System thinking applied to near misses: a review of industry-wide near miss reporting systems

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Abstract

Learning from near misses is an important component of maintaining safe work systems. Within safety science it is widely accepted that a systems approach is the most appropriate for analysing incidents in sociotechnical systems. The aim of this article is to determine whether industry-level near miss reporting systems are consistent with systems thinking. Twenty systems were identified, from a range of work domains, and were evaluated against systems thinking-based criteria. While none of the reporting systems fulfilled the full set of criteria, all are able to identify actors and contributing factors proximal to events in sociotechnical systems and many capture information on how accidents were prevented. It is concluded that the explanatory power of near miss reporting systems is limited by the systems currently used to gather data. The article closes by outlining a research agenda designed to ensure that near miss reporting systems can fully align with the systems approach.

Keywords: Near Miss, Incident Reporting, Reporting Systems, Accident Causation, Systems Thinking

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Relevance to human factors / ergonomics theory: This article contributes an extension of human factors and ergonomics theory. An extension of a systems accident causation model to address both potential accident trajectories and protective trajectories in near misses is presented and applied to the evaluation of industry-wide near miss reporting systems.

Introduction

It is widely accepted that reporting near misses is important for improving safety (Lukic, Littlejohn, and Margaryan 2012; Jones, Kirchsteiger, and Bjerke 1999; Phimister, Bier, and Kunreuther 2004). Near misses have been formally defined as: a serious error that has potential to cause harm but does not due to chance or interception (WHO 2005); a potential significant event that could have consequences but did not due to the conditions at the time (IAEA 2007); and as an incident that could have caused serious injury or illness but did not (OSHA 2015). The uniting factor amongst these definitions is that a near miss has a successful outcome, where an adverse outcome did not occur.

Near misses are seen as a valuable tool for improving safety for three primary reasons. First, due to their higher number of occurrences as compared to accident outcomes (Bird, Germain, and Veritas 1996; Heinrich 1931), they provide low consequence insights into safety prevention. Second, as the contributing factors are consistent between accidents and near misses (Heinrich et al. 1980), near misses provide insights on potential accident trajectories. Third, as near misses are successful outcomes, they provide information on a systems' capacity for resilience through identifying error recovery factors (Kanse et al. 2005).

Reporting systems are the main mechanism used to capture data about near misses (Van der Schaaf, Moraal, and Hale 1992), and industry-wide systems have been developed across a range of sectors, including medical, nuclear, air travel, and rail to identify hazards and potential accident pathways (Barach and Small 2000; van der Schaaf and Kanse 2004) in order to eliminate error-producing factors and prevent accidents. It is therefore important to evaluate whether such systems support the collection of appropriate data to understand near misses.

Within the safety science literature, it is now widely acknowledged that the systems thinking approach is required to understand and prevent accidents (Underwood and Waterson 2013; Stanton, Rafferty, and Blane 2012; Salmon, Cornelissen, and Trotter 2012; Salmon, Walker, et al. 2016). The systems thinking approach views both safety and accidents as emergent phenomena arising from interactions among components at multiple levels of a sociotechnical work system (Rasmussen 1997). This approach sees accident causation as a system-wide event (Leveson 2004; Reason 1997; Carayon et al. 2015). Applying this approach to accident analysis has exposed how multiple interacting factors contribute to incidents in many industries including space exploration (Johnson and Muniz de Almeida 2008), aviation (Branford 2011), rail (Underwood and Waterson 2014), public health (Cassano-Piche, Vicente, and Jamieson 2009a), disaster management (Salmon, Goode, Archer, et al. 2014), road freight transport (Newnam and Goode 2015a; Salmon et al. 2013), and led outdoor activities (Salmon, Goode, Lenné, et al. 2014; Salmon, Goode, et al. 2016). Although it is likely that near misses will benefit from a systems perspective, the extent to which the systems thinking approach has been applied to the understanding, reporting, and investigation of near misses is unclear.

The purpose of this review is to define the characteristics of near misses from a systems perspective and evaluate whether current near miss reporting systems capture this type of information. These aims are important to understand the capacity of current near miss reporting systems to capture appropriate information to understand near misses. The following sections present; first, a brief overview of the history of near miss reporting systems. Second, a brief overview of the systems approach to accident causation to develop evaluation criteria of near miss reporting systems from a systems perspective. Third, a case study is presented showing how the evaluation criteria appear in near miss reports. Finally, the information near miss reporting systems should capture is discussed.

