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"Old" and "new" safety thinking: Perspectives of aviation safety investigators

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ABSTRACT

The development of various safety paradigms over time has led to public discussions that tend to highlight a dichotomy between the so-called "old" and "new" safety thinking. Although these two approaches might be based on opposite views that can feed debates and discussions, the degree to which they are binary in practice and respective explanations have not been adequately researched. Following a review of literature, we developed a framework that refers to nine aspects that denote new safety thinking practices pertinent to safety investigations and includes the three basic safety model categories: sequential, epidemiological and systemic. We administered a survey to examine the extent of agreement of safety investigators with statements reflecting the old and new safety thinking practices as well as the familiarity with and degree of application of the latter and the three safety model types above, and we collected respective comments. The 41 safety investigators who participated in the study were quite familiar and agreeable with the new safety thinking aspects. Overall, they had applied these aspects with a moderate frequency during investigations, without though abolishing practices related to the old paradigm due to time, resource, data and training limitations and cultural or managerial influences. Epidemiological models were the most frequently applied due to their optimum efficiency-thoroughness balance. In general, our findings suggested that the sample was not unanimously against or in favour of each of the old and new investigation practices included in the survey, this indicating that the duality between these two paradigms might not be valid in real-world settings. Although the results of this study cannot be generalised, this paper communicates insightful messages as well as recommendations and could function as an impetus for further research on this topic.

1. Introduction

Perspectives of scientists and professionals towards safety have shifted over time, and the safety paradigms nowadays are different than they were decades ago. Moving from the overemphasis on technical reliability to the consideration of human performance effects, and, relatively recently, the examination of organisational and regulatory influences and overall system complexity (Martinetti et al., 2018), signifies that safety thinking focuses more on systems than components. Albeit safety approaches evolve continuously in the light of the accumulated scientific knowledge and practical experience, observations of safety conference topics and discussion threads in professional media and fora indicate that there has been a debate about the novelty and practicality of "new" safety thinking and its potential and need to either replace or complement "old" safety approaches. It is noted that the terms "new" and "old" used in this paper do not aim to attribute any positive or negative notion to the various approaches to safety and human error. We adopted the specific terms in alignment with the language used in the literature reviewed in the following paragraphs and sections.

The differentiation between the old and new safety paradigms lies principally on whether humans are seen as safety achievers or potential safety problems. The older perspective interprets operational safety events as results of human errors, tends to focus on individuals and local teams, evaluates system performance based on a small number of unwanted events, and does not systematically consider the safe practices evolving at the work floor under the reality of conflicting goals or varying conditions. This set of views has been described by Hollnagel (2013) as 'Safety I' and by Dekker (2007) as "old" or "traditional" view and it is frequently linked to safety investigation practices. The new

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Table 1
Distinction between old and new approach to human error (Dekker, 2014).

Old approach	New approach
States what people failed to do	Tries to understand why people did what they did
States what people should have done to prevent the outcome	Asks why it made sense for people to do what they did
Asks who is responsible for the outcome	Asks what is responsible for the outcome
Human error is considered the cause of trouble	Human error is considered a symptom of deeper causes
Human error is considered unreliable behaviour	Human error is considered systematically connected to aspects of people's tools, tasks and operating environment
Human error is seen as an acceptable conclusion of an investigation	Human error is seen as the starting point for further investigation

safety thinking is aligned with the modern organisational paradigm that treats employees as assets and not only as probable hazards (Pettersen and Aase, 2008) and suggests the establishment of internal and external synergies through open communication which fosters loyalty and commitment and minimises the use of rigid language (Zeffane et al., 2011; Trombetta and Rogers, 1988). Organisational knowledge is shaped through the daily turnover of experiences from both failures and successes (Madsen and Desai, 2010). Employees' mobility and flexibility and the efforts for enhancing the clarity and simplicity of procedures indicate that the workforce is at the centre of the business (Juul, 2016; Estival and Molesworth, 2009).

Overall, although some resistance to change is expected for managers and safety professionals when exposed to anything that contradicts established practices and norms (Serban and Iorga, 2016), the dichotomy which is implied in the publications advocating the new safety thinking and during informal and non-systematically observed debates (e.g., social media, blogs, fora, safety-related events) has not been examined. Furthermore, considering that most of the cases used to demonstrate the necessity for the new safety thinking regards accident and incident investigations reports, to-date there has been little research to examine to what extent this paradigm is known, accepted and practised in safety investigations specifically. A study published in 2001 based on the analysis of the information collected by an industry-wide, large-scale phone survey as well as face-to-face interviews at companies in the United Kingdom (Henderson et al., 2001) targeted to a broad spectrum of investigation-related topics and not particularly on investigation practices that could reflect underlying thinking. Also, Frederick et al. (2018) explored the extent to which the higher-level principles of the "new view" on safety are valued by safety & health representatives (i.e. Work as planned vs Work as performed, Learning from work, Learning Teams) without a particular focus on safety investigations.

Examples of possible pitfalls when promoting new safety approaches without proper criticism and examination of their validity and applicability were recently articulated by Busch (2018), whereas another work examined the degree to which new safety thinking traces have been visible in safety investigation reports (Karanikas and Chionis, 2019). The former publication regards positions of the author, and the latter entails an assessment of documented information. Therefore, to the best of knowledge of the authors of this paper, to date, there has been no empirical study about the perspectives of investigators. In an attempt to shed more light on this topic, this paper presents the principal aspects reflecting the new safety paradigm pertinent to safety investigation practices and communicates the results of a survey amongst safety investigators regarding embracement of old and new safety thinking aspects, the knowledge and application of the latter and related barriers and enablers.

2. Literature review

2.1. New safety thinking

The focal and starting point of the new approach to safety is the consideration of human error as a result of underlying problems instead of being the final or primary cause of a safety event; organisation-wide behaviours or systemic flaws might predispose individuals to commit an error (Reason, 1990a,b). Safety investigations that embody this approach attempt to determine conditions that rendered the identified errors possible (Dekker, 2014). The new approach to human error is also based on the local rationality principle, according to which individuals are subject to elementary and systematic errors in their reasoning, judgement, and decision-making (Vlaev, 2018). Due to the finite capacity of human rationality, a predisposed attribution of blame to persons committing an error can be seen as a mere accusation (Woods and Cook, 1999). According to the new view, safety investigators should stand in the shoes of the people who committed errors and explore reasons behind the respective decisions and deeds (Dekker, 2014). According to the same author, the new safety thinking is different from the old one in more than one characteristic (Table 1). Contemplating the particular features as the basis of the new safety paradigm, additional review of the literature led to the detection of nine aspects which denote new safety thinking and are discussed in the subsections below. Considering the vast volume of literature about the sociotechnical concepts presented hereafter, we clarify that the sources cited and discussed in this paper are indicative and do not mean to cover each topic exhaustively. Moreover, we reviewed sources stemming from domains other than "safety", as a means to indicate the transdisciplinary nature of the approaches presented.

2.1.1. Human error seen as symptom

The new approach to human error entails that underlying reasons such as poor working conditions, company pressure or conflicting goals might lead to the commission of errors stemming from the inevitable compromises and trade-offs the workforce adopts in their honest endeavour to achieve all system objectives at the same time. From this perspective, human error should not be seen as a result of human performance failure and should not be the conclusion of investigations; human error is an effect of a process failure and must trigger further investigation and justification as well as consideration of contextual information (Dekker, 2014; Woods et al., 1994).

2.1.2. Hindsight bias avoidance

Hindsight bias is the belief that if we look retrospectively at the sequence of events that led to an adverse outcome, we can fully explain its causality and label it as predictable (Roese and Vohs, 2012; Bernstein and Atance, 2007). Hence, the effects of hindsight bias can lead investigators to turn a complex event into a linear, relatively simple one by overlooking the way the people involved in the event understood the situation at that specific time (Henriksen and Kaplan, 2003). Safety investigators may tag as inappropriate any decisions and actions which individuals perceived as rational under the circumstances of a given moment (Ragain, 2011; Woods and Cook, 1999).

Under the new safety paradigm, hindsight bias should be minimised since it oversimplifies the causality based on backwards reasoning and may drive false conjunctions of the investigated event with similar but unrelated eventualities (Dekker, 2014; Henriksen and Kaplan, 2003; Woods and Cook, 1999). As Roese and Vohs (2012) suggested, hindsight bias can be reduced by using a multiple-points-view approach and using simulation, the latter being a resourceful way to counter investigators' biases and infuse more realism during investigations (Woodcock et al., 2005).

2.1.3. Shared responsibility

During a safety investigation, fundamental attribution of error (Berry, 2015) might empower focus of higher organisational levels on the individuals closest to the safety event and underestimation of the contribution of wider factors (Hoffman and Stetzer, 1998). Individuals may also develop a defensive attribution bias due to the fear of being blamed, deny any personal responsibility and call solely for external attributions (Burger, 1981). According to Dekker (2014), the inner circle of individuals represents a sharp-end, while the external layers of management engulfing the sharp-end comprise the blunt-end; instead of assigning responsibility only to the sharp-end, the blunt-end should also be attended, and responsibility should be shared. An attitude of shared responsibility is more likely to foster cooperative practices towards accident prevention (Friedman, 2018).

