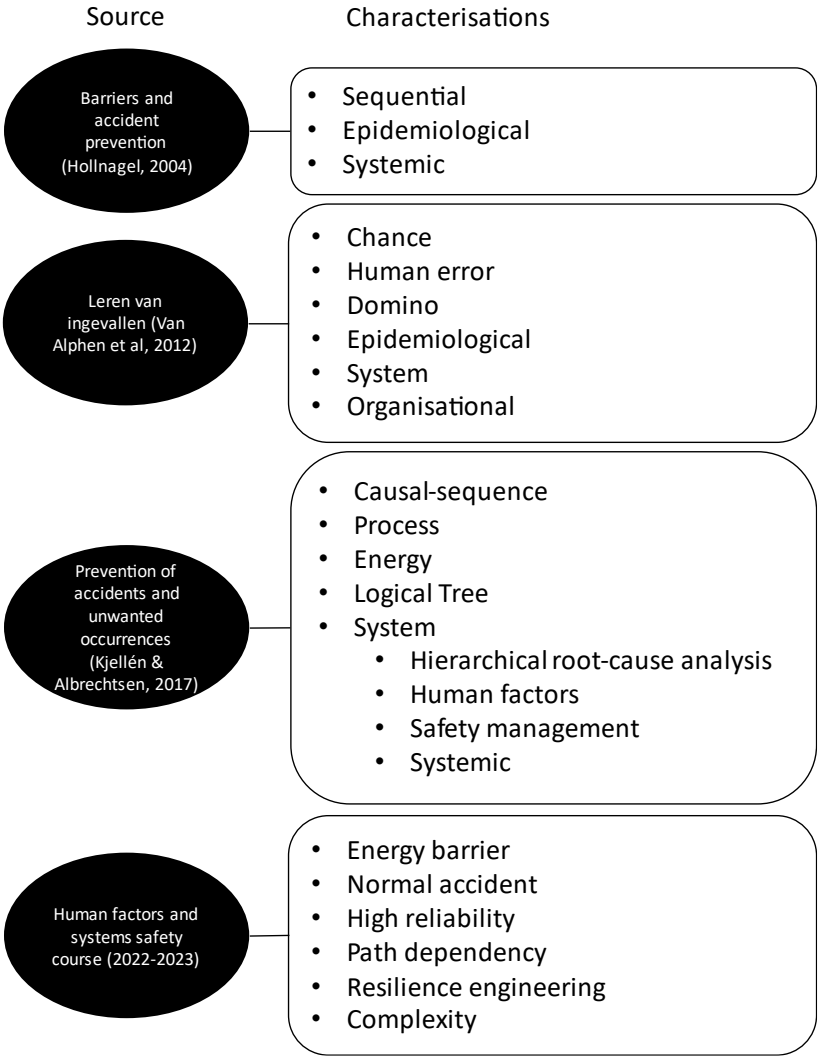


Table 2 shows that the research on the investigation models focuses mainly in the period between 2000 and 2012. Besides the revised model scheme of Kjellén & Albrechtsen in 2017, there has been not much research in this area in the last ten years.

In this literature review, the focus is on the existing investigation methods and their characteristics. This section provides an introduction to the body of literature (embedded study of previous knowledge) and how this body relates to one another regarding incident investigation approaches. The models are different, may be used in different circumstances and can probably complement each other (Hollnagel, 2002).

For this research, it makes sense to use only the characteristics of Hollnagel as basis to review the investigation reports. The models distinguished by Hollnagel are described in the paper “Understanding accidents - From Root Causes to Performance Variability” published in 2002 and later extended in the book “Barriers and Accident prevention” published two years later. Both publications are mentioned in Table 2. Hollnagel distinguishes three model types: sequential, epidemiological, and systemic. These model types are relatively simple and general (which is needed to contain a wide range and great variety of incident investigation metaphors) and comprehensive without being designed for accidents of a particular type. Thereby these model types are widely used (in among others Underwood & Waterson, 2013; Wienen et al, 2017). Therefore only the model of Hollnagel is described here. This is achieved by distinguishing the models between search principles, analysis goals, relating metaphors and underlying assumptions. These aspects give an overview of the specifics of the different model types.

The first paper listed on the prioritisation list, ‘Understanding accidents’ (Hollnagel, 2002) is the main source of the characterisation types of accident investigation models as defined by Hollnagel. In addition to the paper, the book ‘Barriers and accident prevention’ is used because the same characteristics are provided with more details and context. The book may be seen as an extended non-peer reviewed resource of the paper.

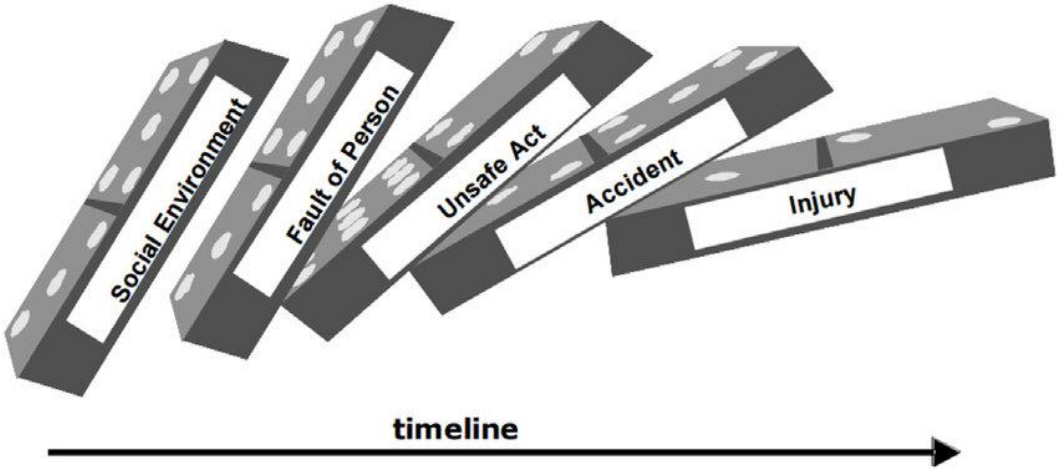
Hollnagel distinguishes three sets of assumptions of what the underlying mechanisms of individual accident investigation methods are. These models are called sequential, epidemiological and systemic accident models. These are stereotypical ways of thinking about how an accident occurs. Table 3 shows these three model types.

The sequential model type may be explained with the metaphor of a chain of sequence of events, also known as the domino model (Heinrich, 1931). The domino model is visualised in Figure 6. The principle follows a causal series where the social environment leads to a fault

of a person leads to unsafe acts leads to an accident and ultimately leads to an injury. This is a resultant phenomenon: an outcome that arises as a consequence of a specific cause. This cause-effect chain is assumed to be linear and deterministic (Underwood & Waterson, 2013). This model searches therefore for specific cause-effect links. It is assumed that 'finding' and removing a domino, preferably the root cause, prevent this accident in the future. The search for a root cause implies a focus on broken components. The system is functioning 'normally'. In the 1970's, several major industrial accidents (i.e. Three Miles Island, Chernobyl, Bhopal) happened. Organisational influences played a significant role. The sequential model was not able to 'explain' these accidents and organisational factors. This resulted in a new model type: the epidemiological model.

Figure 6

Domino theory



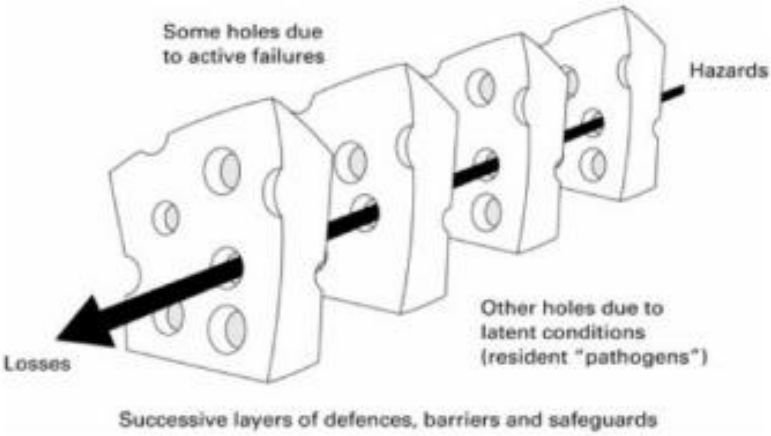
Note: The domino theory represents a causal sequence of events where the social environment results in a fault of person, resulting in an unsafe act, resulting in an accident and eventually resulting in an injury (Heinrich, 1931).

The second model distinguished by Hollnagel, the epidemiological model, provides a basis for discussing the complexity of accidents that overcome the limitations of sequential models. Accidents are viewed as a combination of both latent and active failures in a system, like the spreading of a disease. The epidemiological model may be explained with the metaphor of the Swiss cheese. The Swiss Cheese Model is visualised in Figure 7.

. The Swiss cheese analogy explains how systems are vulnerable to failure and how multiple layers of defence can help to prevent accidents (Reason, 1997). The analogy compares a system to multiple slices of Swiss cheese, each with holes in different places. The holes represent weaknesses or vulnerabilities in the system and the slices represent different layers of defence. Both failures and conditions are dynamic. When the holes line up, a trajectory of accident opportunity emerges. This is visualised by the arrow and may result in losses. However, the presence of multiple layers means that it becomes less likely for all the holes to align at once, reducing the chances of undesired outcomes. The combination of various defences creates a more robust system. The Swiss cheese model emphasizes the importance of having redundant and diverse safety measures in place to minimize the risk of accidents or failures. Each layer of defence is not perfect (like the holes in Swiss cheese), but the combined effect of multiple layers significantly enhances overall safety. Epidemiological models are difficult to specify in further detail (Hollnagel, 2002). Still the cause-effect relationship is apparent in this model. The increasingly complex nature of socio-technical system accidents could no longer being explained with the epidemiological model. Systems theory was thought to be a solution.

Figure 7

The Swiss Cheese Model



Note: The latest version of the Swiss Cheese Model represent holes due to active failures in layers of defences making an accident trajectory possible resulting in loss (Reason, 2008).