History of near miss reporting systems

In the early 1930's, Heinrich (1931) introduced the idea that near misses occur more frequently than accidents and therefore provide important information about safety improvement. In order to learn from near misses, organizations (mainly in aviation) began developing reporting systems in the 1950's (Taylor 1977). In the 1970's, several industries (e.g. nuclear, chemical process, aviation) were implementing near miss or precursor analysis. This shift from including investigations into near misses as well as accidents coincided with the emergence of safety management systems (SMS) in safety critical work domains following accidents such as the 1976 Seveso chemical spill and the 1988 Piper Alpha disaster in oil production (Thomas 2012). In these safety management systems, the functions of near miss reporting are to track the assurance of safety and inform safety risk managements (ICAO 2009). These SMS functions have commonly been performed by industry-wide reporting systems.

One of the earliest examples of an industry-wide reporting system capturing information about near misses is the Aviation Safety Reporting System (ASRS) launched in 1975. This was a response to the tragic crash of TWA 514 which was foreshadowed by a previous near miss involving a United Airlines crew nearly impacting Mount Weather on the same approach six weeks earlier. The Accident Sequence Precursor Program (ASP) began by the United States Nuclear Research Commission in 1979, inspired by the success of the ASRS. Industry-wide reporting systems began to spread across industries as prior near misses were identified as precursors to significant accidents such as the Three Mile Island nuclear disaster (1979), Ladbroke Grove rail crash (1999), and the Columbia space shuttle disaster (2003).

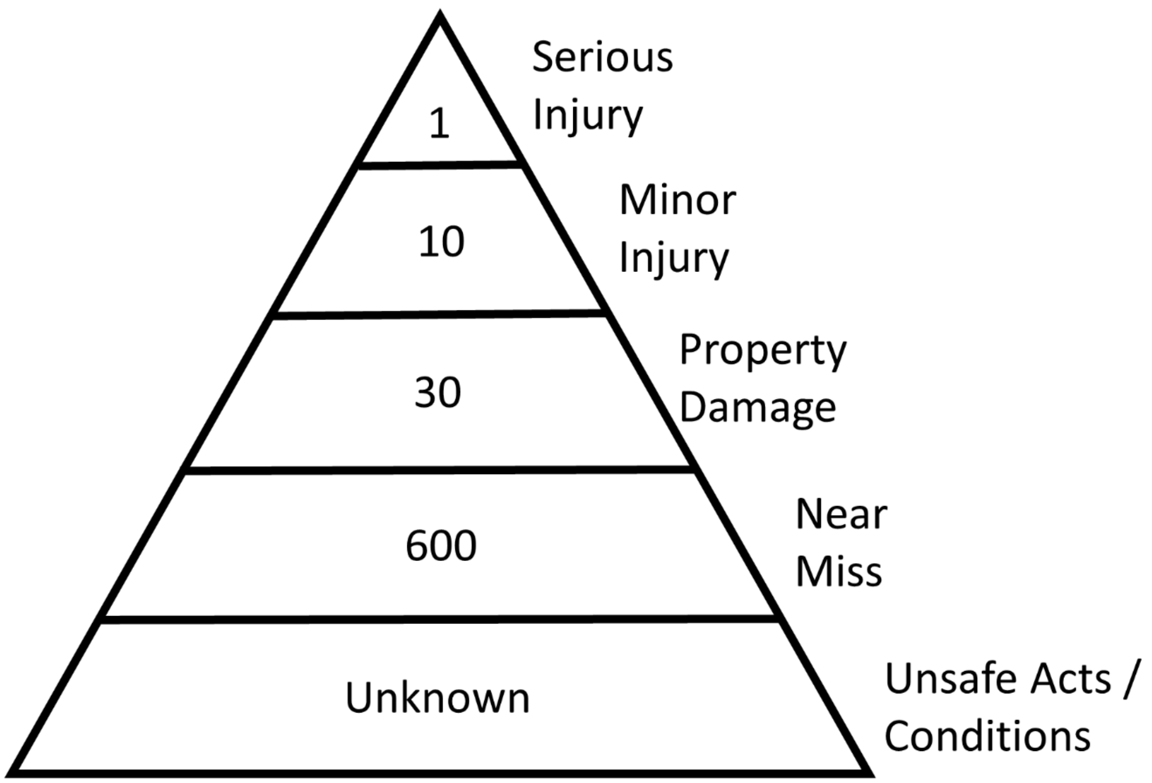

Figure 1: The ‘Safety Pyramid’

(adapted from Bird et al, 1996 and Phimister et al, 2003)