2.1.4. Non-proximal approach

A proximal approach represents the imbalance when investigating the blunt-end and sharp-end, where an increased emphasis on the latter is observed (Dekker, 2014). Although a shared responsibility might be recognised, the emphasis is frequently given on the end-user level due to limitations in time or other types of resources (Hollnagel, 2014a,b; Dekker, 2002). New safety thinking advocates a proportional investigation depth across all organisational functions (Katsakiori et al., 2009), a practice that has been visible quite recently (Reason, 2008). The background of investigators and the methods employed to gather and analyse factual data may also influence the equilibrium when addressing and researching individual and broader factors (Kletz, 2006; Woodcock et al., 2005).

2.1.5. Decomposition of folk models

The use of folk models in investigations represents the labelling of constructs (e.g., “complacency”, “poor culture”, “loss of awareness”) as causes of events (Dekker and Hollnagel, 2003). Under the particular practice, investigators do not decompose constructs and, sometimes, transfer to the event under study entire constructs from irrelevant contexts (Patterson and Wears, 2009). Folk models resist quality assessments because they are more descriptive than explanatory, they are immune to falsification, and they are easily overgeneralised (Dekker and Hollnagel, 2004). Moreover, folk models do not necessarily represent commonly accepted terms or meanings of causality, and they can reflect collaborative or social aggregated tags (Alavi and Denford, 2011), while they drive the reduction of problems into the sole identification of responsible individuals (Dekker and Nyce, 2011). Consequently, the new safety thinking approach strongly proposes the maximum possible decomposition of folk models and the rejection of their use as principal causes of events (Massaiu, 2006).

2.1.6. Non-counterfactual approach

A counterfactual view leads to the conclusion that individuals might have missed opportunities to avoid a safety event because they did not perform according to “facts” (e.g., checklists and standard operating procedures), without, though, explaining the underlying reasons or questioning the suitability of standards to the unfolding situation (Dekker, 2002). The same author suggests that this aspect is also connected with the hindsight bias through the story-building of how an event unravelled. During an investigation, a counterfactual norm (e.g., unused or misused procedures) will bind the investigator's objectivity (Hollnagel, 2012). Furthermore, investigators may fixate onto organisational factors as relevant to the main probable causes and may miss causal links among those causes or connections related to other factors and conditions (Holloway and Johnson, 2006, 2004). Therefore, through a non-counterfactual approach an investigator is more likely to search for additional causal and missing links and consider that the absence of various conditions which could have prevented an event cannot constitute causes (Reason, 2008) and unfavourable events occur in the absence of corrective factors or the presence of system malfunctions (Strauch, 2015).

2.1.7. Non-judgemental approach

A non-judgemental attitude means that an investigator focuses on the deeds of involved individuals and not what these should have done (Dekker, 2002). Although in the literature a judgmental approach seems close to the counterfactual thinking, the authors of this paper interpreted the former as a tendency to charge persons for not meeting expectations without properly investigating the rationality of these, whereas the latter refers to performance against standards. Expectations stand as a determinant agent in the way we perceive the world and they even possess the power to shape perceptions at a neural level (de Lange et al., 2018). Hence, attributing blame can be an expression of defending common values and expectations (Nadler and McDonnell, 2012). Additionally, fixating on expectations leads to labelling individuals as predestined to err yet again (Willis, 2018). Considering that our judgement might be fallible (Munro, 2005), a judgmental approach should be avoided, and the validity of expectations should also be scrutinised.

2.1.8. Safety II – Investigation of successes

The traditional approach to safety entails that lessons for the future can be acquired through a retrospective binary logic between errors that happened and led to unwanted outcomes and errors that were avoided (Hollnagel, 2013; Nelson, 2005). According to Madsen and Denai (2010), learning from failure, while avoiding stigmatisation of individuals, constitutes a great challenge for an organisation's knowledge and growth. Typically, occasions of daily safety-bid successful practice do not receive proper attention in safety management activities while they might be necessary or even crucial for processes such as risk identification, safety promotion or safety assurance (Hollnagel, 2013; Madsen and Desai, 2010). In the Safety II paradigm, the focus is not only on mishaps but also on understanding why systems work properly during daily operations and under varying conditions (Hollnagel, 2013). When a system knows how and why it functions safely and effectively, it can maximise the production of the desired outcomes in the majority of situations (Patterson and Deutsch, 2015).

2.1.9. Feedback loops

Feedback loops are circular control and information mechanisms used to manage complex interactions and coupling and achieve or maintain system resilience (Swanstrom, 2008; Leveson, 2004; Leveson et al., 2003). Feedback loops provide the users of a system with information on the state of the system they operate, and they can be classified as positive (reinforcing) and negative (balancing) (Kontogiannis, 2012; Leveson et al., 2003). In reality, however, feedback loops are not always embedded into systems across all levels, processes and functions or cannot inform system operators effectively. This problem becomes even bigger when the interactive complexity and coupling surpasses the end-user's cognitive capacity (Leveson, 2004). The “fallible” end-user is required to maintain constant awareness and knowledge of the system while being inside or outside the loop and avoid conditions that could trigger unfavourable events or unsafe system states (Reason, 2008, 1990a,b). Conversely to the old approach that addresses mainly reinforcing feedback loops, new safety thinking focuses on balancing feedback loops and attempts to locate the reasons for the degradation of safety controls rather than emphasising on human performance flaws (Leveson et al., 2003). Additionally, the effectiveness of feedback loops is of crucial importance to ensure mindful interventions of users into the system under control (Swanstrom, 2008).

Table 2
Old and new safety thinking and practices.

Old safety thinking & practices (OSTPs)	New safety thinking & practices (NSTPs)	Short title of NSTP	Code
Human error can be the principal cause of accidents.	Human error is always the result of deeper troubles within a system.	Human error seen as symptom	HES
Looking to the event backwards and simply detecting failures, errors, inaccurate assessments and wrong decisions.	Considering why choices made sense to users at that time and what options they had before each decision and action.	Hindsight bias minimisation	HBM
Focus on the end-user(s) without consistently examining influences of other organisational/system levels.	End-user must not be the only focal point, and organisational/systemic factors must also be investigated.	Shared responsibility	SHR
Shared responsibility might be recognised, but an emphasis is given mainly on the end-user level.	Proportional investigation depth of all organisational/system functions.	Non-proximal approach	NPA
Constructs and ill-defined concepts (e.g., culture, complacency) can be named as accident causes.	Constructs and folk models must be decomposed and adequately explained.	Decomposition of folk models	DFM
Standards and procedures constitute the unquestionable basis for comparing human performance.	Examining the assumptions on which standards are based and explaining reasons for deviating from standards, including the investigation of the applicability of standards to the context of events.	Non-counterfactual approach	NCA
Actions and decisions are judged against established norms and expectations (e.g., experience and training).	Examining the validity of established norms and expectations and explaining the reasons for not meeting expectations.	Non-judgmental approach	NJA
Emphasis on explaining failures where humans are seen as a potential hazard.	Humans are seen as a resource necessary for system flexibility and resilience. Explanation of successes in addition to failures.	Safety-II	SII
End-users must maintain their awareness and are responsible for being always and fully knowledgeable of their system's state.	Feedback mechanisms are examined to identify whether/how system awareness and control are maintained. The effectiveness of feedback must be investigated.	Feedback loops examination	FLE

2.2. Safety investigation models

Safety investigations might implicitly or explicitly be driven by principles included in various human error management methods applied to safety-critical areas of high-risk industries such as road transport, rail transport, aviation and healthcare (Salmon et al., 2010). Depending on the approach to human error and the safety/accident model followed, safety investigations can comprise the gates through which organisations may overemphasise human performance flaws and (in) directly assign blame to individuals and teams or investigate further and comprehend deeper and wider factors within and across systems (Leveson, 2004; Leveson et al., 2003). According to Lundberg et al. (2009) and the literature review performed by Kaspers et al. (2016), the investigation models can be grouped into three categories as follows:

1. Sequential (Cause-Effect) Models: The focus lies on fixed linear relationships of end-users to equipment and does not usually move further than the line management level. One of the earliest linear models, Heinrich's Domino Model (Heinrich, 1931; Heinrich et al., 1980), proposed to investigate the immediate surroundings, except the higher management, with two stems. One considered the end-user and the surroundings, while a second stem assessed the reasons the line manager did not prevent the accident. At a later stage, the domino representation included direct links to management and cascade effects of accidents (Bird and Germain, 1985) as well as event linkages in a timeline (Viner, 1991; Benner, 1975).
2. Epidemiological (Multiple Causes-Effects) Models: They approach safety events similarly to disease epidemics, considering that an event is a combination of at least a host, the agent itself, and their shared environment (Gordon, 1949). The focus of this approach lies on a fixed multi-linear relationship of end-users with probable causal factors transcending through organisational levels. This category of models includes active errors and latent conditions along with their implications as an accumulative chain of events that after an incubation period, produce multiplying effects (Turner, 1978). Reason (1987) acknowledged the existence of 'resident pathogens' in a system, later described as active and latent flaws (Reason, 1997). The Swiss Cheese Model (Reason, 1990a,b) is one of the most popular models in this category.
3. Systemic (Complex) Models: The first two model categories mentioned above might lag realism because non-linearity is the fundamental trait of sociotechnical systems (Benner, 1983). The triggers and causal factors of an event are entangled with human needs and experience, and, therefore, are often circular (Rasmussen et al., 1990). In systemic models, the focus lies on two system properties, namely coupling and interaction. Coupling refers to the level of control as direct (tight) or indirect (loose) (Perrow, 1984). Interaction refers to the proximity amongst systemic actors and processes and their relevant communication (control or feedback) loops (Tenner, 1996). Examples of models in this category are the AcciMap (Rasmussen, 1997) and STAMP (Leveson, 2004).