The third and last model distinguished by Hollnagel, the systemic model, overcomes this limitation and provides an analogy to "describe the characteristic performance on the level of the system as a whole, rather than on the level of specific cause-effect 'mechanisms' or even epidemiological factors" (2002, p. 1-2). The systemic accident model views accidents as the result of interactions within a complex system rather than simple cause-and-effect relationships. It focuses on how different components, elements, and actors in a system interact and influence each other. Accidents are seen as the result of functional resonances, where various system components align in unexpected ways, leading to an undesired outcome. These resonances occur when different parts of the system come together in a particular configuration that allows an accident to happen. The different parts may function as intended locally but interacting may lead to unexpected behaviour of the whole system. The model recognizes that human performance and system behaviour are inherently variable due to a range of factors. This variability can contribute to functional resonances and accidents. Rather than assuming that accidents happen due to a lack of control, the model acknowledges

that control and adaptation are present in all systems. However, accidents can still occur even in well-controlled environments when functional resonances emerge. The systemic accident model emphasizes the importance of understanding system functions, variability, and interactions to prevent accidents. Instead of seeking a single root cause, the focus is on identifying potential functional resonances and strengthening system defences to make accidents less likely or their consequences less severe.

Table 3

The three types of accident models as defined by Hollnagel (2002; 2004).

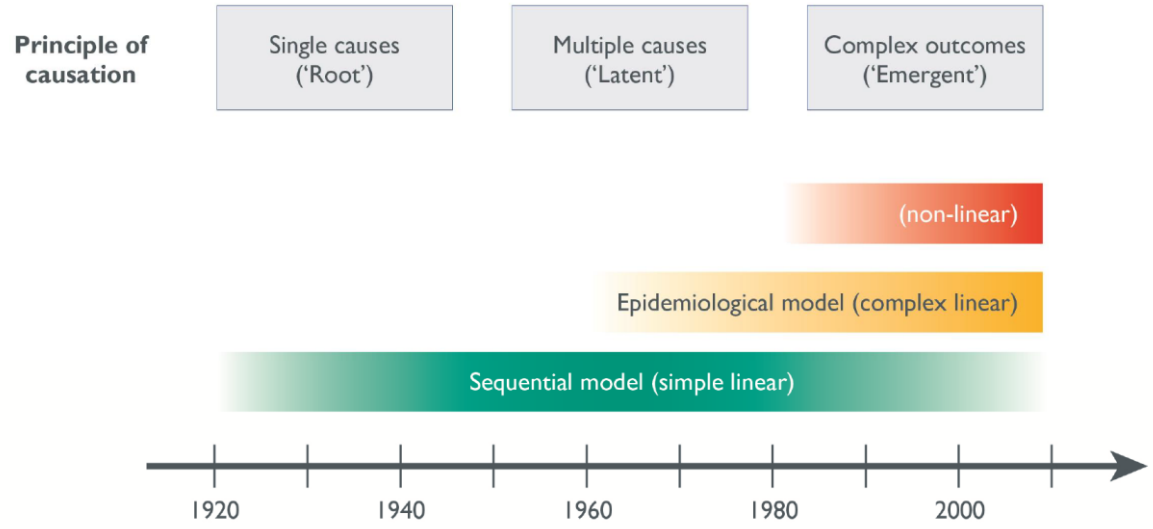
Attribute	Model type		
	Sequential	**Epidemiological**	**Systemic**
Search principle	Specific causes and well-defined links	Carriers, barriers, and latent conditions	Tight couplings and complex interactions
Analysis goals	Identify cause-effect links and eliminate or contain causes	Make defences and barriers stronger	Monitor and control performance variability.
Relating metaphors	(Linear) chain of sequence of events (domino) Tree models Network models	Latent conditions Carrier-barriers Pathological systems Swiss cheese analogy	Control theoretic models Chaos models Stochastic resonance
Underlying assumption	Resultant phenomenon Causal series	Resultant phenomenon Causal network	Emergent phenomenon Dynamic interactions and dependencies
Characteristics	Error management: root cause	Performance deviation management: manifest and latent causes	Performance variability management: functional resonance
	Assumptions or hypotheses about internal mechanisms.	Assumptions or hypotheses about internal mechanisms.	Understanding the functional characteristics of the system.
	Encourages thinking in causal series.	Encourages thinking in causal net(work)s.	Avoid sequence or ordering.
	Easy to represent graphically.	Cluttered in graphical representation.	Difficult to represent graphically.
	System is functioning normally. Focus on broken components, i.e. ‘human error’.	Performance deviations.	Characteristic performance on the level of the system as a whole

Reductionist and systems approach

The three model types show a paradigm shift in thinking. This paradigm shift is visualised in Figure 8. When viewed in a more abstract way, the model types on the left of the time scale represent a reductionist approach (sequential model) whereas the model types to the right of the time scale represent a systems approach (non-linear). Both approaches may be seen as two worldviews that complement each other and are explored hereafter.

Figure 8

Summary of a history of accident modelling.



Note: This summary shows the three model types plotted in time and principle of causation. From around 1920 the sequential model type was leading with a focus on a single (root) cause. From around 1960, the epidemiological model type with a focus on multiple (latent) causes arised. From around 1980, the systemic non-linear model type with a focus on complex (emergent) outcomes arised (Hollnagel, 2010, slide 7; HaSPA, 2012).

Based on the underlying science of Newtonian named after its creator Newton, *the reductionist approach* tries to understand systems by breaking those systems down into smaller, simpler components and analysing each component individually (Heylighen et al,

2007). It is based on the belief that understanding the behaviour of individual parts will lead to an understanding of the entire system. In a reductionist perspective, phenomena are seen as the sum of their individual, isolated parts. For example, in the context of investigations, a reductionist approach might involve analysing accidents by examining component failures such as technical failures or 'human errors'. These factors are studied in isolation to determine their role in the occurrence of the incident. It is assumed that "everything that happens has a definitive, identifiable cause and a definitive effect" (Dekker et al., 2011, p. 940) where cause and effect are symmetrical (Dekker et al., 2011). In a reductionist approach a completeness of knowledge is assumed, harm is foreseeable and time is reversible.

While the nature of accident causation changes due to among others technological advances and more complex relationships between humans and technology, a shift to a more *holistic approach named systems approach* is visible in the model types on the right side of figure 7. A system may be defined as "the intentional organisation or arrangements of parts that makes it possible to achieve specified and required goals" (Hollnagel, 2009, p. 19). The systems approach is based on the science of complexity and views a system as a whole, interconnected entity, where the behaviour and properties of the whole system cannot be fully understood by analysing its individual parts in isolation (Heylighen et al, 2003). Instead of breaking down a system into its components, the systems approach emphasizes understanding the interactions, relationships, and feedback loops between those components. It recognizes that the behaviour of a system emerges from the interactions of its individual components. This approach considers how these elements are interconnected and how changes in one part of the system can have (unforeseen) effects on the entire system. A complex system is an open system. The boundaries of such a system are problematic to define (Cilliers, 2001). The boundary may be identified based on the system functions, hence are relative (Hollnagel, 2009).

To illustrate the difference between the two approaches, consider a car engine. A reductionist approach might involve studying individual components of the engine, such as the pistons, valves, and spark plugs, to understand how they function. In contrast, a systems approach would focus on how these components work together to produce engine power, taking into account factors like fuel efficiency, emissions, and overall performance.

Both approaches have their merits and may be used in combination to gain a comprehensive understanding of complex phenomena.

Findings

The characteristics and effects of incident investigation reports pre and post 2017

For this research, the following selection of random investigations are used. It is important to note that these investigation reports are not publicly available.

- Investigation reports published pre 2017:
    - 27 August 2011, SPAD Houten
    - 16 November 2012, collision between trains in Zutphen
    - 9 February 2013, SPAD Alkmaar
    - 1 February 2014, SPAD Rotterdam
    - 26 Mai 2016, SPAD Liempde
- Investigation reports published post 2017:
    - 23 June 2017, SPAD Alkmaar
    - 17 December 2017, SPAD Waddinxveen
    - 2019, three SPADs Castricum
    - 1 May 2021, collision between two locomotives in Amsterdam

Each investigation report published before and after 2017 is assessed based on Hollnagel's characteristics (described in Table 4). It is argued what characteristics are noticeable in the specific report. Thereafter the characteristics of the reports published before 2017 are compared resulting in an overview to what model type these investigations belong. The same is done for investigation reports published after 2017. This paragraph culminates by highlighting the extent to which the reports written before 2017 differ from those written after 2017 based on the characteristics.

Table 4

Characteristics of accident models based on Table 3.

	Model types		
	Sequential	**Epidemiological**	**Systemic**
Characteristics	Error management: root cause	Performance deviation management: manifest and latent causes	Performance variability management: functional resonance
	Assumptions or hypotheses about internal mechanisms.	Assumptions or hypotheses about internal mechanisms.	Understanding the functional characteristics of the system.
	Encourages thinking in causal series.	Encourages thinking in causal networks.	Avoid sequence or ordering.
	Easy to represent graphically.	Easy to represent graphically.	Difficult to represent graphically.
	Focus on ‘human error’ (sharp end).	Performance deviations.	Characteristic performance on the level of the system as a whole

Investigation reports pre 2017

Five investigation reports written before 2017 serve as illustrative examples of the investigations before 2017. The choice of five reports is based on the relatively limited number of reports available from this period. A preliminary assessment of twenty reports indicated that the investigation reports are generally similar, making the specific selection less critical. The emphasis here is on the examination of these five reports that are seen as representative of the period pre 2017.

The contents of the reports are described with a special interest in the effects (or more specifically the measures) of the investigations. Only information that is written down in the reports is mentioned here. Besides the measures, other effects on the organisation are not distinguishable from these written reports.