There are two critical reasons that near miss reporting systems have been widely adopted in industry. First, the safety pyramid model, by Bird, et al (1996)) (figure 1), illustrates a ratio of many near misses to a single serious accident. Near misses therefore provide frequent, low consequence insights into a systems’ safety. This claim is supported by numerous studies (Wright 2000; Phimister et al. 2003; Saleh et al. 2013; Kessels-Habraken et al. 2010; Alamgir et al. 2009; Jones, Kirchsteiger, and Bjerke 1999). Second, the identical causation hypothesis, states that the contributing factors involved in all the types of incidents are equivalent (Heinrich et al. 1980). It is therefore has been argued that the accident trajectories of near misses and accidents differ only by their outcome (Barach 2003; van der Schaaf 1995). This hypothesis has been supported by several analyses of near misses and accidents across multiple industries (Wright and Van der Schaaf 2004; Saleh et al. 2013; Phimister et al. 2003; Barach 2003; van der Schaaf 1995).

In addition, more recent research has viewed near misses as successful outcomes which did not result in an accident. It is therefore argued that near misses provide information on the systems' resilience by identifying the capacity of a system to recover from accident trajectories (Kessels-Habraken et al. 2010) and error recovery-factors (Kanse and van der Schaaf 2001; Kanse et al. 2005; Kanse et al. 2006). While error recovery has been identified as one of defining components of a near miss (van der Schaaf and Kanse 2004; Barach and Small 2000; Battles et al. 1998), it is unknown whether industry-wide reporting systems capture information on the factors that contribute to error recovery.

The systems approach to accident causation and extension to near misses

Rasmussen (1997) argues that accidents are seen to be caused by the '*interaction* of the effects of *decisions made by several actors* in their *normal work context'* (pg. 189; emphasis added). Accordingly, three core principles underpin the systems thinking approach to accident causation. First, safety is an emergent property arising from actions and decisions at all levels of the sociotechnical system (Leveson 2004; Dekker, Cilliers, and Hofmeyr 2011); second, that the cause of incidents is non-linear, arising from the interactions of multiple contributing factors (Leveson 2011); and third, that factors contributing to accidents do not need to be a product of errors, but rather occur as unanticipated results of normal variations of work done to fulfil local goals and constraints (Hollnagel 2014; Rasmussen and Svedung 2000). It has also been argued that the resilience of a system (i.e. the ability to adapt and recover from disturbance) is an emergent property, which is caused by multiple factors and influenced by performance variability (Hollnagel, Woods, and Leveson (eds.) 2007; Hollnagel 2013). Currently, there are several researchers whose accident causation models and analysis methods are based on system thinking (Dekker 2014; Hollnagel 2014; Leveson 2004; Perrow 1984; Woods and Cook 2002).

One frequently used systems accident causation model, Rasmussen's (1997) risk management framework (RRMF), describes sociotechnical systems as hierarchies of interconnected levels, where individual decisions and actions dynamically influence and impact an entire system through controls and feedback (Figure 2-Left). RRMF provides seven tenets regarding accident causation (Table 1). These tenets reflect the three core principles of accident causation underpinning the system approach and describe the role that vertical integration and the migration of work practices play in accident causation. Vertical integration reflects how hierarchical system levels influence each other through differing types of feedback (Leveson 2004; Cassano-Piche, Vicente, and Jamieson 2009b). The migration of work practices describes how competing influences of organizational (e.g. financial) and work load (e.g. the 'efficiency-thoroughness trade off' - (Hollnagel 2009)) pressures define a 'safety space' where locally normalised decisions can drive a system towards a safety boundary (Figure 2-Right). This migration occurs because actors throughout a sociotechnical system vary performance in order to accomplish goals (Hollnagel 2009), leading to both successful actions (Hollnagel 2009) and work system migration (Rasmussen 1997; Hollnagel 2014).

The following section presents an example illustrating how the tenets presented in Table 1 describe both the potential accident trajectory and protective trajectory (i.e. the factors which led to it becoming a near miss). Based on these tenets, the type of information near miss reporting systems should ideally collect is described.