Literature suggests that sequential models discourage in-depth analyses of events because they limit investigators to a linear causality reasoning (Leveson, 2004) although, it has been for long recognised that in complex sociotechnical systems, multiple organisational, technical and social factors are combined (Trist and Bamfort, 1951). Also, sequential and epidemiological models adhere to the current safety management assumption that systems are tractable and well-understood (Hollnagel, 2014a,b). However, from a sociotechnical approach, the aviation, and not only, context is a complex non-linear system and "models and methods which require that systems are linear with resultant outcomes cannot and should not be used for non-linear systems where outcomes are emergent rather than resultant" (Hollnagel, 2014a,b, p. 23). Nonetheless, irrespective of the simple and complex sequential reasoning adopted, investigators might fixate excessively on the factors closely related to the event under examination, and withhold themselves from searching overreaching causes (Rollenhagen et al., 2017).

3. Methodology

3.1. Development of the analysis framework

Taking into account the literature reviewed in Section 2 above, the authors with the assistance of undergraduate students developed an analysis framework that includes the individual aspects that denote new safety thinking and practice (NSTP) relevant to safety investigations. The framework was used to design a questionnaire and administer a survey to aviation safety investigators as a means to collect data about the familiarity with and applicability of its aspects along with respective comments. The analysis framework consists of ten items: the nine safety thinking aspects and practices presented in Table 2 and the type of safety models used (Table 3). The aspects shown in Table 2 include statements reflecting the old and new safety paradigms as a means to help the reader understand their differences. The third and

Table 3
Safety model types.

Type	Brief description	Example model(s)	Code
Sequential	Direct cause-effect relationships: clearly defined timeline of failures, errors and violations that lead to an event.	Domino	SEQ
Epidemiological	Direct and indirect cause-effect relationships: clearly defined timeline of active failures along with long-lasting effects of latent problems that contribute to active failures.	Swiss cheese	EPD
Systemic	Dynamic, emerging and complex system behaviours: examining interactions, interdependencies and relationships between parts to understand a system as a whole, including effects of the behaviour of individual elements.	STAMP AcciMap	SYS

fourth columns of Table 2 mention correspondingly the short titles and codes we use in the rest of the paper for each of the NSTP aspects. The tenth item of the framework presented in Table 3 regards the safety model types as those have been grouped in the literature reviewed above. Table 3 also includes a short explanation for each model type along with the code used in the results section.

3.2. Survey design and administration

Based on the suggestions of Korzilius (2000), Fink (2003) and Harvard University (2007), we designed an online questionnaire with a mixture of closed and open-ended questions to capture (1) to what degree investigators agree with the OSTP/NSTP aspects, (2) whether they are familiar with the NSTP aspects and model types, and (3) the degree to which they apply NSTPs/model types along with corresponding reasons. A questionnaire was preferred over interviews because, to the best of knowledge of the authors, this was a first exploratory study of its kind, we aimed to reach professionals from various geographical regions, avoid unfavourable effects of the interviewers (e.g., biases in favour or against OSTP/NSTP could affect the formulation of questions) and allow the participants to join the survey at their convenience regarding time and location. To ensure that the questionnaire used plain language, the wording would not threaten its validity, and the layout of its online version was user-friendly and functional, we organised eleven peer-review sessions with four researchers, and we ran a pilot study with the participation of five safety investigators.

After an introductory section explaining the goal of the survey, its voluntary character and the anonymity of participation, the questionnaire prompted participants to answer the following demographic information: the year the respondent started being actively involved in safety investigations; the country of nationality; the country in which the majority of the investigation-related tasks have been performed; the highest level of education received; the number of investigations the participants had been involved. The authors intended to use the demographic variables above to examine associations with familiarity as well as the agreement and application levels per OSTP/NSTP aspect and model type. However, the relatively low number of responses did not allow to include more hypotheses and tests in our study. Nonetheless, demographic data are reported below to describe the synthesis of the sample.

The main part of the questionnaire consisted of three sections. In the first section, the respondents were asked to state the degree of their agreement with nine statements reflecting the old safety thinking and practices (OSTP) by using a 5-point Likert scale (Appendix A). The second section of the main questionnaire part included nine statements (Appendix B) representing the NSTPs along with the five questions shown in Table 4 in order of appearance for each of the statements. It is noted that there were no conditional exclusions regarding the particular questions; for example, someone could not have heard of the statement presented about each specific approach, but still might had applied it through practice. It was not possible for the participants to navigate back to the first section of the main questionnaire part after moving to the second one; this ensured that the respondents would not alter their scoring of OSTPs after getting exposed to the NSTP statements.

In the last section, the respondents were presented the statements

Table 4
Questions per NSTP statement.

No	Questions	Possible answers
3.1	Have you ever heard of this approach?	• YES • NO
3.2	Please indicate the extent to which you agree with this approach	• Strongly agree • Agree • Neither agree nor disagree • Disagree • Strongly disagree
3.3	Please explain your answer on the previous question	(Free text)
3.4	To approximately what percentage of safety investigations have you applied this approach?	• 0%–20% • 21%–40% • 41%–60% • 61%–80% • 81%–100%
3.5	Please explain your answer on the previous question	(Free text)

and questions reported in Table 5 regarding the three types of safety models. It is stressed that the statements mention specific models to help the participants understand the corresponding type. This strategy was adopted following the comments collected during the peer-reviews and the pilot study of the survey instrument.

The researchers preferred a snowball sampling strategy as a means to approach a broad spectrum of respondents from different regions and backgrounds. Email messages explaining the goal of the survey and including the questionnaire link were sent to agencies, companies and individuals of our contacts database as well as to the email addresses of national aviation investigation authorities mentioned in the official directory of the International Civil Aviation Organisation (ICAO) webpage.[1] Both the email body and the introductory section of the questionnaire mentioned that the survey should be filled only by aviation safety investigators. About 100 email messages were sent out in March 2018, and follow-up emails were sent two weeks after the initial invitation. The survey remained open for one month, and 41 valid answers were recorded (Table 6).

3.3. Data processing and analysis

The responses to the statements/questions of Appendix A, 3.2 and 3.4 per aspect (Table 3) and 4.2 per model type (Table 4) were converted into ordinal figures as follows:

- Strongly Disagree: −2, Disagree: −1, Neither Agree Nor Disagree: 0, Agree: +1 and Strongly Agree: +2
- 0%–20%: +1, 21%–40%: +2, 41%–60%: +3, 61%–80%: +4, 81%–100%: +5

We performed Mann-Whitney tests to examine possible associations of the familiarity with each of the NSTP aspects and safety model type with the degree of their application. The hypothesis was that *HYP1: The*

[1] https://www.icao.int/safety/AIA/Pages/default.aspx.

Table 5
Statements and questions per safety model type.

Model types	Statements used
Sequential	The Domino model explains the event as a result of several problems, each of the problems causing the next in a straight timeline.
Epidemiological	The Swiss Cheese model takes into account contributing factors that lead to problems without a direct timeline (e.g., a causal factor could be in place long before the event).
Systemic	Models like STAMP, FRAM and ACCIMAP look beyond individual causal factors, technical failures and human errors and also explore the role of dependencies and connections amongst people and technical components within a system.
Questions (common across all statements)	**Possible answers**
4.1 Have you ever heard of this (these) or a similar model?	● YES ● NO
4.2 To approximately what percentage of safety investigations have you applied such a model?	● 0%–20% ● 21%–40% ● 41%–60% ● 61%–80% ● 81%–100%
4.3 Please explain your answer on the previous question	(Free text)

Table 6
Demographics of the sample.