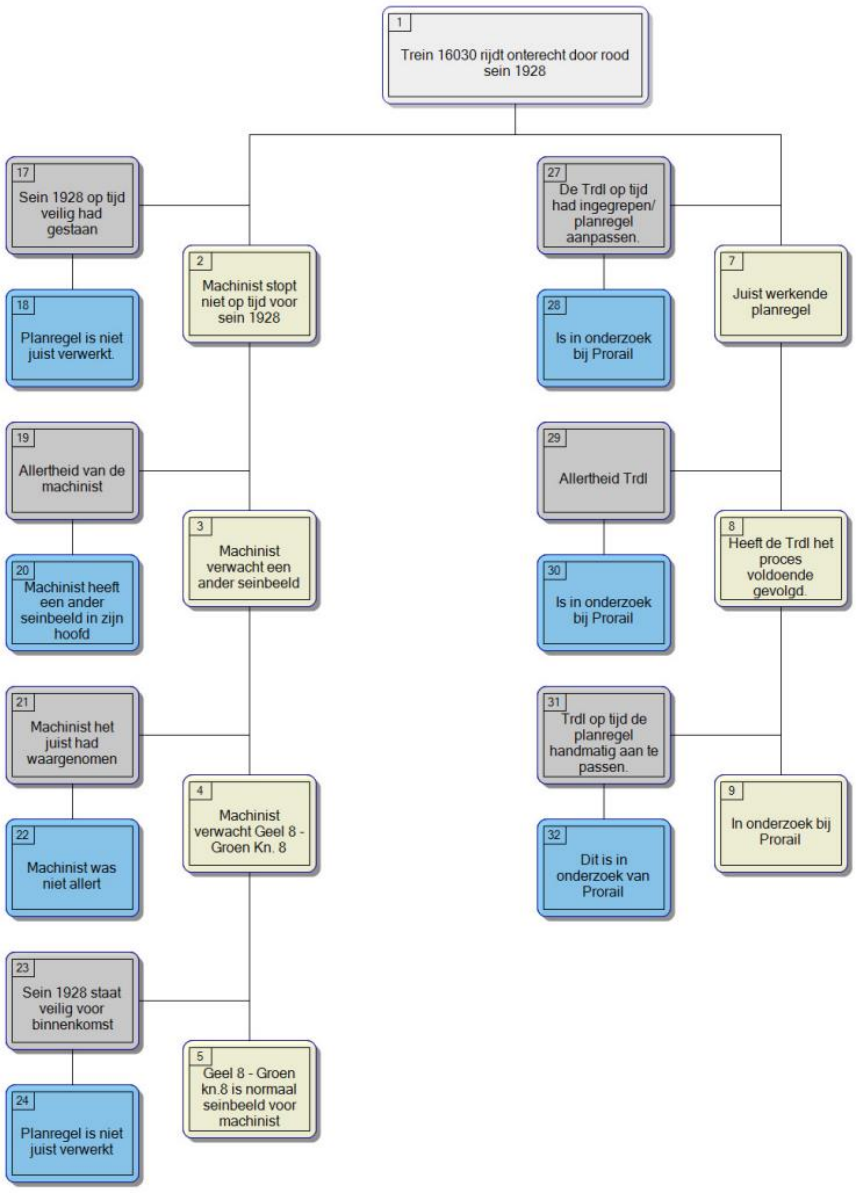
SPAD in Houten. The seven-page report describes a train that passes a signal at danger near Houten. The occurrence is described whereafter a brief analysis takes place, focusing on the specific occurrence. The report is organized around a simple fault tree model. This tree model is shown in Figure 9. The analysis is framed by two main branches. The first branch focuses on the actions (or lack thereof) of the train driver, emphasizing that the train driver does not stop timely before the signal and the expectation of the train driver that the signal show a different signal aspect than stop. This branch of the tree delves into the train driver's responsibilities and potential solutions, such as ensuring the signal is clear and enhancing the driver's alertness. The second branch focuses on the rail infrastructure manager, evaluating the effectiveness of the plan rule and the adherence of the train dispatcher to the established process. Solutions proposed include timely changes to the plan rule by the train dispatcher and improving the dispatcher's alertness.

The report concludes with recommendations, aligning with the two branches of the tree model. The first recommendation addresses the train driver, suggesting a discussion with

the train driver on maintaining alertness during shifts and providing a folder with tips and tricks on alertness. The second recommendation pertains addresses the train dispatcher employed by the infrastructure manager, urging the infrastructure manager to scrutinize the dispatcher's role and explore preventive measures against SPAD incidents. Both recommendations prevent a specific root cause from happening again by a focus on the specific component ‘human error’ on the sharp end, the train driver and train dispatcher.

Figure 9

Fault tree as represented in the investigation report of the SPAD in Houten.



Collision between trains in Zutphen. The ten-page report describes a collission between a shunting movement and parked freight wagons in a siding. An analysis tree is used to construct why the train collapsed with the wagons. Two branches are distinguished. The first branch focuses on the train driver. The train driver drives the train into an occupied siding with engaged traction under low visibality circumstances and talks on the radio with the train dispatcher. The report describes these three factors as self-reinforcing factors. ”Remove one of these factors and a collission would be prevented”. The second branch focuses on the circumstances. Dark freightwagons without lightning on a track without any lights in low visibility circumstances. Interestingly, the two measures written in the report focus only on train drivers. The first ’learning action’ says ”discuss the report with the driver of the shunting train and pay attention to the following two important aspects: 1. the train driver took a risk by driving with engaged traction, under poor visibility conditions, to an occupied track, and 2 conducting a radio conversation while driving (shunting) under this specific circumstances is risky and undesirable”. The second ’learning action’ involves ”publish the circumstances, consequences and actions following this incident by means of a message to all train drivers”. Altough the findings in the report focus on both the train drivers and systemic circumstances, the two recommendations focus on the specific component ‘human error’ on the sharp end.

SPAD Alkmaar. The eight-page report describes a train passing a sign without permission of the responsible train dispatcher. In contrast to the two previous reports, this report describes a direct cause and underlying cause. According to the author of the investigation report, the direct cause is “a failure to comply with the stated assignment associated with the sign” (not asking permission from the responsible train dispatcher before passing the sign). The underlying cause is “the train driver assumes the sign is not applicable for the route of his train”. Here the analysis ends. The analysis tree consist of one branch and

involves counterfactuals, essentially exploring a parallel universe where certain events that may could have prevented the incident, did not occur (Dekker, 2014). (a) The speed of the train is not reduced sufficiently, (b) the train does not stop for the sign and (c) the train driver does not ask permission of the responsible train dispatcher. The report describes one recommendation, namely "discuss the findings of the safety investigation with the train driver". The focus of the recommendation is therefore only on a specific component, 'human error' on the sharp end.

SPAD Rotterdam. The twelve-page report describes a train passing a signal at danger near Rotterdam. In this report a distinction is made between the direct cause and underlying causes. The direct cause is according to the author "a failure of the train to stop in time at the stop signal". The three underlying causes are "distraction of the train driver", "the train driver's assumption that the yellow signal in the distance is intended for him" and "the train driver's brake strategy gives a minimal deceleration". The analysis tree consist of two branches. The first branch focuses on the signal at danger mentioning that the signal is red because of a delayed train. The second branch focuses on the train driver mentioning that the train driver does not consciously perceive the yellow signal and that the train driver assumes the yellow signal in the distance is intended for his train. The report does not contain recommendations.

SPAD Liempde. The last report described here is the signal passed at danger near Liempde. This ten-page report follows a similar structure as the previously discussed reports mentioning a direct cause and underlying causes. The direct cause is "passing the signal at danger without permission from the train dispatcher". The underlying causes are "no plan when trains are delayed", "the train driver did not follow the rules at a yellow signal", "the train driver did not brake strongly enough to come to a stop before the signal at danger" and "the train driver is not alert and his thoughts wander due to private situations". In this case,

the analysis tree also involves counterfactuals, essentially exploring a parallel universe where certain events that may could have prevented the incident, did not occur (Dekker, 2014). The top event, the train passing a signal at danger, branches into two aspects: “train driver stops before the signal” and “train driver is alert”. The second branch focuses on the clarity of the signal. Although these scenarios did not unfold, they are mentioned in the report and may be seen as possible preventive measures. Specific recommendations are not mentioned in the report.

Overview. Each of the five reports has been written by one author (HSE advisor) and are peer reviewed by another HSE advisor. The five reports all have different authors. All investigations share a common structure and adhere to the 'SIM' (Simple Incident Analysis Method) format. In the report related to the SPAD in Houten, it is explicitly stated "it has been agreed to carry out a SIM (Simple Incident Analysis Method) investigation for each SPAD." This indicates a mandatory procedure within NS at that specific time to investigate SPADs according to established protocols. The five reports are in PDF format and consist between seven and twelve pages per report. The reports follow a standardized framework, encompassing an introduction to the occurrence and an analysis of the incident's cause(s). Three reports include recommendations. The other two reports finalise with conclusions without recommendations or measures. The analyses conducted in these reports are based on a graphical visualisation similar to a clear fault tree model, suggesting a linear cause-effect relationship. Despite the uniformity in structure, the five investigation reports are hereafter described to give examples of these types of investigation reports.

It can be concluded that the characteristics of the sequential model type and the epidemiological type applies to the investigations caried out before 2017. The characteristics in italics in Table 5 seem to be applicable to the investigation reports written before 2017

based on the aforementioned summery of the investigation reports. The characteristics are hereafter explored in relation to the investigation reports.

The reports all describe what happened and what and mostly who failed focusing only on the specific occurrence that happened. Examples are a train driver who did not follow up the rules of a specific signal or a lack of attention of a train dispatcher. The search for this kind of failures may be best described as ‘error management: root cause’. After all, the search is based on finding a root cause that could (possibly) prevent the occurrence from happening. The analysis in the reports are conducted with linear fault trees. Such a fault tree indicates ‘assumptions or hypotheses about internal mechanisms’ and ‘encourages thinking in causal series’ because the tree has a clear starting and ending point where, with several steps, the starting point naturally results in the ending point. The fault tree is also easy to represent graphically because of the simplicity of the model. The search for what and especially who failed naturally leads to a main focus on the individual(s) involved, the train driver and in one case also the train dispatcher. When measures are mentioned in the reports, the measures focus only on the sharp end individuals (i.e. discuss the findings of the investigation with the train driver). This indicates a ‘focus on ‘human error’ at the sharp end’. Why the occurrences happened seems to be not a matter of concern. Although not explicitly mentioned, the underlying thought seems to be that if a train driver follows the rules, the occurrence would not have happened at all. This is underlined by written recommendations and measures that all suggest in one way or another to do the work better, to try harder.

This leads to the conclusion that the reports written and published before 2017 all have characteristics of the sequential accident model type and two same characteristics that are also mentioned in the epidemiological model.

Table 5

Characteristics of incident investigation reports written and published before 2017 marked in italics.