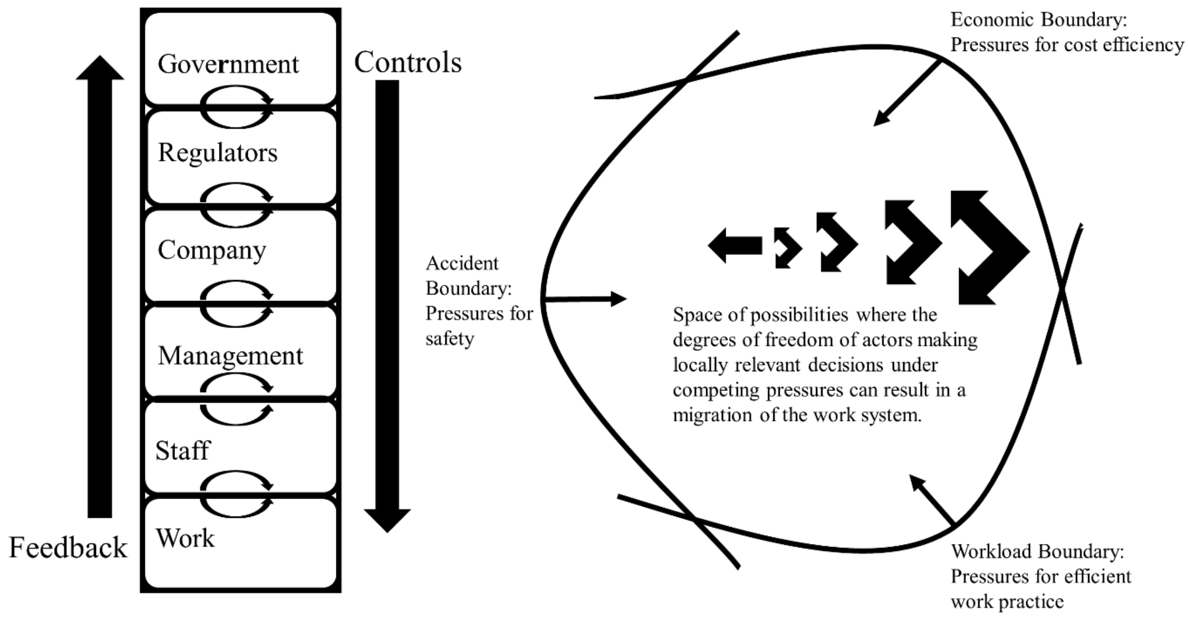

Figure 2: Rasmussen's Risk Management

Framework and Migration Model (adapted from Rasmussen, 1997)

Table 1: Extension of Rasmussen's Seven Predictions of accident causation applied to near misses and evaluation criteria (Cassano-Piche, Vicente, and Jamieson 2009b; Vicente and Christoffersen 2006)

	Prediction applied to accident causation	Prediction applied to near miss	Criteria derived from prediction for a near miss reporting system
1	Safety is an emergent property of a complex sociotechnical system. It is impacted by the decisions of all of the actors-politicians, managers, safety officers, and work planners-not just the front-line workers alone.	Near misses are emergent in complex sociotechnical systems. The potential accident trajectory results from decisions and actors throughout the system. Similarly, protective trajectories result from decisions and actor throughout the system.	[1] System gathers information on decisions or actions from actors across the overall sociotechnical system. This includes those decision or actions which create the potential accident trajectory and those which create the protective trajectory.
2	Threats to safety or accidents are usually caused by multiple contributing factors, not just a single catastrophic decision or action.	Potential accident trajectories are usually caused by multiple, interacting contributing factors. Similarly, the protective trajectories are usually caused by multiple, interacting contributing factors.	[2] System gathers information on multiple contributing factors, rather than only on a root or primary cause. This includes those factors which create the potential accident trajectory and those which create the protective trajectory. [3] System gathers information on relationships between contributing factors. This includes those relationships contributing to the potential accident trajectory and those which contribute to the protective trajectory.
3	Threats to safety or accidents can result from a lack of vertical integration (i.e. mismatches) across levels of a complex sociotechnical system, not just from deficiencies at just one level.	Potential accident trajectories can result from a lack of vertical integration across levels of a sociotechnical system, rather than from one level alone. Protective trajectories can result from vertical integration (i.e. matches) across levels of a	[4] One of the purposes of the system is to monitor vertical integration across levels of the sociotechnical system. This includes vertical integration mismatches which contribute to the potential accident trajectory and vertical integration matches which contribute to the protective trajectory.