Demographic information	Values & distribution (N, %)		
Year started being involved in investigations	≤2001 (13, 31.7%)	2002–2010 (14, 34.15%)	≥2011 (14, 34.15%)
Region of nationality	European (30, 73.2%)	Non-European (11, 26.8%)	
Region majority of investigations were executed	European (31, 75.6%)	Non-European (10, 24.4%)	
Highest education level	Bachelor or lower (16, 39.0%)	Master or higher (25, 61.0%)	
Number of investigations being involved	≤10 (15, 36.6%)	11–50 (17, 41.46%)	≥51 (9, 21.95%)

participants who were familiar with each of the NSTP/model type had applied them at a larger degree than participants who had declared unfamiliar. Also, Spearman's correlations were conducted to explore associations of the extent of agreement with the degree of application per NSTP aspect under the hypothesis *HYP2: The higher the agreement with an NSTP aspect, the higher the frequency of its application.* Furthermore, we applied the same test to explore correlations between the degree of agreement with the statements representing OSTP (Appendix A) and the degrees of agreement and application of NSTP aspects reflected by the statements of Appendix B. The hypotheses were that *HYP3: The higher(lower) the agreement with each OSTP, the lower(higher) the agreement with its respective NSTP*, and *HYP4: The higher(lower) the agreement with each OSTP, the lower(higher) the extent of application of its respective NSTP*. The overall Type I error rate (α) across all tests was set to 0.05. To avoid the build-up of errors, we adjusted the level of significance for the four tests based on the Bonferroni correction: $P_{crit} = \alpha/k$, where k is the number of comparisons (i.e. four hypotheses tested) (Armstrong, 2014), resulting in $P_{crit} = 0.05/4 = 0.0125$ per test. We performed all analyses of quantitative data in the SPSS Software version 22 (IBM, 2013).

In terms of the data from open-ended questions, one student performed an initial thematic analysis on the results which were first reviewed by the first author of this paper. Following the revision of the grouping codes, we calculated the inter-rater agreement amongst five participants (two external researchers and three students). The raters were given the coding scheme and two comments randomly selected from the responses to each of the open-ended questions, and they were asked to choose the code(s) applicable to each comment. The results showed an inter-rater agreement of 90.5%, which was deemed as sufficient (e.g., Bell et al., 2006; Gwet, 2008). It is noted that in several cases the survey participants did not explain their choice regarding their agreement or application of a specific NSTP aspect/model type, but they instead simply confirmed their answers or expressed general remarks. We excluded these cases from the analysis. The small number of valid comments per topic did not allow for processing their themes statistically against the sample's demographics.

4. Results

4.1. Quantitative analysis

4.1.1. Old safety thinking and practices (OSTP)

The findings from the first part of the questionnaire (i.e. degree of agreement with statements reflecting OSTPs) are shown in Appendix A. The medians showed a neutrality of the respondents for the *Hindsight approach*, *Judgmental approach* and *Safety I*. The OSTP aspects of *Human error seen as cause* and *Folk models as causes* were the only ones with a moderately positive median of +1.0 (i.e. Agree). The rating of the rest of the OSTPs aspects resulted in a moderately negative median of −1.0 (i.e. Disagree). Nonetheless, some participants expressed a strong agreement or strong disagreement across all the OSTPs.

4.1.2. New safety thinking and practices

The frequencies the participants were familiar with each of the NSTP statements are shown in Fig. 1. The percentages varied from 80.0% for the *Non-proximal approach* (NPA) and *Shared responsibility* (SHR) to 97.0% for the *Non-judgmental approach* (NJA).

The distribution of answers across the sample and the median values regarding the agreement with each of the NSTPs and the extent of their application are reported in Appendix B. The medians of all aspects were at the level of agreement. Regarding the degree of application, median values suggested that the *Hindsight bias minimisation* and *Safety II* had been applied to about half of the investigations, and the participants had applied all other aspects in the majority of their investigations. It is noted that strong agreement and extreme values for application

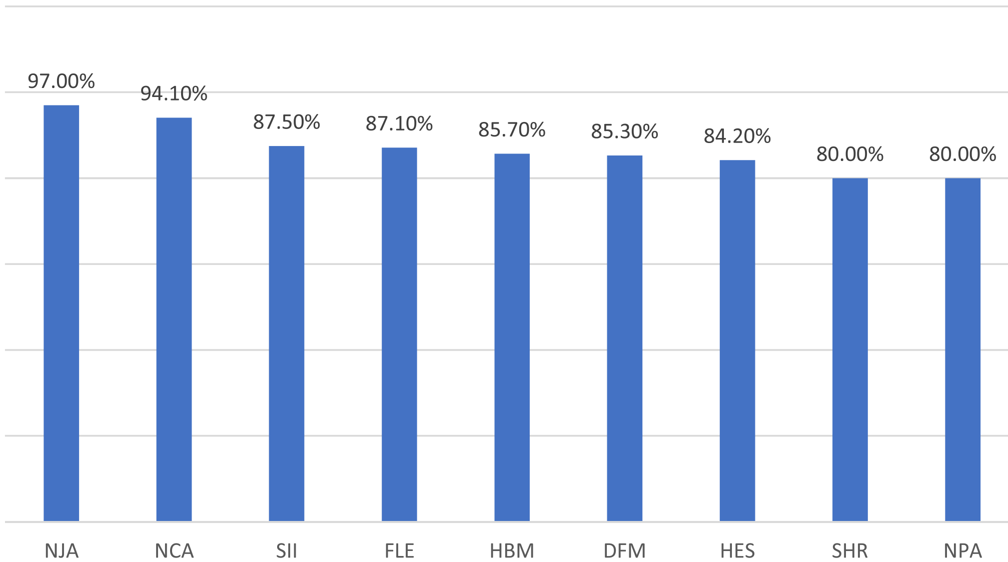

Fig. 1. Frequency of familiarity with NSTP aspects.

(0%–20% and 80%–100%) were recorded for all statements. Apart from the NSTPs *Human error seen as symptom* and *Hindsight bias minimisation*, with which about 3% of the sample strongly disagreed, none of the respondents disagreed strongly with the rest of the aspects.

4.1.3. Safety model types

The frequency analysis showed that a Sequential model had been heard by 87.1% of the respondents, an Epidemiological model by all the survey participants and a Systemic model by 54.8% of the sample. The extent of application of each model concerned, a Systemic model was the least frequently applied (median = 1.0: 0% − 20%) followed by a Sequential model (median = 2.0: 21% − 40%) and an Epidemiological model (median = 4.0: 81% − 100%). There were answers given at the extreme scale points for all model types.

4.1.4. NSTP intra-aspect associations

Regarding the association between the familiarity (i.e. Yes/No) with each aspect and the degree of its application (*HYP 1*), the Mann-Whitney tests resulted in significant variances only for the *Human error seen as symptom* ($N = 38$, $U = 30.5$, $z = -2.723$, $p = 0.006$), and *Shared responsibility* ($N = 35$, $U = 26.5$, $z = -3.062$, $p = 0.002$). In both cases, the positive answers about familiarity were linked to increased frequency of application with HES having a medium effect size ($r = 0.44$) and SHR a large effect ($r = 0.517$). Regarding the relationship between the extent of agreement with each safety aspect and the degree of its application (*HYP 2*), Spearman's correlation tests showed positive associations only for *Shared responsibility* ($N = 35$, $p = 0.000$, $r = 0.658$), *Folk models decomposition* ($N = 34$, $p = 0.000$, $r = 0.606$) and *Feedback loops examination* ($N = 31$, $p = 0.000$, $r = 0.654$).

4.1.5. OSTP and NSTP cross-aspect associations

The results from the correlations amongst (1) the degrees of agreement between OSTPs and their corresponding NSTPs (*HYP 3*), and (2) the extent of agreement with each OSTP and the extent of application of its respective NSTP (*HYP 4*), showed the following statistically significant findings:

- OSTP agreement – NSTP agreement: The higher(lower) the agreement with a *Human error seen as cause* (OSTP), the lower(higher) the agreement with its respective NSTP ($N = 38$, $p = 0.004$, $r = -0.460$).
- OSTP agreement – NSTP application: The higher(lower) the agreement with the OSTP *Folk models as causes*, the lower(higher) the degree of application of its corresponding NSTP ($N = 34$, $p = 0.004$, $r = -0.485$).

4.2. Qualitative analysis

The results of the thematic analysis are presented in Appendix C. Table C1 in the specific Appendix shows in parallel columns the comments regarding agreement and application to allow comparisons and support the reader in obtaining an overall understanding. Table C2 reports the comments related to the extent of application per safety model type.

5. Discussion

5.1. Safety thinking and practice aspects

Overall, the frequencies across the answers (Appendix A) suggest that the sample did not express uniformly (strong) agreements or disagreements across the OSTPs considered. Out of the nine OSTPs included in this study, two yielded a median of 1.0 (agree), three scored a median of 0.0 (neither agree nor disagree) and the rest four were rated with a median of −1.0 (disagree). The divergence observed amongst the OSTPs might indicate that the set of the aspects presented do not comprise a single and solid set of tenets, and, overall, investigators might appreciate their validity separately. Notably, the sample declared a relatively high familiarity with all NSTPs (Fig. 1). Also, the respondents scored almost unanimously the NSTP aspects with a median of 1.0 (agree) except the *Feedback loops examination* that scored a median of 2.0 (strongly agree). Hence, in the case of NSTP, the overall scores showed more homogeneity.