	Model types		
	Sequential	**Epidemiological**	**Systemic**
Characteristics	*Error management: root cause*	Performance deviation management: manifest and latent causes	Performance variability management: functional resonance
	Assumptions or hypotheses about internal mechanisms.	*Assumptions or hypotheses about internal mechanisms.*	Understanding the functional characteristics of the system.
	Encourages thinking in causal series.	Encourages thinking in causal networks.	Avoid sequence or ordering.
	Easy to represent graphically.	*Easy to represent graphically.*	Difficult to represent graphically.
	Focus on 'human error' (sharp end).	Performance deviations.	Characteristic performance on the level of the system as a whole

Investigation reports post 2017

Four investigation reports written after 2017 serve as illustrative examples of the investigations after 2017. The choice of four reports is based on a preliminary assessment indicating that the investigation reports post 2017 are generally similar, making the specific selection less critical. The emphasis here is on the examination of these four reports as representative of the period.

The contents of the reports are described with a special interest in the effects (or more specifically the measures) of the investigations. Only information that is written down in the reports is mentioned here. Besides the measures, other effects on the organisation are not distinguishable from these written reports.

SPAD Alkmaar. This report describes a signal passed at danger near Alkmaar where a train passes two open level crossings and a railway bridge. The report is constructed by three authors of whom two are employed by NS and one author is employed by the infrastructure manager. The 34-slide PowerPoint report is organized

around a situation sketch (one-pager) shown in Figure 10 and timeline shown in Figure 11. The analysis that follows the timeline is specifically designed for the particular occurrence answering questions around the main focus ’Why did it made sense to do what one did?”. In this particular occurrence, the train driver and conductor played specific roles. Naturally, this leads to questions why it made sense for both the train driver and conductor to do what they did. The analyses therefore focuses on the following three aspects:

- The conductor starts the departure process without operating the employee box on the platform and without observing the departure light or signal;
- The driver departs without a clear signal;
- The driver does not immediately stop the train and drives over two open level crossings and crosses a railway bridge.

The reasons and motivations may be very different. Everyone has its own perspective and thoughts and therefore reasons to (not) do something. In this particular investigation, the authors use Neisser's perceptual cycle, Hollnagel’s ETTO, situational awareness and mental models to explain why it made sense what happened. Factors may come together in ways not foreseen before. The three earlier mentioned aspects were possibly imaginable as solo occurrences, but not coupled together in one occurrence. Therefore dynamic interactions and dependencies may be revealed that emerge in a specific situation.

Those involved in the occurrence are also involved in the investigation. This can be concluded from the fact that the written recommendations stem from those involved. The following aspects are mentioned as recommendations from those involved: (1) Those involved ask themselves: “Why is there no system that intervenes when I have arrived at such a dangerous point?” (2) When a system is available that intervenes when a train passes a signal at danger, this specific occurrence at this specific location will be prevented. But how about other locations where the same situation exist? This point is further extended with a

better visibility of employee boxes, a trill function of a specific device such as smartphone when a special action needs to take place by a conductor and a system that informs the train driver when the train approaches a signal at danger may help to get the train driver out of the 'wrong movie'. (3) In this case, those involved act from a mental image that is different from the 'real' situation. This is a broader human factors problem that is seen also by other signals passed at danger. This point is further extended with suggestions to organise a human factors workshop to make staff on the train aware that they may be in the 'wrong movie' and how to handle these situations and secondly to add this experience into the training of new train drivers.

The report concludes with four decisions made by responsible management. The first measure is to check if the specific system to intervene in case of a SPAD is operational on the specific signal. The second measure is to discuss the amount of discretionary space that train drivers have to make considerations between conflicting aims. The third measure is discussing the need of a risk analyses regarding inconsistencies of infrastructure (such as the employee box on the platform). The last measure is presenting the investigation to the local management team. The occurrence serve as a motivation to consider the system in a broader way by discussing discretionary space and a risk analysis regarding infrastructure specialties. Therefore the measures seem to focus primarily on (components) of the system. The involved individuals or other sharp end workers are not directly subject of any measure.

Figure 10

Situation sketch of the SPAD Alkmaar.

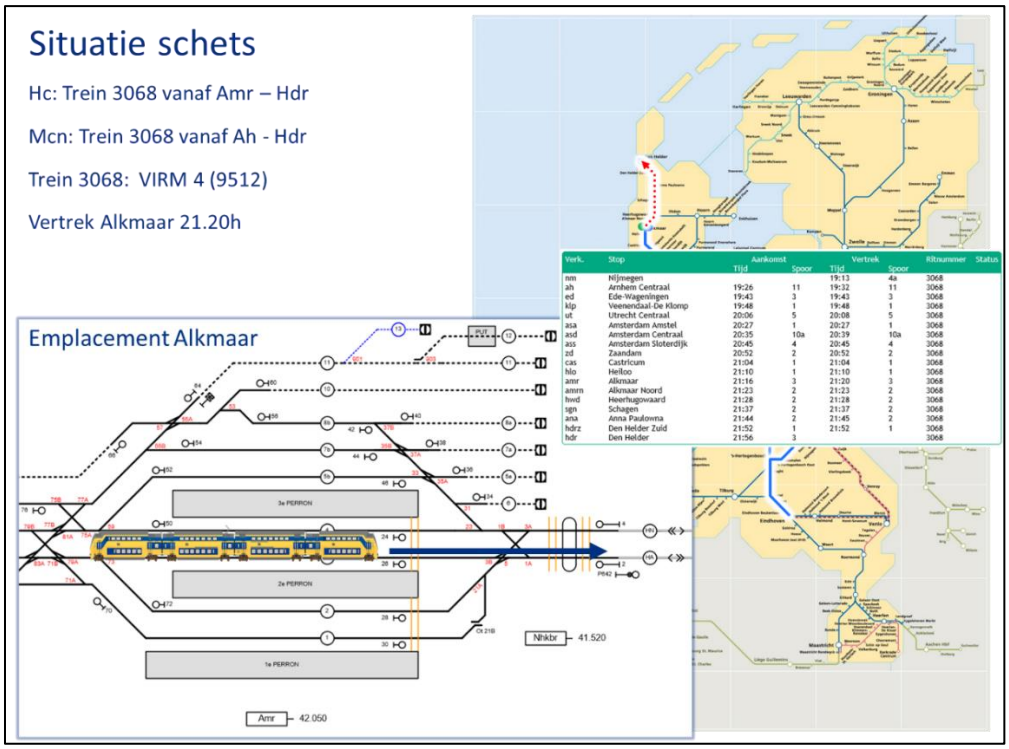
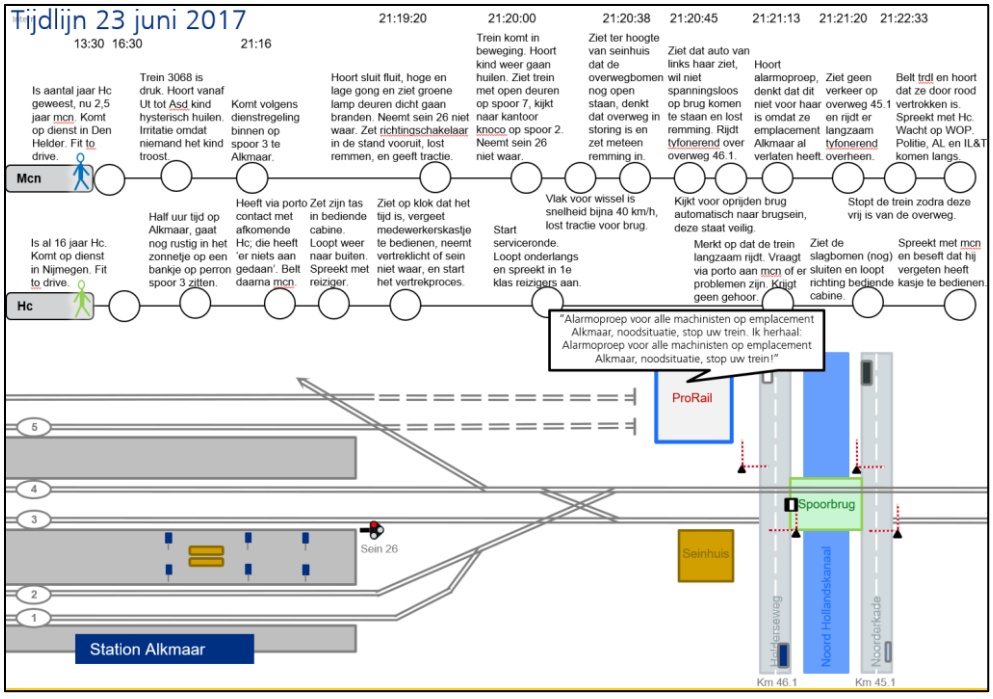


Figure 11

Timeline of the SPAD Alkmaar.



SPAD Waddinxveen. This report describes a signal passed at danger near Waddinxveen, authored by a three member investigation team employed by NS. The report comprises 21 pages in powerpoint format. It starts with describing the goal and approach of the investigation. Thereafter an analysis is presented starting with a situation sketch of the specific occurence. This sketch is followed by a broader inspection of the train services on the line. The service is special in the sense that this is the only railway line of NS where trains drive without conductor. There is only one operator on the train, namely the train driver. Thereby the train driver makes per shift approximately seven round trips on the line. The analysis explores the various specialties on the line. Besides the two specialties already mentioned, the selected group of train drivers on this line start their train driver career on this line. Directly after the initial train driver training (implying limited experience), these train drivers serve approximately one year on the line whereafter the train drivers get the opportunity to drive on the broader NS network. The line is single track except three stations where trains are able to pass each other. On the line, the frequency of trains is relatively high with four trains per hour per direction on workdays. These factors result in a tightly coupled process. A small delayment immidately results in delayments for other trains. The report concludes with recommendations from those involved and measures approved by management.

The first recommendation by the involved train driver is to drive on the specific line instead of driving on the wider NS network (where a conductor is mandatory on every train) during the training. The second recommandation is to introduce a new departure process procedure. The measures taken by management are (1) train drivers have to use a timetable on paper instead of on the smartphone, (2) train drivers have to speak out loud the actions they execute during the departure process and (3) this case has to be discussed within the dedicated train driver team. Altough the investigation report zooms out from the specific SPAD to the

broader system wherein the SPAD occured, the three measures focus solely on the individual sharp end operators.