		sociotechnical system, not just from decisions at just one level.	
4	The lack of vertical integration is caused, in part, by a lack of feedback across levels of a complex sociotechnical system. Actors at each level cannot see how their decisions interact with those made at other levels, so the threats to safety are far from obvious before an accident.	Potential accident trajectories are caused, in part, by a lack of feedback across levels of a sociotechnical system where actors cannot see how their decisions interact with those made at other levels. Protective trajectories are supported by feedback across levels of a sociotechnical system. Controls (propagated downwards) and feedback (propagated upwards) allow actors to see how their decisions interact with those made at other levels.	[5] System gathers information on communication (e.g. contributing factor categories enable the capture of information about communication both across and within levels of the system). This includes contributing factor categories of both effective and ineffective communication which contribute to the potential accident trajectory and those which contribute to the protective trajectory.
5	Work practices in a complex sociotechnical system are not static. They will migrate over time under the influence of a cost gradient driven by financial pressures in an aggressive competitive environment and under the influence of an effort gradient driven by the psychological pressure to follow the path of least resistance.	Practices leading to potential accident trajectories in sociotechnical systems are not static. They migrate over time under the influence of cost gradient driven by financial pressures in an aggressive competitive environment and under the influence of an effort gradient driven by the psychological pressure to follow the path of least resistance. Practices leading to protective trajectories are not static. They migrate over time under the influence of a safety gradient	[6] One of the purposes of the system is to monitor the migration of the work system towards the safety boundary. This includes system migration leading to a potential accident trajectory and system migration leading to a protective trajectory. [7] System includes specific fields relating information on the influence of external and internal pressures for increased safety, cost effectiveness, and work efficiency on the work system (e.g. why are current work practices considered normal).

		driven by social pressures and individual psychological pressures to do no harm.	
6	The migration of work practices can occur at multiple levels of a complex sociotechnical system, not just one level alone.	The migration of work practices leading to both potential accident trajectories and protective trajectories occur at multiple levels of a complex sociotechnical system, not just at one level alone.	[8] One of the purposes of the system is to monitor the migration of work practices (i.e. the behaviour of individuals throughout the sociotechnical system). This includes migration at all levels of the system, not just the system or organization as a whole. [9] System includes specific fields on migration of work practices (e.g. contributing factor categories capture information on influences to work practices).
7	Migration of work practices can cause the systems' defences to degrade and erode gradually over time, not all at once. Accidents are released by a combination of this systematically-induced migration in work practices and a triggering event, not just by an unusual action or an entirely new, one-time threat to safety.	Migration of work practices can result in the degradation of defences over time. Similarly, migration can result in the introduction of new defences over time. Potential accident trajectories are released by a combination of systematically-induced migration and a triggering event. Protective trajectories are released by identifying and evaluating potential accident trajectories and triggering protective factors.	[10] One of the purposes of the system is to monitor changes in the effectiveness of defences. [11] System gathers information on where, why, and how the potential accident trajectory was initiated (i.e. triggering events). [12] System gathers information on where, why, and how the incident was prevented from becoming an accident (i.e. identifying and evaluating potential accident trajectories and protective trajectories)

The characteristics of near misses from a systems perspective: example incident

This example is presented to illustrate the extensions of Rasmussen's tenets proposed in Table 1. The following details are taken from the French Civil Aviation Safety Investigation Authority report (BEA 2014). On June 29, 2010, two Airbus 319 aircraft experienced two serious near miss loss of separation events, coming first within .29 nautical miles (NM) horizontal and 1760 feet vertical of each other, and second within 2.2 NM at the same elevation (i.e. 16 seconds of flight time), above the Basel Mulhouse airport. The risk of a mid-air collision was characterised by the duel triggering of the TCAS (Traffic alert and Collison Avoidance System) and STCA (Short Term Conflict Alert). The factors leading to the potential accident trajectory and factors leading to the protective trajectory indicated in the report are shown as they apply to the extension of Rasmussen's seven predictions (see Table 2).

Table 2: Example of Rasmussen's Seven Predictions of accident causation and near misses

Tenet	Causation factors of the potential accident trajectory	Protection factors of the protective trajectory
1	• Adjustment to airspace under Basel Mulhouse control • Instructor controller decision to turn on unreliable radar • Instructor controller physical position • Trainee controller speech error	• Ascending pilot response to TCAS • Descending pilot response to TCAS • Instructor controller response to loss of separation
2	• Unreliable radar • Thunderstorm Cells • Trainee Controller (i.e. speech error, workload, untrained-for situation) • Instructor Controller actions (i.e. physical location making continuous direct supervision impossible and reactivating the unreliable radar) • Conventional Procedural Control	• TCAS alerts • STCA alerts • Instructor controller identified loss of separation and alerted trainee controller • Ascending flight crew actions • Descending flight crew actions

3	• Communication error between trainee controller and ascending aircraft • Initial airspace change safety paper did not identify radar capacity in risk assessment	• Radar issue communicated to all flight crews using airspace • Crew communication management between pilots and co-pilots
4	• Trainee controller lack of attention to read back on request for ascending aircraft to FL110 • Trainee controller use of unreliable radar after it was reactivated • Unclear procedure for horizontal separation in procedural control situation	• TCAS and STCA systems provided feedback to flight crews initiating recovery actions
5	• Increase in workload due to change in air space to be managed created a mismatch between the radar system and the characteristics of traffic involved • Time pressure on equipment replacement due to the delay in identifying the issue with radar capacity	• Safety study completed for transfer of air space by regulatory bodies
6	• Lack of radar requiring use of procedural controls • First cycle of shifts where instructor and trainee controllers using procedural control at airport	• TCAS procedures applied in simulator training for both pilots • Radar failure experienced in simulation training for both Trainee and instructor controller
7	• The planned defence of reliable radar was lost	• Descending pilots' previous experience at airport informed potential for loss of separation prior to TCAS

What information should near miss reporting systems collect?