More specifically, when considering the median values, *Human error seen as cause* and *Folk models as causes* appeared as the OSTPs most appreciated by the participants. When observing the frequencies of the responses, it seems that *Hindsight approach* was also stated quite often as a sufficient approach to explaining an event (i.e. almost 49% agreed or strongly agreed with the particular aspect). On the other hand, the respective NSTPs (i.e. *Human error seen as symptom*, *Hindsight bias minimisation*, and *Decomposition of folk models*) yielded medians of 1.0 regarding the agreement (i.e. agree) and above-average percentages of application in practice. This suggests that the OSTP and NSTP aspects mentioned above might not be perceived as strictly opposite.

The comments of the sample appeared complementary and offered insightful explanations. Although it was recognised that human error could be detected early in investigations and trigger a more in-depth search into the system, organisational policies and the lack of data might not always allow the full application of the respective NSTP along with the expectation to still address personal responsibility in addition to any other systemic factors. This means that the identification of causes might be based on a combination of retrospective and prospective investigation paths. This does not mean the causes revealed initially in hindsight, such as individual or supervisory performance problems, are cancelled by default in the light of causes detected later in either hindsight or foresight. Cause-effect relationships during an investigation might be singular or multiple, linear or not, local and wider, and seemingly simple or complex to establish; every new finding can complement, dispute or alter older ones and lead to a web of causes. The challenge to find data was also mentioned when applying a foresight approach which, at the same time, was appreciated as positive and complementary to the hindsight approach. Nevertheless, the participants did not clarify whether the difficulty to access data was driven by personal factors (e.g., not trained or know how to distil data) or organisational parameters (e.g., lack or inconsistent records). However, many respondents declared limited familiarity with the corresponding NSTP; this could stand as an explanation of the relatively high frequency of agreement with the respective OSTP.

Notably, based on the spread, appreciation and application of epidemiological models across the industry, as discussed in the following section of this paper, the moderate agreement with the *Human error seen as final cause* aspect of OSTP could be characterised somewhat surprising, although its counter-aspect NSTP yielded a fair agreement too. Interestingly, the cross-aspect correlations showed that the degree of agreement with this human error-related aspect of the old and new paradigms was the only one significantly correlated and, additionally, it appeared with a negative association. Thus, although the overall scores showed moderate agreements with both "opposite" aspects, at the individual participant level, the lower the score on the particular aspect of OSTP, the higher the score on its counter-aspect of NSTP and vice versa. This suggests that the perspectives towards the function of human error as a possible final cause or a proxy to investigate further are stronger compared to the rest of the OSTP and NSTP aspects explored in this study.

The use of folk models concerned, the sample's comments focused on the declaration of constructs as causes (30% of the replies) and the need to decompose constructs further (70% of the answers). Once more, the availability of data and low familiarity with the respective NSTP were stated by a few respondents as possible reasons for naming folk models as valid causes of events. The opposite perspectives mentioned above could be explained by considering two factors. On the one hand, standards require the reporting of clear and unambiguous (contributory) causes as a means to drive targeted, specific and effective remedies. This accords with the literature reviewed in Section 2.1, which claims that the attribution of constructs as causes without further exploration of their underlying mechanisms renders investigations incomplete. Nonetheless, we should not neglect that accident factors adopted by organisations as suggested by various classification models (e.g., Human Factors and Accident Classification Systems – HFACS; Wiegmann and Shappell, 2003) could be mistakenly used as causes, although the original intentions of their authors were different. For example, in HFACS, the 2nd level of accident causation (i.e. Preconditions for Unsafe Acts) includes the possible influence of weather conditions, which several investigation reports state as a cause.

Furthermore, the language used in literature and practice often attributes personalised and direct cause-effect characteristics to immaterial constructs (i.e. phrases similar to "good safety culture *supports* organisations", "poor just culture *hinders* safety reporting", "complacency *leads* to decreased situational awareness"). For instance, the work of Lawrenson and Braithwaite (2018) provides various accident cases where safety culture was named as a cause; the authors discussed how the particular construct has become a legal concept when determining culpability. Such practices and viewpoints that Le Coze (2019) classified as functionalistic in his commentary on safety culture, which can be arguably extended to other constructs, might have shaped perceptions that *Folk models* can stand as causes of events and not just influencing factors. Certainly, this can serve the need for the brevity of investigation reports (i.e. possibly lengthy and difficult to read and understand reports due to the elaboration of all constructs through decomposition), which must be also understood by their readers, especially people without extensive technical knowledge. However, such practice might have distorted the intended use of constructs as building blocks of theories and their intended purpose as moderating or mediating variables.

Besides, the agreement with the OSTP *Folk model as causes* was the only one negatively associated with the application of its respective NSTP with moderate strength. The particular finding signals a more direct translation of perspectives into practice regarding the use of constructs. As discussed above, this, on the side of decomposing folk models, could be attributed to the necessity to derive actionable recommendations to improve systems, and, on the side of accepting constructs as causes, could be explained by the lack of detailed information or the effects of convenience, time limitations and investigation efficiency.

The *Judgmental approach* and *Safety I* aspects of OSTP were neutrally rated by the participants (i.e. neither agree nor disagree) whereas their corresponding NSTP scored a median of 1.0 (i.e. agree) and were regularly applied by the sample. Thus, the distances of the scores between OSTP and NSTP regarding the particular points are smaller than the ones discussed in the previous paragraphs. Both the *Non-judgmental approach* and *Safety-II* gathered several positive comments about their value, accompanied by a few statements noticing the necessity to appreciate the lessons from failures still when additionally looking at successes. Interestingly, some participants stated that investigation standards do not visibly promote investigations of achievements. Indeed, when observing the directions given by safety investigation policies and recommended practices, such as the ones published by ICAO (2014) and FAA (2018), these do not visibly drive research into successful aspects across the whole envelope of operations. Recently, Eurocontrol published white papers on systems thinking, including the concept of *Safety-II* (Eurocontrol, 2013, 2014); this is a testimony to a burgeoning interest of the aviation industry in exploring alternative avenues to safety management and investigation. However, typically, novel approaches require time to be tested on the field, become recommended practices and be included in standards. Nonetheless, the majority of the investigators appreciated that the *Safety-II* approach would lend analysts an improved understanding of the systems under study.

The minimum distances between the perspectives in agreement with NSTPs and disagreement with OSTPs were observed for the aspects related to local/shared responsibility, (non)proximal and (non)counterfactual approaches, and the (non)examination of feedback to end-users. All these points yielded medians of -1.0 on the side of OSTPs and 1.0 – 2.0 medians as well as above-average application frequencies for the respective NSTPs. The participants accepted that a focus on teams or individuals could foster a blaming culture, and a wider and deeper examination of events would reveal additional contributing and causal factors, the cases of inapplicable procedures and poor feedback included. On the other hand, some respondents argued that the boundaries between the sharp and blunt ends are not always clear, the labelling of causes as direct or indirect is not relevant and that management or prevailing cultures might dictate investigation limits. However, this could also be attributed to the anchoring to standards that drive a detailed description of background information, performance assessments and other information pertinent to employees whose deeds were closer to an event regarding time and space. A navigation through investigation directives (e.g., ICAO, 2015) shows that these require the collection of factual data regarding directly involved actors (e.g., physical and mental conditions and records, training reports, history of vocational performance) and do not visibly ask investigators to gather similar data for less-proximal actors (e.g., senior managers) whose actions and decisions had contributed to the safety event under study.

In general, the cross-aspect correlations did not reveal consistent associations either amongst the familiarity/agreement and application scores for each of the NSTPs or amongst the agreement with each OSTP and the agreement/application of its corresponding NSTP. Thus, in conjunction with the comments of the sample, none of our four hypotheses was confirmed, which indicates that the nine OSTP and NSTP aspects in practice might not always be perceived as opposite and binary as presented in the literature. The particular finding might also reflect the effects of practice; investigations engage more than one person with diverse backgrounds and perspectives, irrespective of the personal views towards any approach. Therefore, common practice and approaches might mask any individual (dis)agreement with a specific NSTP/OSTP.

5.2. Safety models

The safety model types concerned (i.e. root-cause, epidemiological and systemic), although uniformity of efforts is encouraged, the application of "…useful or effective investigation techniques…" (ICAO, 2010, p. 36) has been left to the choice of the investigators, organisations and investigation authorities. Although this freedom is welcome as a means to foster flexibility, according to the database of Everdij and Blom (2016), there are hundreds of methods and techniques available as a means to search and explain a safety event. Epidemiological models were introduced in the '90 s and are regularly mentioned in standards and investigation training material; hence, somewhat expectedly, they have displaced the use of sequential models. On the other hand, it seems systemic models have not yet extensively entered the field of practice.