Three SPADs Castricum. This report describes three signals passed at danger involving three different train drivers of the same signal near Castricum. The report starts with three case studies of the three different SPADs of the same signal in a period of seven months in 2019. From the report is not clear who the author(s) is (or are). The report comprises 29 pages in powerpoint format. After the case studies, an in depth analysis is found of the situation to understand what happened and above all why it happened from the viewpoint of train drivers. The analysis are named one after another endangerment & risk assessment, signal follow-up, expectation to stop along the platform, visibality of the signal, short blocks and signal 209, and the influence of the timetable 2019. It almost seems if the whole rail system is analysed in order to understand the characteristics of this system. The analysis result in a summary and conclusion with the central question ’why did it made sense’?. The report concludes that expectations of the train driver and short distances between signals result in a very small margin to err. According to the report, ”given these various factors, improvement measures require a broader (chain and system) approach than the actions already taken aimed at informing train drivers.” Those involved have four recommendations: (1) explicitly mention the signal that is frequently passed at danger in the routebook and examen the signal, (2) share this case in national instruction or task oriented working meetings, (3) investigate whether a different signal aspect is possible if you may not enter the station of Castricum and (4) investigate whether the timetable as currently applied is adequate related to delayed trains and the risk of red signals before the station of Castricum. Management has decided to act on three measures: (1) the infrastructure manager investigates the possibility to change the signal aspect or location of the signal, (2) sending a safety masage to the train drivers and (3) use the

case to inform train drivers about the importance of using TimTim, an application on the tablet which gives an indication about trains further ahead.

The first solution is systemic in nature. The other two measures aim to inform the sharp end operator, the train driver.

Collision between two locomotives in Amsterdam. This report describes the collission between two locomotives during shunt movements. The report comprises 16 pages in powerpoint format. The investigation report starts with ”what we are going to do” including the focus ”why did it make sense to do what one did?”. Three assumptions of the investigation are mentioned: (1) a positive view of humanity (people come to work to do their job), (2) embracing complexity (complex environment with many processes and actors, cause and effect of occurences are not immediately clear) and (3) behold without judgment and openly (in retrospect, it is easy to see that people could have reacted, acted or decided differently. To avoid this way of judging, it is important to move forward through the timeline and try to see the world from the logic of those involved at that moment). The analysis that follows the introduction starts with a timeline and informs about work as done practices of specific activities. The Efficiency–Thoroughness Trade-Off principle (ETTO) is used to visualise the precair balance between efficiency and thoroughness in the daily work of the train drivers. The report concludes with three decisions made by local management: (1) align the relevant procedures with working methods in practice, (2) discuss and maintain the risks associated with driving a locomotive backwards and (3) discuss the differences between how a specific procedure is handled in practice by the train dispatcher and the train driver and how the procedure is written in the manuals and procedures. Discuss the findings with the infrastructure manager and find a solution for the gap between practice (work as done) and paper (work as described).

The starting point for the three measures seems to be work as done. The measures are not focused on individuals directly but are intended to discuss the circumstances under which train drivers work.

Overview. The four investigations share a common structure in PowerPoint presentation form with animations comprising between 16 and 35 pages (or slides) per report. The reports follow a standardized framework, encompassing the aim(s) of the investigation, the approach, a visualisation of the situation in one-pager and or timeline form, analysis, recommendations from those involved and concluding with measures for improvement decided by responsible management. The reports explicitly state the starting point for the investigations, "Search for causes/factors to learn from and thus increase safety". In time, the follow up sentence changed from "Don't look for the guilty" to "Why did it make sense to do what one did?". The analyses conducted in these reports are based on a timeline, suggesting a linear cause-effect relationship. On closer inspection, every occurrence happens at a given time. Although framed in this way, it does not necessarily imply cause-effect. Events may follow each other up in time but those events do not necessarily lead to other events. The one-pager and timeline are easy in visualisation. When the analysis is extended with for example an AcciMap, the visualisation becomes more difficult and cluttered because there may be many links between events and factors involved in the occurrence. In these analyses theory is combined with the specific case. Here an AcciMap or the ETTO principle may be used to show the interactions and difficulties in practice and work as done.

It can be concluded that the characteristics of the systemic model applies to the investigations caried out after 2017. The characteristics in italics in

Table 6 seem to be applicable to the investigation reports written after 2017 based on the aforementioned summery of the investigation reports.

The reports all describe what happened and why it happened zooming out from the specific occurrence to the broader system wherein the occurrence happened. The one-pager and timeline visualise the specific occurrence. These visualisations are easy to represent graphically. When the analysis is extended with for example an AcciMap, the visualisation becomes more difficult and cluttered because there may be many links between events and factors involved in the occurrence. In these analyses theory is combined with the specific case. Here an AcciMap or the ETTO principle may be used to show the interactions and difficulties in practice and work as done. These visualisations are difficult to represent graphically. The change of level from the from the specific to the broader system may be categorised as ‘characteristic performance on the level of the system as a whole’. The central focus is the question ‘why did it made sense to do what one did’, described in every report. This seems to correspond with ‘performance variability management: functional resonance’ because sharp end operators try to do their job under various and sometimes even unknown circumstances. These circumstances are investigated in the reports. Explicitly mentioned in the reports, the underlying thought seems to be that work as done differs from work as described. This is underlined by written recommendations that mostly suggest to discuss discretionary space, work as done and change procedures in such a way that work as done is described. This leads to the conclusion that these reports have characteristics of the systemic accident model type.

Table 6

Characteristics of incident investigation reports written and published after 2017 marked in italics.

	Model types		
	Sequential	**Epidemiological**	**Systemic**
Characteristics	Error management: root cause	Performance deviation management: manifest and latent causes	*Performance variability management: functional resonance*
	Assumptions or hypotheses about internal mechanisms.	Assumptions or hypotheses about internal mechanisms.	*Understanding the functional characteristics of the system.*
	Encourages thinking in causal series.	Encourages thinking in causal networks.	*Avoid sequence or ordering.*
	Easy to represent graphically.	Easy to represent graphically.	*Difficult to represent graphically.*
	Focus on 'human error' (sharp end).	Performance deviations.	*Characteristic performance on the level of the system as a whole*

Summary

The previous two sections show respectively the characteristics associated with the investigation reports before and after 2017. It can be concluded that the two time periods have different underlying accident models: before 2017 the sequential model and after 2017 the systemic model. The themes in Table 7 show the distinct characteristics of the investigation reports.

Regarding effects of the investigation reports pre and post 2017, it can be concluded that the reports pre 2017 mention recommendations constructed by the authors of the investigation. These recommendations focus without any exception on individuals. The reports post 2017 consists of recommendations constructed by the involved individuals followed by measures approved by responsible management. The recommendations consist of individual sharp end and systemic ideas to prevent similar situations in the future. The measures focus primarily on the system wherein occurrences happen and secondary on the

involved individuals. The focus on individuals in the two time periods differ because pre 2017 discussions are based on work as described instead of work as done after 2017.

Table 7

Overview of the characteristics of investigation reports pre and post 2017.

Theme	**Pre 2017**	**Post 2017**
Format	PDF	PowerPoint presentation
Presentation	Static	Dynamic (animations)
Author(s)	Mainly one, the HSE advisor and peer-reviewed by a different HSE advisor	Mainly several (three), from both NS and the infrastructure manager
Recommendations by	HSE advisor	Those involved
Measures focus on	Primarily individuals	Primarily the system and secondary on those involved individuals
Characteristics	Error management: root cause	Performance variability management: functional resonance
	Assumptions or hypotheses about internal mechanisms.	Understanding the functional characteristics of the system.
	Encourages thinking in causal series.	Avoid sequence or ordering.
	Easy to represent graphically.	Difficult to represent graphically.
	Focus on ‘human error’ (sharp end).	Characteristic performance on the level of the system as a whole.
Based on model type	Sequential	Systemic

The effects of the investigations on the organisation according to actors involved in the investigation process

The interviews serve as a qualitative tool to describe the process and foremost the effects of the investigations as experienced by actors involved in the investigation process. The qualitative insights derived from the interviews are categorized based on the perspectives of three key actors involved in the investigation process: two HSE managers, three HSE advisors, and two middle managers and one senior manager. Presenting the results per actor allows for a nuanced understanding of the diverse perspectives within each role. This analytical approach is adopted under the assumption that the effects of the investigations will exhibit similarities across actors.

HSE managers (informants 1 and 2)

Before 2017 three primary types of investigations were conducted at NS: SIO, SIM and extensive thorough investigations. SIO, a predefined (normative) checklist, was used by Nedtrain to investigate occupational health occurrences while NS Reizigers focussed on railway safety using a SIM. This research focuses on railway safety and the SIM. Therefore Nedtrain and its SIO structure is out of scope. According to informant 2 “SIM is a very rudimentary TRIPOD. So you describe the occurrence, you actually create the timeline with a graphical visualisation and you determine the direct causes. That is the essence of a SIM. So actually a TRIPOD light.” It can therefore be said that a SIM is a brief TRIPOD; a standard method with a particular structure to visualise and construct fundamental risk factors, especially used to investigate signals passed at danger (SPAD). The policy was to investigate every SPAD with the aims to (a) make conducting investigations more natural and (b) to identify the root causes. According to informant 1, “to write a SIM was time consuming, while some of the information is actually not very relevant.” Much text was needed to fill in the format with the required information. This created an environment wherein this kind of

investigation felt like a mandatory thing in order to be compliant with the organisation's own policies. The organisation did not actively ask for these investigations. The occurrences were briefly discussed in the safety control board. This resulted in mostly local individual measures. When several SIMs showed a same pattern, a theme investigation could be conducted. Such an investigation focused more on the system than the separate SIMs did. Concrete measures of theme investigations are for example ORBIT and ATB-Vv. The former is an information system (voice in the train cab) that informs the train driver when the train approaches a signal at danger 'too fast'. It is up to the train driver to react if necessary. The latter is a system that stops a train when a train approaches a signal at danger too fast or passes a signal at danger. Both are systemic measures but only available for specific signals. The major railway accidents, approximately two per year, were investigated thoroughly. These investigations were executed by the HSE managers together with an external party. Both HSE managers agree the SIMs have not generated insights for the organisation or effects on the organisation. It did not necessarily increased safety in one way or another. Informant 1 mentions "but I don't have the feeling that research was seen then as things that make your company better, safer". Informant 2 agrees in slightly different words: "I don't know if it had that much effect in the sense of providing insights. I think that it has led to people finding it normal to talk about direct and underlying causes".