The tenets described in table 1 have several implications for the design of near miss reporting systems. First, the purpose of near miss reports should be to identify factors contributing to potential accident trajectories. Additionally, specific information about near misses needs to be captured which goes beyond just the causation of the incident. Information about why the incident was a near miss provides critical information about the performance on the system.

Protective factors may show how adverse outcomes are prevented. Therefore, a secondary purpose of near miss reporting systems should be to identify factors which increase the number of successful outcomes (e.g. what went right) as well as those which may lead to unsuccessful events (e.g. what went wrong) (Hollnagel 2014; Salmon, Walker, et al. 2016).

Based on these ideas, in this study the extended tenets in Table 1 were used as criteria for assessing near miss reporting systems. Table 1 describes the information that near miss reporting systems need to collect to understand why near misses occur, and how an accident is prevented, from a systems perspective. These criteria are then used to evaluate existing industry-wide reporting systems.

Methods

Search strategy

The following databases were searched in May 2016: ScienceDirect; Taylor and Francis; Scopus; and Web of Science. The following search terms were used: "Near Miss", "Close Call", "Near Accident", "Accident Precursor", "Precursor" with "Reporting System". These represent all the phrases associated with the common definition of an accident or incident which does not cause harm (Phimister, Bier, and Kunreuther 2004). The search was restricted to papers published from 1997, the time at which Jens Rasmussen's seminal paper was published (Rasmussen 1997), and would have been able to have an impact on the design of near miss reporting systems. These searches resulted in 359 papers for initial review.

An initial review was completed of titles and abstracts; 155 relevant papers were identified. Subsequent full paper review identified seventeen papers on near miss reporting systems for inclusion. As many of these papers did not provide full descriptions of the near miss reporting systems, additional information was sought through a grey literature search (e.g. Google, Google Scholar, system web sites, white papers, and government documents). This search identified five additional near miss reporting systems as well as provided for full descriptions of the reporting systems identified through the literature review. Twenty reporting systems were identified throughout the review with appropriate data from all sources to be included in the evaluation.

Data extraction

The following data was extracted for each near miss reporting system: domain of application, stated purpose of reporting system, accident causation model, analysis method, reporting criteria/definition, whether a detailed incident description is required, the listed fields in the data entry tool, and specified contributing factors. The data extraction table is provided as supplementary material.

Evaluation of near miss reporting systems

The 20 reporting systems were evaluated using the criteria presented in Table 1. The first author developed the criteria from the tenets, resulting in 14 original criteria. The second and third authors, who have extensive experience applying a systems approach in various domains, independently reviewed the list. Disagreements were resolved through discussion until consensus was reached. The total number of criteria is 22.

Each reporting system was evaluated on the systems' capacity to fulfil the criteria for causation factors relating to potential accident trajectories and protective factors relating to protective trajectories. The evaluation involved examining the data extracted for each reporting system, and giving a "Yes, "Partial" or "No" rating for each criterion. "Yes" and

"Partial" ratings had to be supported by examples. For example, when evaluating criterion 1 (e.g. factors are identified throughout the socio-technical system), a 'yes' rating would indicate factors can be captured at all levels of Rasmussen's Risk Management Framework where a 'partial' rating would indicate that factors can be captured at more than three (but less than all) of the levels of the framework (see Table 3 for the definitions specific to each evaluation criteria). The evaluation was conducted by the first author and reviewed by the second and third authors; disagreements were resolved through discussion.