The quantitative analysis showed considerably higher familiarity and application of epidemiological models, which, according to the participants, were convenient to apply but recognisably limited in analytical power. Root-cause type models were deemed very simplistic, and systemic ones were seen as richer but not engulfed for reasons related to organisational maturity and inadequate training. Furthermore, the preference in the epidemiological models was attributed to their inclusion in investigation standards. Indeed, to the best of the authors' knowledge, rather recently the AcciMap model, which is viewed as a systemic one, has been communicated occasionally by governmental agencies (e.g., ATSB, 2008; Centre for Cognitive Work and Safety Analysis, 2019). Also, training in the STAMP model and its derivative accident investigation technique CAST became first available during a workshop in 2012 at the MIT in Boston, US (Partnership for Systems Approaches to Safety and Security (PSASS), 2018a) followed by one in Europe a year later (Partnership for Systems Approaches to Safety and Security (PSASS), 2018b). Only lately agencies, such as the one of the newly-launched Air Accident Investigation Authority of Hong-Kong started exploring the application of CAST (Straker, 2019) and communicating its potential (Singapore Ministry of Transport, 2019).

Therefore, it seems that although systemic models have been published since decades and literature consistently communicates that system complexities might not be sufficiently addressed through (multi) linear thinking, the respective efforts have not yet yielded the expected results. On the positive side, more than half of the sample declared familiar, presumably at least with the fundamental underpinnings of such models, and none of the respondents formulated a negative comment against the potential value of systemic models. Under the inevitable constraints surrounding every safety investigation, it seems that the "middle" path of using epidemiological-type models, based either on individual preference and convenience or best practice, comprises a trade-off between investigation quality and depth and invested resources. Another probable explanation for this could the time lag between the development of safety/accident models and their acceptability by the investigation community and, consequently, their embodiment in training. As a few of the participants commented, some NSTPs, as well as the systemic safety models, were deemed too innovative, and the sample on average did not have the chance for respective training.

Nevertheless, the adoption and application of any safety/accident model must be evaluated within its context, as new safety thinking acknowledges when examining the choices and decisions of persons involved in accidents and incidents. The comments provided by the participants of our empirical study accord with the recent report of Wienen et al. (2017) whose systematic literature review showed that (a) simple linear models are easy to execute, understand and communicate, (b) epidemiological models necessitate more analysis time but can reveal more systemic causes even by following linear thinking, and (c) systemic models are more powerful to acknowledge and investigate system complexities and tight couplings but far more expensive and time-consuming to apply. The research-practice gap identified by Underwood and Waterson (2013) when examining the limited acceptability of systemic accident models could be closed through improved communication of respective research and genuine efforts to meet the needs of the intended users. Moreover, as stated by Karanikas and Roelen (2018) in their attempt to introduce the concept of a Standard Safety Model that unifies STAMP, AcciMap, FRAM and the Swiss Cheese Model, the academic debate is invaluable for the growth and maturity of science, but rather irrelevant to the interests of the industry.

5.3. Overall picture and reflection

When examining the list of new safety thinking aspects included in this study, it can be claimed that they propose an absolving direction towards human error and point to a deeper and broader examination of underlying and overlying systemic factors. However, this position does not seem very "new" in literature; for example, Heinrich et al. (1980) had pointed out that employees exposed to same risks were more frequently involved in accidents when management was not ensuring safe working conditions. Similarly, Swain and Guttmann (1983) reported that the probability of human error depends heavily on the conditions under which humans have to make (safety-critical) decisions. Furthermore, the acknowledgement of the need and value to investigate beyond local human errors has been further spread since the '90s, as, for example, suggested by the popular Swiss Cheese Model (Reason, 1990a,b) and the Human Factors Analysis and Classification System (HFACS) (Wiegmann and Shappell, 2003). This indicates that a different perspective on the investigation has been conceptualised since decades, which has expectedly shaped the views of investigators; the avoidance of pointing and blaming individuals and teams is one the most frequently communicated principles in literature and standards. Typically, investigators are trained and supposed to search for factors beyond the end-user's level, and this endeavour might lead them to also focus on the wider system and not only on the persons who were closest to the adverse events in temporal and location terms.

Referring indicatively to other new safety thinking approaches included in this study, even publications related to safety investigation techniques and dated decades ago (e.g., Ferry, 1988; Wood and Sweginnis, 1995) have encouraged a systems approach concerning the complexity of systems and component interactions, although, admittedly, such references were somewhat brief and not accompanied by suggestions about particular models or techniques. Moreover, the necessity for closing feedback loops at all levels has been repeatedly communicated in several works published more than 20 years ago (e.g., Oh et al., 1998; Hale et al., 1999). Although it is outside of the scope of the paper to review the whole body of literature to trace the genesis of each of the NSTP considered in this study, the examples above along with the literature briefly reviewed in Section 2 of this paper and the sources used by the authors of most recent publications on NSTP, suggest that the respective concepts are not new. Nonetheless, regardless of whether the tag "new" is appropriate to describe these approaches, we should not underestimate the merit of revisiting and respreading them to communities unaware of them as long as any dogmatism about their practical and additional value is avoided.

Also, regardless of the literature references to NSTPs, the listing of which in this study might look quite "technical" and "procedural", we should not ignore that empathy can regulate the evaluations of practitioners due to cognitive, emotional, and physical proximity to those whom they investigate and the consideration of the magnitude of consequences of the results of any inquiry (Mencl and May, 2009). Since investigators are required to stand in the shoes of those they investigate as a means to understand the perspectives of the latter, the probability for a blameless attitude towards end-users is higher. As Jouty (2016) articulated when addressing the broader investigation context, independence is not equivalent to isolation; during real-time collection and analysis of investigation data and report writing, investigators cannot, and, perhaps, should not, disassociate from the context.

As frontline employees do not typically go to work to inflict harm and damages deliberately, under the same premise, investigators (i.e. the frontline persons in the context of investigations) do not perform their tasks with intention to harm others. The whole set of investigation standards in aviation and other industry sectors and even legislation in many regions suggest that safety investigations are not carried out to assign blame. Furthermore, safety investigators have their share of experience from their actions and involvement in systems before investigating events, so the convergence of scores towards the agreement with the NSTPs may also reflect desires of investigators that have been shaped through their experience. However, as the comments revealed, system boundaries might be unclear, and no academic literature suggests when and where an investigation shall cease. Consequently, even when formal investigation reports are the result of honest efforts and investment of recourses and are accepted by the majority of the stakeholders, from an academic perspective they might be still seen as incomplete because investigators did not fully satisfy the scientific curiosity of scholars, regardless of inevitable resource, data and time constraints.

Furthermore, any implied or voiced binarity between the old and new safety thinking might spark intense debates and develop a defensive attitude from both sides, but, at the same time, might function as a catalyst to reconsider and blend different perspectives. For example, the position expressed by the Reliability Centre (2017) was triggered by claims stated during a conference that Root Cause Analysis is obsolete, and the Learning Teams approach should be preferred as an alternative approach. The rejection of the former approach by the presenter stimulated the authors of the position document to reflect, search literature, detect commonalities, and conclude that these two approaches are not opposite, but complementary: "…both sides have a greater appreciation for the views of the other" (Reliability Centre, 2017, p. 2). However, although in the particular case the (re)enforcement of the new safety paradigm through a polarised statement triggered reflection and reconciliation, this cannot be guaranteed in every similar occasion due to the diversity of personalities (e.g., adaptive and receptive or defensive and unadaptable) as well as contextual and organisational boundaries (e.g., limited time to access and review new theories, preferences and comfort of stakeholders). Hence, any dogmatism of the practical superiority of old or new safety thinking might lead to isolation instead of a shared understanding and, possibly, unison over time.

Another challenge might be the vagueness of definitions and unclear boundaries between approaches, as, for instance, proposed by Ale et al. (2019) when discussing the qualitative nature of the Safety-I and Safety-II concepts due to the ambiguity in the definitions of failure and success, a situation that does not render the choice between one or another concept easy to make as a means to inform decision-making. This case becomes more understandable through the fact that in the aviation context it is imperative to investigate accidents and serious incidents while the launch of an incident investigation depends on various parameters, with the available investigation resources the most important driver due to the occurrence of numerous incidents daily. Accidents are unanimously classified as failures, and their investigation falls under the Safety-I category subject to opportunities to still learn from successes (Safety-II) while studying failures (e.g., timely and effective performance of emergency response services). However, serious incidents can both seen as failures (i.e. the system approached the boundaries of an accident) or successes (i.e. the worst-case scenario was avoided). Thus, the mandatory investigation of a serious incident, under the label of failure corresponds to Safety-I but under the label of success relates to Safety-II; regardless of the label, it is about the same event and the same investigation. The above could also apply to aviation incidents with the difference that these are not always investigated and are not reported as failures in annual statistics. Therefore, incidents are predominantly seen as successes and opportunities for learning rather than failures. Under this perspective, each incident investigation can be classified as a hybrid investigation that attempts to uncover problematic areas (i.e. Safety-I) while praising positive behaviours and outcomes (Safety-II). Hence, the boundaries between success and failure and Safety-I and Safety-II are blurry.