After 2017, the nature of investigations is contingent upon the specific occurrence, allowing for a nuanced approach to determine the extent of inquiry. Informant 1 highlights the advantage, stating "this also allows you to leave behind the things that you no longer get much out of. And, what is perhaps even more important, is that you can do the things that really matter, that you can do them well. And that you can also get a lot out of it." Generally, investigations revolve around a central question: why did it make sense to do what one did? Informant 1 emphasizes the importance of this approach, stating, "we always look further in

the sense of okay, why did that person do that?" The utilization of a timeline is considered crucial by Informant 1, explaining, "simply because you know exactly what happened, which makes it much easier to explain the analysis and zoom in on certain things." The method employed is secondary; it is the involvement of individuals that ensures the functionality of the process. These investigations provide a fresh perspective on the phenomenon under scrutiny, incorporating the entire system. Informant 1 notes, "we look at the whole situation, the whole system. So we take into account the complex environment." However, this occasionally results in extensive investigations that may surpass the organization's manageability. The direct implications of investigation findings for the organization may not always be immediately clear. Informant 2 questions the balance between satisfying the thirst for insight and realizing the hunger for improvement. Informant 1 acknowledges this challenge and hears signals from line managers who express uncertainty about what to do with the investigation outcomes. Despite this, Informant 1 sees value in sparking meaningful conversations within management teams.

The investigations receive positive feedback from involved individuals, often serving as a confirmation of their perspectives. Informant 1 shares "I often get feedback that it was nice to see [the occurrence] again and that people have the feeling that they learned something from it themselves." Even instances where individuals believed they made the right decision but faced adverse outcomes are reflected in the investigation, providing a form of confirmation. By the way the investigations are presented, people feel involved in the story. Informant 1 tells "I mean, the few times I've done it myself, I just see people being quiet every now and then. And sitting there breathless so to speak."

Presenting the findings to responsible management is described as stimulating and confrontational. Informant 2 emphasizes that management gains the ability to weigh possibilities, make decisions, and consciously accept associated risks. Informant 1 cites a

specific systemic effect of an investigation, where the limited visibility under specific circumstances of trains was recognized, leading to a tangible improvement – changing the front colour of trains to enhance visibility.

According to Informant 1 requests from line managers for investigations signal the significant effects of the current investigative approach on the organization, The investigation process post 2017 is deemed essential, encompassing thorough research and analysis, comprehensive feedback and valuable discussions within management teams.

Differences. Divergences in the perspectives of the HSE managers suggest differences in the effects of investigations conducted before and after 2017. Pre-2017, a standardized format, the SIM, akin to a concise TRIPOD model, was employed for investigating minor occurrences. It appears these investigations were initiated by the QHSE department to gain investigative experience. The primary reflex after an occurrence was a focus on what the sharp end operator did wrong. Remedial actions were mostly local and predominantly targeted the individuals directly involved, while major incidents received thorough scrutiny, often led by external entities. Both informants did not experience improved safety levels as a result of the conducted investigations. The SIMs did not generate new insights.

Post-2017, the SIM format ceased being obligatory. Investigations now adopt a more flexible structure, tailored to the specific occurrence, with the central question being 'why did it make sense to do what one did?'. The involvement of curious individuals ensures the functionality of the process. The effects on those involved are a sense of being heard, understood, and recognized. The investigations describe suggestions from those involved, resulting in learning points. Remedial measures shift towards addressing systemic aspects such as the visibility of the trains in a variety of surroundings, at times posing challenges for the organization in their implementation due to their scale. Risk assessments are conducted to gauge the necessary degree of intervention.

HSE advisors (informants 3, 4 & 5)

Before 2017, the investigation process primarily relied on the SIM. The three HSE advisors shared similar views on SIMs, considering them a sort of predefined checklist because of the chapter division and the associated direction the chapter division guides (i.e. the use of specific chapters and methods such as a fault tree). The SIMs provided structure to the research process because every investigation was constructed in the same way. Informant 3 regarded SIMs as "a way of reporting." According to informant 4, SIMs followed the TRIPOD method, serving as a more graphic and refined version of it. Informant 5 perceived SIMs as "a whole description, a lot of paper, a technical explanation."

Informant 3 found the structure of SIMs both helpful and restrictive. Informant 5 managed to tweak the structure to add more context. Informant 4 compared the SIMs with an extended 5why questionnaire, with all informants agreeing that the SIMs resulted in investigation reports with a substantial amount of technical text. Informant 4 noted that the feedback session with those involved, if conducted at all, was small, and SIMs were not shared within the organization. In the words of Informant 3 SIMs were "a paper tiger," generating extensive reports that often went underutilized, reduced to summaries and conclusions. “What is interesting for many managers or supervisors is often the summary or conclusion only.”

Informant 5 questioned whether SIMs increased the level of safety of the organisation, expressing that procedures were followed but not much more. The SIMs were mainly used for small daily accidents, focusing on the last barrier in the system, the sharp-end worker. Actions concentrated on informing, educating, training, and enforcing organizational regulations.

Informant 5, although not using these terms, expressed a similar perspective and posed a more profound question: "Did it bring us a higher level of safety? No, we had carefully carried out the procedures. No more. We had it recorded."

In contrast, Informant 4 viewed the SIMs as a way forward, emphasizing its increasing prominence in the occurrence investigation process. Informant 4 highlighted the evolution of the research process within the operation, noting its permanent place. Comparing it to 2005, where incidents were addressed mainly locally, Informant 4 described a shift toward a nationally standardized working method and uniform analyses.

Informant 5 added that SIMs were primarily utilized for relatively small daily accidents, focusing mainly on the last barrier in the system: the sharp-end worker. This focus was evident in the actions originating from the investigations, which emphasized informing, education, training, and organizational regulations. Informant 5 mentioned elements of punitive measures, such as drivers or conductors receiving acknowledgment, training and or guidance.

Two out of the three HSE advisors noted that after investigations were conducted, there was no further contact with the involved individuals. While interviews with the involved parties took place after the occurrence, the investigation findings were not shared with them. There was a lack of real feedback. The investigation was deemed finished from the perspective of sharp end operators who already underwent a medical and psychological test directly after for example a SPAD. This approach left the involved parties with lingering questions about the occurrence itself and a sense of having been treated unfairly, without any further resolution.

Large accidents were centrally investigated, often involving external partners taking the lead. These kind of investigations fall outside the scope of the current research.

After 2017, informants recognize a shift in the investigation process. SIM investigations were replaced by so-called 'one-pagers,' which could be expanded with additional in-depth analyses. Informant 5 noted that not all incidents (especially SPADs) were automatically investigated. Now there needs to be a thorough question to justify the

investigation. According to Informant 5, “the investigation is more useful than investigations were in the past”. Informant 4 thinks the new 'one-pager' approach is graphically appealing but at the same time feels like a simplification compared to the SIM methodology. Informant 3 appreciated the visual aspect of the new approach, making incidents more tangible. “I like the visualisation because you can form an image [of the occurrence]. If you have never been outside or you have never driven a train, then it is very difficult for that person to have the same experience the driver or employee had, and even more difficult to understand why it did make sense to make that decision at that moment. What spheres of influence did the employee have on all of this, what stimulated the employee? That makes it much more tangible.”

The 'one-pager' approach is less structured than the SIM, providing investigators with the freedom to choose their own structure. Informant 5 mentioned a new role, the 'central investigator,' that changed a vision in incident investigations, focusing more on the system than components. Unlike SIMs, which mainly targeted the last barrier (the human), the new approach focuses more on the entire system. Thereby “the investigations that are done centrally are being received more seriously than all those local studies. Because the big picture was not seen. For example, you had a particular incident in one location but that same particular incident happened also in other location. Those occurrences were all handled one by one. But it lacked an overarching picture lacking questions should we do something about that companywide? It was all handled locally, local investigation finished and moving on to the next occurrence.”

Informant 4 was initially unhappy with the change to the one-pager format, perceiving it as a simplification because there was among others no mentioning of direct and underlying causes. However, Informant 3 observed that the current investigation process is more appreciated, offering more understanding within the organization. Informant 5 highlighted that the investigations give employees peace of mind, confirming that there is more to the

incidents than their individual contributions. Informant 4 added that the organization found the new investigations more appealing, with sessions attended not only by involved persons but also other members within and outside the organization.

Informant 3 highlights a positive shift towards increased collaboration and the sharing of information, particularly with other parties such as the rail infrastructure manager. Bringing together individuals involved in a specific incident helps to understand the specific circumstances wherein work is done. When done properly, these sessions fosters open conversations, preventing a blame game between roles like train dispatchers and train drivers. This collaborative approach recognizes the interconnected nature of roles within the railway system. According to Informant 3, such integration yields more information and, importantly, greater effectiveness in addressing measures because the investigation is supported by the involved parties. This collaborative environment, as described by Informant 3, fosters a better understanding of the rationale behind individuals' choices during incidents. It promotes a comprehensive view that considers how decisions logical for one role, such as a train dispatcher, might negatively affects a train driver at that moment. This shift toward a broader perspective wherein all actors are involved in the investigation process aims to provide more understanding for the circumstances under which actors work.

Informant 4 emphasizes that the model used in investigations is not the critical factor; rather, the essential aspect is the interaction among individuals. This perspective is shared by Informant 5, reinforcing the idea that effective incident investigations require meaningful communication and collaboration.

Informant 4 introduces the concept of the system within which they operate. In this system, every element has specific consequences and influences other parts. Incident investigation, according to Informant 4, plays a crucial role in influencing the organizational culture.

The three informants collectively observe that measures and actions are better followed up in the current approach. According to Informant 3, the effects are evident as measures are registered in a digital system, leading to a more structured follow-up. A target date is coupled to a specific measure. When the measure is not yet implemented on the target date, the owner of the measure is informed in order to monitor and act on the measure. Local safety meetings serve as natural forums for periodic evaluations, ensuring ongoing scrutiny of all reports. This continuous evaluation allows for a better understanding of the status quo and facilitates improved monitoring of actions. Consequently, this enhanced monitoring and triggered responses contribute to a more proactive safety culture.