Table 3: Evaluation criteria definitions for near miss reporting systems

	Criteria derived from prediction for a near miss reporting system	**Criteria for a 'Yes' Rating**	**Criteria for a 'Partial' Rating**	**Criteria for a 'No' Rating**
1	[1] System gathers information on decisions or actions from actors across the overall sociotechnical system. This includes those decisions or actions which create the potential accident trajectory and those which create the protective trajectory.	[1] The reporting system contributing factor categories allow for the identification of decisions or actions at all six levels of RRMF	[1] The reporting system contributing factor categories allow for the identification of decisions or actions as 2-5 levels of the RRMF	[1] The reporting system lacks contributing factor categories or allow categories at 1 level of the RRMF
2	[2] System gathers information on multiple contributing factors, rather than only on a root or primary cause. This includes those factors which create the potential accident trajectory and those which create the protective trajectory. [3] System gathers information on relationships between contributing factors. This includes those relationships contributing to the potential accident trajectory and those	[2] The reporting system allows for the selection of multiple contributing factor categories [3] The reporting system allows for relationships to be identified between contributing factors at	[2] Not Applicable to this criterion [3] The reporting system allows for relationships to be identified between contributing factors at 1-5 levels of RRMF	[2] The reporting system does not allow for the selection of multiple contributing factor categories [3] The reporting system does not allow for relationships to be identified between contributing factors

	which contribute to the protective trajectory.	all six levels of RRMF		
3	[4] One of the purposes of the system is to monitor vertical integration across levels of the sociotechnical system. This includes vertical integration mismatches which contribute to the potential accident trajectory and vertical integration matches which contribute to the protective trajectory.	[4] The purpose of the near miss reporting system includes the identification of vertical integration (i.e. matches or mismatches) between levels of the RRMF	[4] Not Applicable to this criterion	[4] The purpose of the near miss reporting system does not include the identification of vertical integration (i.e. matches or mismatches) between levels of the RRMF
4	[5] System gathers information on communication (e.g. contributing factor categories enable the capture of information about communication both across and within levels of the system). This includes contributing factor categories of both effective and ineffective communication which contribute to the potential accident trajectory and those which contribute to the protective trajectory.	[5] The reporting system contributing factor categories include categories regarding communication	[5] Not Applicable to this criterion	[5] The reporting system contributing factor categories does not include categories regarding communication
5	[6] One of the purposes of the system is to monitor the migration of the work system towards the safety boundary. This includes system migration leading to a potential accident trajectory and system migration leading to a protective trajectory. [7] System includes specific fields relating information on the influence of external and internal pressures for	[6] The purpose of the near miss reporting system specifically includes the monitoring of system migration [7] The reporting system contributing factor categories	[6] The purpose of the near miss reporting system includes an aspect of the monitoring of system migration [7] The reporting system contributing factor categories	[6] The purpose of the near miss reporting system does not include the monitoring of system migration [7] The reporting system contributing factor categories does

	increased safety, cost effectiveness, and work efficiency on the work system (e.g. why are current work practices considered normal).	include categories regarding external and internal pressures at all six levels of RRMF	include categories regarding external and internal pressures at 1-5 levels of RRMF	not include categories regarding external and internal pressures
6	[8] One of the purposes of the system is to monitor the migration of work practices (i.e. the behaviour of individuals throughout the sociotechnical system). This includes migration at all levels of the system, not just the system or organization as a whole. [9] System includes specific fields on migration of work practices (e.g. contributing factor categories capture information on influences to work practices).	[8] The purpose of the near miss reporting system specifically includes the monitoring of work practices at all six levels of the RRMF [9] The reporting system contributing factor categories include categories regarding influences to work practice	[8] The purpose of the near miss reporting system specifically includes the monitoring of work practices at 1-5 levels of the RRMF [9] Not Applicable to this criterion	[8] The purpose of the near miss reporting system does not include the monitoring of work practices [9] The reporting system contributing factor categories does not include categories regarding influences to work practice
7	[10] One of the purposes of the system is to monitor changes in the effectiveness of defences. [11] System gathers information on where, why, and how the potential accident trajectory was initiated (i.e. triggering events). [12] System gathers information on where, why, and how the incident was	[10] The purpose of the near miss reporting system specifically includes the monitoring the effectiveness of defences [11] The reporting system captures information on how the incident was initiated	[10] The reporting criteria, definition, or contributing factors of the near miss reporting system identify defences [11] Not Applicable to this criterion	[10] The near miss reporting system does not capture information on the effectiveness of defences [11] The reporting system does not capture information on how the incident was initiated

	prevented from becoming an accident (i.e. identifying and evaluating potential accident trajectories and protective trajectories)	[12] The reporting system captures information on how the near miss prevented an accident	[12] The reporting system captures information of the prevention of a similar near miss in the future	[12] The reporting system does not capture information on how near miss prevented an accident

Results

Description of reporting systems

As shown in table 4, the reporting systems covered a range of industries including: transportation, medical, emergency services, and led outdoor activities. All of the systems provide for confidential or anonymous reporting.