The safety models concerned, various critical reviews and comparison studies have observed their remarkable diversity and occasional conflicts which, as Benner (1985) justifiably stated decades ago, raises questions about their validity “Since they conflict, all models cannot be valid” (p. 124). The work of Underwood and Waterson (2014) observed that whereas the STAMP model might be more suitable for scientific research, models like AcciMap and Swiss Cheese Models might be more appropriate for professionals, as also indicated by participants of our study regarding the latter model. Also, the work of Salmon et al. (2012) recognised that although predefined taxonomies and failure modes like the HFACS (Wiegmann and Shappell, 2003) might restrict analysts, they could also be helpful with multiple case studies as a means to derive trends, similarities, differences etc. longitudinally and ethnographically. Even further, case studies such as the one presented by Martinetti et al. (2018) identified the necessity for an integrated approach of the overarching concepts of Safety I, Safety II, Resilience and Antifragility Engineering to increase our understanding and develop capabilities to confront unexpected situations and unfavourable events that emerge from complex socio-technical systems. These works suggest that context does not drive only the development of safety models but also their adoption and application by their users. Thus, model developers would be expected to communicate to the industry when and where each model could be appropriate or not to use along with underlying limitations. Certainly, though, the danger that organisations might misinterpret each safety model or use it inappropriately due to various reasons (e.g., inadequate training, lack of theoretical understanding, one-size-fits-all approach) still exists.

6. Conclusions and recommendations

This research was conducted under the reality of ever-changing safety investigation theories and practices. Related to this change, two, seemingly rival, paradigms have been discussed in the literature: the so-called old and new safety thinking. The nuclei of these paradigms focus on the role of the human element in the functioning of sociotechnical systems and unfolding of adverse events. Old Safety Thinking and Practice (OSTP) resonates with situations where the culpable persons or teams hold the principal or sole role in a series of events leading to a major one. New Safety Thinking and Practice (NSTP) has evolved during the recent decades and approaches human error as a consequence of underlying systemic issues which frame the end-user’s viewpoint and shapes her/his local rationality (e.g., Reason, 1990a,b; Woods and Cook, 1999; Dekker, 2014; Vlaev, 2018).

This study reviewed relevant literature and used an analysis framework to examine the familiarity, agreement and application regarding nine NSTP aspects, agreement with corresponding OSTP statements as well as familiarity and application of the three families of safety models (i.e. linear, multilinear/epidemiological and systemic), and collected perspectives of safety investigators towards these two paradigms. The study aimed to evaluate whether or not OSTP and NSTP are the opposite in practice as occasionally presented in literature and if the polarisation and dogmatism sometimes appearing in social media and sporadically implied during seminars, conferences and other safety-related events is justifiable.

The review of the literature shows that most of the foundations of the NSTPs included in this research are stated in work published since decades already, although they might have not found fertile ground and suitable opportunities to become available and known to a wider audience and the investigation community. The results from the survey suggested that the safety investigators, on average, recognised the potential and partially embraced the NSTP aspects in their practice, even when they did not declare full familiarity with the NSTP statements presented. However, the positive perspectives of the sample, which were also aligned with the literature reviewed, did not mean the rejection of OSTPs ex-prior and any ultimate preference in particular paths to investigate events; this accords with other studies which explored evolutions in safety investigation and management approaches (Henderson et al., 2001; Frederick et al., 2018). In our study, statistically, only the perspectives towards the “Human error” related aspect of new and old safety thinking appeared significantly oppositional. The higher/lower the agreement with the statement labelling human error as a valid (final) cause the lower/higher the agreement with the position that human error is a symptom respectively. On the side of the practice, the more the respondents believed that constructs could be tagged as valid accident and incident causes, the more frequently they applied this approach to investigations.

The contribution of prevalent cultures, inaccessibility and unavailability of data and information and constraints imposed by management and stakeholders (e.g., limited time and resources, outdated/inadequate training and personal expectations), according to the comments of some of the study participants, comprise common denominators that could hinder deeper and wider search for accident and incident causes. Overall the comments of the sample suggested that remaining sceptical towards new approaches does not mean that professionals reject them in overall, and the individual embracement of novel thinking does not always mean that the conditions allow its operationalisation, as also claimed by Busch (2018).

Indeed, an unspecified portion of investigators might actively support linear cause-effect associations, which is often linked to the old way of thinking, but this does not always come with intentions to blame teams or individuals. It must also be acknowledged that investigation training and experience rarely start immediately by addressing system complexity. Professionals are gradually immersed in the field of investigations starting from linear models, then transitioning to multi-cause models, and, recently, practising models that arguably are more suitable to address system complexity. Nevertheless, any attempt to implement the new safety paradigm does not directly mean that it will be successful. The Efficiency-Thoroughness Trade-Off (ETTO) principle (Hollnagel, 2009) does not apply only to work floor staff, but anyone who performs their designated tasks, the investigators included.

Based on the diversity of the comments in favour or against the various new and old safety thinking statements presented to our sample, the position of Zotov (2001) who encouraged the application of scientific methods to safety investigation reports could be a solution to minimise the gap between theory and practice detected in our study as well as that by Underwood and Waterson (2014). For instance, the work of Plioutsias et al. (2017) revealed that there are no criteria to enable quality assessments of investigations along with the lack of recognition of the assumptions that are made inevitably in every study. Transparent and documented investigation choices with reference to items that are typically included in scientific studies (e.g., selection of a model where applicable, data and information collection samples and techniques, verification methods, limitations) is what the field of practice should consider as a means to increase the credibility of investigation deliverables, reflect and improve in the future and allow the scientific community to assist investigators in overcoming the most prevalent obstacles and limitations. Thus, instead of scholars introducing and enforcing various safety approaches and models to the industry unidirectionally, practice would seek support from academia and would be keen to collaborate in the development of techniques and tools that satisfy the needs of all stakeholders and minimise investigation weaknesses over time, and render binary and polarised positions void and obsolete.

Furthermore, the development of a collective voice of academics when communicating scientific developments to the industry via conferences, education and training would increase the impact of safety research on practice. Instead of each scholar presenting and defending their safety/accident model, by sometimes addressing the weaknesses of respective work of others, we propose to restrict academic debates to scientific conferences and projects, agree on a unified approach and suggest the latter to the industry. This will not discourage scientific advancements, and, on the other hand, it will increase the credibility of theoretical and empirical positions in the eyes of professionals, and, possibly, rendering it easier to incorporate blended approaches into standards and vocational training.

Despite the efforts of the authors to approach participants through a wide variety of means, this study failed to attract a large sample, perhaps due to the lack of interest, face validity or practicality when discussing new and old safety thinking in the investigation context. Therefore, we cannot claim generalisation of our findings, and we were not able to perform statistical tests across the demographic variables recorded. Consequently, we were not in place to test whether the scores given to the statements of OSTP and NSTP included in our study and the nature and frequency of the comments stated vary across incident (i.e. organisation-led) and accident (i.e. State-led) investigators, levels of experience, regions, training background etc. Thus, we prompt the reader to avoid evaluating the comments of our study participants based solely on their frequencies; it can happen that perspectives against or in favour of any safety approach are held by senior staff that influence the shaping of investigation practices, and the standpoints and voice of junior investigators can be masked. The same remark applies to the distribution of the scored answers; albeit strong agreements or oppositions were the least frequent recorded for both OSTPS and NSTPS, the respective investigators might be highly influential. Furthermore, we cannot exclude the case of socially desirable answers to the questions about the familiarity, agreement and application of NSTP aspects; the differences of the latter from older approaches have been broadly and intensively enhanced by advocates of new safety thinking through recent publications and events that promise pathways for fairer and deeper investigations, which, nominally, is the preferred direction of all investigators.

However, the results of this research can function as a trigger to reconsider any absolutism when presenting and defending various safety investigation practices. In addition to the suggestions made above, future research could employ large and representative samples to examine whether the system thinking tenets summarised by Grant et al. (2016) and/or the new and old safety thinking aspects adopted in our work collectively represent distinct constructs. Moreover, future work could explore any variances across safety professionals practising in different regions and with various nationalities, educational levels and investigation experience and seniority. Follow-up interviews would also allow achieving further insights that were not possible to reveal during this preliminary research.