Differences. Differences emerge from the viewpoints of HSE advisors when comparing investigations before and after 2017. The SIMs, introduced prior to 2017 represented an improvement over previous investigation processes. The SIMs provided a structured approach, solidifying the investigation process within the organization. It was mandatory to investigate specific occurrences, especially SPADs. The SIMs instilled the habit of visualizing the causes behind incidents. Despite these advancements, the informants agree that the processes before 2017 did not contribute significantly to an elevated safety level. Any contact with involved parties remained limited, especially after the investigation finished. The written measures in the investigations primarily targeted sharp end operators. The SIM methodology and its focus on components indicated adherence to the sequential accident model.

Post-2017, the used investigation report format shifted to one-pagers. Perspectives on one-pagers among informants varied. Notably, the focus transitioned from the individual to the system. The HSE advisors did not give examples of specific measures with a focus on the system, although mentioned the shift due to the changed central question: “why did it make sense to do what one did?” Stakeholders are now more actively engaged in the investigation

process, with discussions involving those directly involved in incidents. The current reporting systems are deemed more effective for monitoring measures, resulting in improved follow-up on actions taken. The responsible person for a specific measure is in the lead to monitor the progress and effect of the measure. The responsible person receives messages from the monitoring system when it takes more time than expected to implement the measure resulting in the possibility to observe and control more closely. The emphasis on the system and the consideration of work as done indicate alignment with the systemic model.

Line managers (informant 6, 7 and 8)

Informants 6 and 7 hold middle management positions, while Informant 8 is a senior manager. Here the three managers are described together in the same paragraph.

Informant 7 has no experiences related to the investigation process **before 2017**, and Informant 8 mentions, "in the past, a guilty party was sought and punished, but that's just hearsay." Therefore, the insights into the period before 2017 are primarily based on the knowledge provided by Informant 6.

Initially, Informant 6 also lacks extensive experience regarding investigations. According to Informant 6, the organization's approach to incidents immediately after their occurrence involved a more locally and less structured process. Safety [HSE] advisors played a significant role in investigating incidents, often acting independently. The involvement of the manager of the involved employee increased during this time, and the investigations were somewhat individualistic, favouring those who were more assertive. Informant 6 describes it "disrespectfully an one-man show. If you could shout the most and the loudest, you could also go the furthest in your investigation, so to speak."

These investigations primarily focused on the individual at the sharp end and what was needed to prevent recurrence for that individual. Thereby sometimes lacking a thorough consideration of the facts. Informant 6 notes a tendency to attribute incidents to factors like

excessive speed without in-depth analysis. The process was relatively quick, with a priority on getting those involved back to work swiftly. The emotional well-being of individuals involved was not a central concern. Train drivers, for example, often felt a sense of guilt, and there was insufficient attention to alleviating this feeling. Professional support workers arriving at the scene did not prioritize understanding the emotional state first; instead, the emphasis was on identifying what went wrong, resolving it quickly, and thereby questioning the train driver's actions.

Informant 6 highlights that in the past, guilt was not effectively addressed, and drivers were swiftly allowed to return to work, sometimes on the same day. This could lead to stress-related issues. The current approach aims to prevent such outcomes by giving more attention to the emotional and psychological aspects of those involved in incidents.

All three informants provide perspectives on investigations conducted **after 2017**. Informant 6 offers a valuable insight into the current situation by emphasizing, "When I look now, there is more attention to the process — what went wrong, what was your role as a train driver in this case? Could you have prevented it, or did you find yourself in a situation where you were actually confronted with something you could not imagine?" This shift towards understanding the context and the individual's experience is echoed by Informant 8, who gives the following example: "So you're not sticking to your handbook. Then the question arises: what makes someone do that? Then you learn, for example, he was just better, blah blah, then it is good to talk about how important it is to conform to the handbook because it can lead to something you really don't want." Especially when the organisation does not implement any measures on the particular findings based on a risk assessment.

Describing the investigations, Informant 6 characterizes them as "the PowerPoint that you then receive as an elaboration of this happening on that day; then you eventually see the train passing by, with the signal, you visualize more of what is happening." Specific

investigations are shared with sharp-end workers in task-oriented working meetings, providing a vivid understanding of the case, which train drivers particularly appreciate. The visualisations make that the investigations come to life. Informant 7 appreciates this addition to task-oriented working meetings, noting that in the past, only technical information was shared.

Informant 6 notes an improvement in the speed of reaching conclusions, which used to take much longer. There's a shift towards more analytical thinking, focusing on learning from experience and analysing the process. Additionally, incidents involve more than one individual, resulting in increased complexity, with multiple circumstances leading to the incident. Informant 6 still experiences that measures focus on tighten processes, rather than at how the process should remain feasible in practice. “You can arrange everything on paper in fantastic lines, green ticks everywhere, great, but then you send people to do the work outside, with the same tick list, and then they think but this is not possible at all.” So the sharp end operators have to work in a split. They sometimes have to bend the rules a little to keep the process feasible. This leads to a difficult situation. Questions are asked, such as did you follow the rules? If the operator answers no, then the operator did it wrong. ”And then you harm people again. While in this case people actually think: I have to ensure that the train is ready in the morning to transport those passengers.”

Informant 8 emphasizes the importance of human factors, highlighting an increased learning mode and a shift in perspective—exploring not only why an incident occurred but also considering if it could have happened to someone else, and why it might make sense for someone to act in a certain way.

Differences. With the limited data of the investigation process before 2017 due to a lack of experiences of the informants, a limited summary can be given. The investigation process was a locally and unstructured process. Those involved felt often guilty after

occurrences with impact. This feeling of guilt was not effectively addressed. These investigations were characterized by judgements and sometimes even lacked a thorough consideration of the facts. The focus after occurrences was on getting those involved back to work swiftly, sometimes on the same day, which could lead to stress-related issues. The investigations were not shared among other employees.

The managers experience various differences in the investigation process post-2017. The investigations take human factors in account. Although the occurrence is mentioned, there is nowadays more understanding of the context and the individual's experience. The investigations are sometimes widely shared, for example in task-oriented working meetings. The visualisations in the investigations are especially welcomed because this feature brings the investigation a life. Although systemic questions are asked, such as “why it might make sense for someone to act in a certain way”, measures still focus mainly on a tighter description in procedures (such as handbooks for sharp end operators) and thereby focus on tighten processes, rather than at how the process should remain feasible in practice.

Summary (all informants)

The previous paragraphs show the perspectives of three actors in the investigation process. It can be concluded that the three actors have different perspectives, logically originating from their background and position in the investigation process.

Throughout the lines, the themes discussed in Table 8 may be distinguished.

Table 8

Comparison of themes between pre and post 2017 investigations according to experiences of informants.

Theme	Pre 2017	Post 2017
Investigation method	SIM (Tripod).	One-pagers, sometimes extended with various analysis (methods).
Degree of freedom to investigate	Low degree of freedom, everything (at least all SPADs) was investigated.	High degree of freedom.
Involvement of those involved	Limited.	Extensive.
Central question	What failed? What did the sharp end operator wrong?	Why did it make sense to do what one did?
Effects on those involved	Felt like blame.	Those involved feel a sense of being heard, understood, and recognized.
Effects on the organisation	Investigation was mandatory, not leading to improved levels of safety.	Investigations offer added value.
Measures focus primary on	Components, human focus such as more training.	Systemic aspects such as the visibility of trains with an undertow of human focus.
Sharing of investigations	Investigations were not actively shared, only with local management.	Investigations are internally shared with all members in the organisation.
Monitoring of measures following investigations	Passive.	Active.

Pre 2017, investigation reports were written in a specific format, SIM. All SPADs were investigated without any exception. Also other railway safety accidents were investigated, especially those accidents with major adverse outcomes. It seems the investigation process of that time did limited justice to those involved. Those involved were only involved in the beginning of the investigation to hear their story with a focus on what failed. For those involved, the investigations resulted in a feeling of blame and guild. As mentioned, the investigation was mandatory but did not lead to improved levels of safety. Measures aimed at components, mostly to solve the component ’human error’. Those measures were fore example more training. The investigations were not actively shared

widely in the organisation. Only local management was informed about the investigation report. When measures were described at all, there was no following up of measures. It was by chance and interest of management when measures were followed-up and monitored.

Post 2017, investigation reports were written in mostly the one-pager format followed by in-depth analysis of the occurence. There is a high degree of freedom to investigate occurences or not. The central question of all investigations, no matter the occurence, is ’why did it make sense to do what one did?’. The involvement of curious individuals ensures the functionality of the process. It seems the investigation process now does more justice to those involved. Those involved are involved in the investigation process from begin til end. For those involved, the investigations result in a feeling of being heard, understood, and recognized. The investigation offer added value for the organisation. Measures aim at systemic aspects such as the visibility of trains with still an undertow of human focus. The investigations are internally shared with all members in the organisation. The investigation reports conclude with measures approved by responsible management. Those measures are followed up with a digital system. This system informs responsible managers actively about the status of measures and signals when it takes more time than estimated to implement measures.

Discussion

The findings of this research support the initial thought that there is a difference in the structure and effects of the investigations before and after 2017. This may be partly a result of the use of a particular incident investigation model, partly due to the changed investigation philosophy and process and partly due to the involvement of curious individuals who execute the investigations.

Although mentioned that the reductionist and systems approach complement each other, this research shows that the systems approach has particular advantages over a reductionist approach. A systems perspective may increase the credibility of investigations, the degree in which those involved feel heard and may lead to measures that justify those involved. A systems approach seems therefore the way forward to improve safety in an organisation by using the systemic model type as distinguished by Hollnagel (2004). Unfortunately, due to the nature of accident investigations this is mainly reactive. When circumstances and capacity allows, it may be valuable to investigate near misses as well. This may be an opportunity to shift from reactive to a more proactive approach.

Hollnagel distinguishes between three types of incident investigation models on which methods are based. I suggest to add three particular aspects to his characterizations that seem to fit in the model types based on the findings of this research: work as imagined and work as done, the local rationality principle and Holnagel's own Efficiency Thoroughness Trade Off (ETTO) principle.

Work as imagined refers to peoples assumptions about how work should be done. This particular characteristic belongs to both the sequential and epidemiological model because both models emphasize deviations. Work-as-done on the other hand refers to how something is actually done. This fits the systemic model because of its emphasis for characteristic performance. The difference between how work is 'imagined' and how work is actually done

may or may not be problematic. From this it follows that the local rationality principle can be seen as part of the latter model type only.

Local rationality is a concept that is thought of for decades, although not defined in this way. Simon, Neisser, Klein, Kahneman, Rasmussen. These authors wrote about the concept without using a common shared word. The central thought is the same: “what people do makes sense given their goals, their knowledge and their focus of attention at time” (Woods et al., 2010, p. 16). Dekker brought this together and called the wide collection of findings ‘local rationality principle’ (Dekker, 2016). Counter to the local rationality principle in the systemic model stands the search for deviations of specified rules without considering any context in the sequential and epidemiological model.

ETTO is a way to understand how work is done (Hollnagel, 2009). One may be thorough or efficient. Both at the same time is not possible. ETTO is therefore a way to understand decisions and is part of the systemic model.

The research in this thesis is qualitative in nature. A qualitative research has specific limitations. The research quality is heavily dependent on the skills of the researcher and more easily influenced by the researcher's personal biases and idiosyncrasies. The researcher's presence during data gathering, which is often unavoidable in qualitative research, can affect the subjects' responses. Qualitative research is not as well understood and accepted as quantitative research within the scientific community (Anderson, C. 2010). Thereby, the research in part 1 is based on a selection of investigation reports and in part 2 based on nine informants.

The selected investigation reports are not publicly available, as these reports often contain sensitive and confidential information. These reports typically include detailed accounts of events, personal data of individuals involved, proprietary company practices, and findings related to potential legal liabilities. Access to these reports is restricted to internal

personnel, regulatory authorities, and relevant stakeholders involved in addressing safety and preventive measures.

It may be difficult (if not possible at all) for the respondents of the qualitative part of the research to share their ideas and perspective regarding the incident investigation reports from before 2017 because the systemic based incident investigation reports are more recent and therefore probably more known. After the interviews were conducted and the analysis of the interviews was complete, it became clear that all informants had a hard time making explicit what concrete effects the two different investigation periods gave. All informants experienced differences of the investigations from individual measures pre 2017 to systemic measures post 2017 and for those involved from feeling guilty pre 2017 to being heard and recognized post 2017. It seems to be a feeling of the informants without concrete examples despite asking various questions in a variety of ways. It is probably safe to say that the term ‘effects’ is very broad and therefore may be interpreted in a variety of ways. Where part 1 focuses on concrete measures, part 2 focuses more on abstract measures.

This research is conducted by one of the four (incident) investigators at NS. In my role, I am involved in the current investigation process and may not be objective regarding the investigation processes in the past. The incident investigation reports used for this study are created by (former) colleagues of the QHSE department. I did not participate in the investigations used in this thesis.

Conclusions

This thesis explored the effects of the implementation of a systems approach in incident investigation at NS by comparison of the incident investigation approach before and after 2017. The research comprises two parts. In part 1 a comparative analysis is conducted on investigation reports. In part 2 insights into the context and experiences of the effects of the investigations of nine individuals engaged in the investigation process are gathered through interviews. The findings show that there are differences in both the nature of the reports and the individual experiences of the investigation process pre and post 2017. It can be stated that the conclusion of part 1 are also found and even enriched by part 2. The conclusions of both parts are hereafter separately explored.

In part 1 a comparative analysis is conducted on investigation reports — scrutinizing five reports pre-2017 and four reports post-2017. The analytical framework is derived from Hollnagel's categorization regarding incident investigation models, which delineates three models: sequential, epidemiological, and systemic.

Making use of these models, the findings show that there are distinctions in the nature of the reports pre and post 2017. The investigation reports written and published pre-2017 exhibit the following characteristics of the sequential model:

- Error management: the search for one or more root cause(s);
- Assumptions or hypotheses about internal mechanisms;
- Encourages thinking in causal series;
- Easy to represent graphically;
- Focus on ‘human error’ (sharp end).

Regarding the effects of the investigations, the last aspect is most relevant. Three of the five reports have written recommendations constructed by the authors (HSE advisors) of

the reports. These recommendations focus solely on the sharp end operators (train driver, train dispatcher) and suggests to try harder.

The investigation reports written and published post-2017 exhibit the following characteristics of the systemic model:

- Performance variability management: functional resonance;
- Understanding the functional characteristics of the system;
- Avoid sequence or ordering;
- Difficult to represent graphically;
- Characteristic performance on the level of the system as a whole.

Regarding the effects of the investigations, the reports contain both recommendations constructed by those involved and measures approved by responsible measure. These two aspects of the report are quite different than only the recommendations constructed by the HSE advisor pre-2017. The recommendations of those involved focus primarely on the system. The recommendations consist of individual sharp end and systemic ideas to prevent similar situations in the future. The measures focus primarily on the system wherein occurrences happen and secondary on those involved individuals. The focus on individuals slightly differ because post 2017 discussions are based on work as done instead of work as prescribe before 2017. This may be a result of the specific underlying accident model. Pre 2017 the focus is on what happened and root causes. Post 2017, the focus is on the question ’why did it make sense to do what one did’ resulting in a different perspective moving away from root causes to contributing factors.

In Part 2 insights into the context and experiences of the effects of the investigations of nine individuals engaged in the investigation process were gathered through interviews.

The informants all experienced that the period before 2017 resulted in different kind of investigations and other effects on the organisation than the investigations carried out in the

period after 2017. Before 2017, the investigations were mandatory but did not seem to have a (positive) effect on the level of safety or let alone improved levels of safety. The investigations were carried out in a specific format called SIM. It seems the investigation process of that time did not do justice to those involved. The investigation process resulted in a feeling of blame and guilt by those involved. Probably because those involved were only involved in the first step of the investigation process where information is gathered. Thereafter those involved were not informed about the tatus or let alone the results of the investigation. This did not do justice to those involved in any occurrence. The reports were not shared internally. It seemed to be a 'party' of the HSE advisor and local management. The measures of investigations focused mainly on fixing broken components with a focus on human operators (train drivers, conductors and train dispatchers). Train drivers had to undergo an additional medical and psychological test after an accident. From a train driver's perspective, the investigation ended here. This approach left the involved parties with lingering questions about the occurrence itself and a sense of having been treated unfairly, without any further resolution. When there was an investigation and this investigation was discussed with those involved, the primary focus was on the individual at the sharp end and what was needed to prevent recurrence for that individual. Mostly addressing that the individual needs to stick to the rules. Thereby sometimes lacking a thorough consideration of the facts. The focus was on getting those involved back to work swiftly. The emotional well-being of individuals involved was not a central concern. Try more, harder, faster and in consideration with the rules seemed to be representative for that time period. According to the informants, these investigations did not result in safety improvements.

After 2017, informants experienced that the investigations are adding value to the organisation. Those involved feel a sense of being heard, understood, and recognized. Probably because there is a genuine interest in what those involved experienced and because

those involved are involved during the complete investigation process from the beginning till the end. The results are shared with those involved and wider in the organisation. Measures of investigations focus more on the system such as the visibility of trains although with still an undertow of human focus regarding for example training. These measures still focus mainly on a tighter description in procedures (such as handbooks for sharp end operators) and thereby focus on tighten processes, rather than at how the process should remain feasible in practice.

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Appendix 1. Interview questions

Please tell me about an investigation you worked with back in 2017.

- Can you elaborate on the investigation process before 2017?
- What characterizes the investigations before 2017?
- What are the effects of these investigations for you?
- Do you have concrete examples?
- What makes that these effects are the result of the investigation(s)?

Please tell me about an investigation you worked with after 2017.

- Can you elaborate on the investigation process after 2017?
- What characterizes the investigations after 2017?
- What are the effects of these investigations for you?
- Do you have concrete examples?
- What makes that these effects are the result of the investigation(s)?

Concluding questions

- What is your opinion on both types of investigation?
- What kind of similarities do you see between the two types of investigations?
- What kind of differences do you see between the two types of investigations?
- What type of investigation has your preference, and why?

Appendix 2. Informed consent for interviews

Project title	Human Factors and Systems Safety thesis: development of accident investigations at NS.	
Purpose of the study	I am inviting you to participate in this research project about incident investigations at NS. The purpose of this research project is to find out to what degree the incident investigations have changed over time.	
Procedures	You will participate in an interview lasting approximately sixty minutes. You will be asked questions about the incident investigation process and reports.	
Confidentiality	Your privacy will be protected to the maximum extent allowable by law. No personally identifiable information will be reported in any research product. Moreover, the researcher only will have access to your responses. Within these restrictions, results of this study will be made available to you upon request. As indicated above, this research project involves making audio recordings of interviews with you. Transcribed segments from the audio recordings may be used in published forms. In the case of publication, pseudonyms will be used. The audio recordings, forms, and other documents created or collected as part of this study will be stored in a secure location in the researchers' offices or on the researchers password-protected computers.	
Statement of consent	Your signature indicates that you are at least 18 years of age; you have read this consent form or have had it read to you; your questions have been answered to your satisfaction and you voluntarily agree that you will participate in this research study. If you had questions, you indicate when signing that you were able to ask these questions and that these questions have been answered clearly. You indicate that you voluntarily agree with your participation in this investigation. You will receive a copy of this signed consent form. I agree to participate in a research project led by Sverre Kompeer. The purpose of this document is to specify the terms of my participation in the project through being interviewed. 1. I have been given sufficient information about this research project. The purpose of my participation as an interviewee in this project has been explained to me and is clear. 2. My participation as an interviewee in this project is voluntary. There is no explicit or implicit coercion whatsoever to participate. 3. Participation involves being interviewed by a researcher from the NS. The interview will last approximately 60 minutes. I allow the researcher(s) to take written notes during the interview. I also may allow the recording (by audio/video tape) of the interview. It is clear to me that in case I do not want the interview to be taped I am at any point of time fully entitled to withdraw from participation. 4. I have the right not to answer any of the questions. If I feel uncomfortable in any way during the interview session, I have the right to withdraw from the interview. 5. I have been given the explicit guarantees that the researcher will not identify me by name or function in any reports using information obtained from this interview, and that my confidentiality as a participant in this study will remain secure. In all cases subsequent uses of records and data will be subject to standard data use policies at the EU (Data Protection Policy). 6. I have read and understood the points and statements of this form. I have had all my questions answered to my satisfaction, and I voluntarily agree to participate in this study. 7. I have been given a copy of this consent form co-signed by the interviewer.	
Signature and date	NAME PARTICIPANT	NAME PRINCIPAL INVESTIGATOR Sverre Kompeer
	SIGNATURE	SIGNATURE
	DATE	DATE