Appendix A

Old safety thinking and practice (OSTP) aspects	Statements used	Valid responses (%)					Median (N = 41)
		Strongly agree (2)	Agree (1)	Neither agree nor disagree (0)	Disagree (−1)	Strongly disagree (−2)	
Human error seen as cause	In some cases, human error can be one of the final/root causes of an event.	14.6	46.3	9.8	19.5	9.8	1.0
Hindsight approach	Starting with the negative outcome of the event and looking back at other failures/problems will fully explain why and how the event occurred.	7.3	41.5	29.3	12.2	9.8	0.0
Local responsibility	The people involved closest in an event are the most responsible for it.	0.0	7.3	31.7	43.9	17.1	−1.0
Proximal approach	In order to fully understand an event, it is sufficient to focus mainly on the actions and decisions of people closely involved.	0.0	14.6	12.2	46.3	26.8	−1.0
Folk models as causes	Poor communication, loss of situational awareness and inadequate knowledge are examples of possible final/root causes of an event.	12.2	39.0	19.5	24.4	4.9	1.0
Counterfactual approach	Comparing performance of people against established rules or checklists or procedures can fully explain an event.	2.4	12.2	23.9	43.9	12.2	−1.0
Judgmental approach	The fact that people did not perform in accordance with expectations (e.g. level of experience or responsibility of their job role) can be one of the final/root causes of an event.	4.9	39.0	17.1	26.8	12.2	0.0
Safety I	Explaining the failures that lead to a safety event is sufficient to fully understand why an event could happen under similar circumstances.	7.3	29.3	19.5	34.1	9.8	0.0
Awareness as the responsibility of end-users	All systems are by default designed in a way that they provide adequate feedback to the end-users of the system components.	2.4	9.8	19.5	48.8	19.5	−1.0

Appendix B

New safety thinking and practice (NSTP) aspect	Statement used in the questionnaire	(Dis)agreement						Application					
		Valid responses (%) - Likert scores in brackets					Median	Valid responses (%) - Likert scores in brackets					Median
		Strongly agree (2)	Agree (1)	Neither agree nor disagree (0)	Disagree (−1)	Strongly disagree (−2)		0%–20% (1)	21%–40% (2)	41%–60% (3)	61%–80% (4)	81%–100% (5)	
Human error seen as symptom	Human error is a symptom of deeper problems into a system and cannot be seen as the final/root cause of an event	36.8	39.5	13.2	7.9	2.6	1.0	18.4	5.3	15.8	23.7	36.8	4.0
Hindsight bias minimisation	Looking forward towards the event, instead of starting with the event and looking back, will support a better understanding of why people acted or decided the way they did	14.3	40.0	40.0	2.9	2.9	1.0	31.4	14.3	14.3	28.6	11.4	3.0
Shared responsibility	All parties involved in an event can be equally responsible for this event, regardless of how close they were in terms of time or location when the event happened	31.4	37.1	20.0	11.4	0.0	1.0	22.9	5.7	17.1	17.1	37.1	4.0
Non-proximal approach	It is necessary to analyze actions and decisions of people who contributed to an event but were not physically involved/present, at the same extent as such an analysis is performed for people that were directly involved/present	25.7	54.3	17.1	2.9	0.0	1.0	17.1	2.9	17.1	22.9	40.0	4.0
Decomposition of folk models	Causal factors such as poor communication, loss of situational awareness or inadequate knowledge should be further explained as part of an investigation	35.3	32.4	11.8	20.6	0.0	1.0	14.7	5.9	23.5	26.5	29.4	4.0
Non-counterfactual approach	When people did not perform in accordance with established rules, checklists or procedures, the applicability/practicality of those rules should be also explored, taking into account the conditions of the event	41.2	52.9	2.9	2.9	0.0	1.0	0.0	8.8	8.8	38.2	44.1	4.0
Non-judgmental approach	When people did not perform in accordance with expectations (e.g., work experience, job role), the validity of such expectations should be also explored	39.4	57.6	0.0	3.0	0.0	1.0	3.0	6.1	15.2	42.4	33.3	4.0
Safety-II	Instead of only understanding why things “went wrong”, understanding also why things usually “go right” under similar circumstances can help improve safety	40.6	46.9	12.5	0.0	0.0	1.0	21.9	18.8	18.8	12.5	28.1	3.0
Feedback loops examination	The existence and quality of feedback loops should be examined to explore if the persons involved into the event were adequately informed about the state of the system(s) they were operating	45.2	35.5	19.4	0.0	0.0	1.0	22.6	6.5	12.9	22.6	35.5	4.0

Appendix C

See Tables C1 and C2.

Table C1
Comments per new safety thinking and practice aspect (degrees of agreement and application).

New safety thinking and practice aspects			
Reasons for chosen degree of agreement	**Frequency**	**Reasons for chosen degree of application**	**Frequency**
Human error seen as symptom	**24**	**Human error seen as symptom**	**18**
Contributes to more accurate/deeper investigations	8	Necessary to identify/verify underlying factors	6
Human performance is influenced by the system	8	Standard practice in investigations	5
In some cases, human error can be a valid cause	4	Due to personal interest	3
People do not purposely make errors	2	Not adequately familiar with the approach	2
Human error is a personal responsibility	2	Access to information not always possible	1
		Organization's system supports the theory of one root cause	1
Hindsight bias minimisation	**20**	**Hindsight bias minimisation**	**12**
Looking forward contributes to a better overall understanding	9	Newer approach / not adequately familiar with the approach	8
Events can be approached both ways	4	Approach not always applicable	2
Not adequately familiar with the approach	3	Necessary data not yet available	1
Looking forward is a predictive approach	2	Rationality behind people's actions/decisions should always be explored	1
Looking backwards is necessary for a better understanding	2		
Shared responsibility	**18**	**Shared responsibility**	**9**
All system agents should be investigated	6	Investigations shouldn't focus on apportioning responsibility/blame	2
There is never one causal factor/party	4	All system components/parties should be investigated	2
Responsibility/involvement is rarely or never equally distributed	4	Due to cultural aspects	1
Investigations shouldn't focus on apportioning responsibility/blame	2	Applied due to the influence of employer	1
Link between directly/indirectly involved hard to find	1	There is never only one root cause	1
Hard to find supportive evidence	1	Purpose of human factors investigation	1
		Access to information not always possible	1
Non-proximal approach	**19**	**Non-proximal approach**	**12**
Contributes to more accurate/complete understanding/investigation	8	Contributes to more accurate/complete understanding/investigation	5
Indirectly involved persons can also be responsible	6	Access to information not always possible	3
Depends on depth/extent of analysis	2	Due to cultural aspects	1
Involvement shouldn't be labelled as direct nor indirect	2	Involvement shouldn't be labelled as direct or indirect	1
Depends on cultural aspects	1	Everyone is considered directly involved	1
		Parties indirectly involved is a second priority	1
Decomposition of folk models	**20**	**Decomposition of folk models**	**11**
Decomposition necessary for more accurate/in-depth investigation	14	Decomposition necessary for more accurate/in-depth investigation	7
Folk models can be labelled as causal factors	6	Standard practice	1
		Not adequately familiar with the approach	2
		Access to information not always possible	1
Non-counterfactual approach	**18**	**Non-counterfactual approach**	**12**
Rules/checklists/procedures not always practical/effective/safe	14	Not always relevant/possible to investigate	4
Not following rules/checklists/procedures indication of deeper issues	3	Standard practice in investigations	3
Standard practice to investigate applicability of standards	1	Necessary to identify reasons for deviations	2
		Rules/checklists/procedures not always practical/effective/safe	2
		Not following rules/checklists/procedures indication of deeper issues	1
Non-judgmental approach	**11**	**Non-judgmental approach**	**9**
Different systemic factors might contribute to deviations from expectations	5	Not always relevant/possible to investigate	3
Expectations might contradict, be too high or be perceived differently	3	Different systemic factors contribute to deviations from expectations	3
Contributes to better understanding/investigation	3	Expectations might contradict, be too high or be perceived differently	1
		Contributes to better understanding/investigation	1
		Recent approach	1
Safety-II	**14**	**Safety-II**	**12**
Helps understanding better a system and its safety barriers	12	Helps understanding better a system and its safety barriers	4
Past success no indication of current performance	1	Not always relevant/possible to investigate	3
Not applicable in practice	1	Traditionally not approached this way	2
		Monitoring success isolates failure	1
		Implicitly applied	1
		Applied to emergence response mainly	1
Feedback loops examination	**8**	**Feedback loops examination**	**9**
System is incomplete without a feedback loop	3	Contributes to more accurate/in-depth investigation	3
Contributes to more accurate/in-depth investigation	3	Not always possible to investigate	2
Investigation of feedback loops decreases subjectivity	1	Recently applied approach	2
Approach too complex in practice	1	Investigation of feedback loops decreases subjectivity	1
		Partially applied	1

Table C2
Comments per safety model type (degree of application).

Safety model types (degree of application)	
Sequential models	**17**
Model is too simplistic/limited	9
Preference for another model	5
Good base for reasoning	1
Not always applicable	1
Not adequately familiar with the model	1
Epidemiological models	**13**
Useful for investigations	5
Useful only for simple cases/has limitations	4
Used because of employer's requirement	3
Easy to apply	1
Systemic models	**11**
Not adequately familiar with the model	6
Organization not mature enough to use	3
Model takes into account more influences/relationships/factors than others	2

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