Table 4: Near miss reporting systems identified by the review

System Name	Domain / Year of Origin	Associated Papers / Grey Literature Sources
Aviation Safety Reporting System (ASRS)	Aviation (US) / 1975	ASRS (2017)
Transport Safety Board of Canada (SERCURITAS)	Marine, Pipeline, Rail, Air (Canada) / 1989 (year of CTAISBA)	SECURITAS (2017)
UK Confidential Human Factors Incident Reporting Programme (CHIRP)	Air (UK) / 1982	CHIRP (2017)
UK Confidential Hazardous Incident Reporting Programme –	Maritime (UK) / 2003	CHIRP-MEMS (2007)

Maritime (CHIRP-MEMS)		
Dispensing Accurately and Near Miss Program (DANMP)	Pharmacy / 2000	Dooley, Streater, and Wilks (2001)
MERS-TM	Medical – Transfusion Medicine (US) / 1998	Battles et al. (1998); Kaplan (2005); Battles and Shea (2001)
University of Texas Close Call Reporting System (UTCCRS)	Health Care (US) / 2002	Simmons et al. (2008); Martin et al. (2005)
National Fire Fighter Near Miss Reporting System (NFFNMRS)	Firefighting (USA) / 2005	Taylor et al. (2015); Taylor and Lacovara (2015); Taylor et al. (2014); Tippett Jr (2007); NFFNMRS (2017)
Confidential Close Call Reporting System (C3RS)	Rail (USA) / 2007	C3RS (2017)
Confidential Incident Reporting and Analysis System (CIRAS)	Rail and Road (UK) / 1996	Wright (2000); CIRAS (2017)
LEO Near Miss (LEONM)	Law Enforcement (USA) / 2013	LEONM (2017)
EMS Voluntary Event Notification Tool (EVENT)	Emergency Services (USA) / 2010	Gallagher and Kupas (2011); EVENT (2017)
Patient Safety Reporting System (PSRS)	Patient Safety (USA) / 2010 (in development)	PSRS (2017)
REPCON - Australian Transportation Safety Bureau (ATSB)	Air, Rail, Marine	REPCON (2017)

	(Australia) / 2013	
Wildland Fire Lessons Learned Center (WFLLC)	Fire and Rescue (USA) / 2012	WFLLC (2017)
Seahealth	Maritime (Denmark) / 2013	Seahealth (2017)
Mariners' Alerting and Reporting Scheme (MARS)	Marine (UK) / 1992	MARS (2017)
Insjo	Marine (Sweden) / 2001	Mazaheri et al. (2015); Insjo (2017)
Understanding and Preventing Led Outdoor Accidents Data System (UPLOADS)	Outdoor Activity (Australia) / 2011	Goode et al. (2015b); Salmon et al. (2017); UPLOADS (2017)
National Incident Database (NID)	Outdoor Activity (New Zealand) / 2005	Goode et al. (2015a); Salmon, Goode, Lenné, et al. (2014); NID (2017)

Evaluation of near miss reporting systems

Table 5 presents the findings relating to the capacity to identify causation factors leading to potential accident trajectories from a systems perspective. Table 6 presents the findings related to the capacity to identify protective factors leading to protective trajectories.

Table 5: Summary of evaluation results - Causation

	Evaluation Criteria related to Causation (see Table 1 for details of criteria)

System	1C – Actors and Factors across systems	2C – Multiple factors	3C – Relations between factors	4C – Vertical Integration in purpose	5C – Communication factors	6C – System Migration in purpose	7C – Factors of normal work	8C – Work level migration in purpose	9C – Work migration factors	10C – Erosion of controls in purpose	11C – Triggering actions
ASRS	No	No	No	No	No	Partial	No	No	No	Partial	Yes
SERCURITAS	No	No	No	No	No	No	No	No	No	Partial	Yes
CHIRP	No	No	No	No	Yes	No	No	No	Yes	No	No
CHIRP-MEMS	No	No	No	No	Yes	No	No	No	Yes	No	No
DANMP	No	Yes	No	No	No	No	No	No	Yes	No	No
MERS-TM	Partial	Yes	Yes	No	No	No	No	No	Yes	Partial	Yes
UTCCRS	Partial	Yes	No	No	Yes	No	No	No	Yes	Partial	Yes
NFFNMRS	Partial	Yes	No	No	Yes	No	No	No	Yes	No	No
C3RS	No	No	No	No	No	No	No	No	No	Partial	Yes
CIRAS	Partial	No	No	No	Yes	No	No	No	Yes	No	No
LEONM	Partial	Yes	No	No	Yes	Partial	No	No	Yes	No	Yes
EVENT	Partial	Yes	No	No	Yes	No	No	No	Yes	No	No
PSRS	No	No	No	No	No	No	No	No	No	No	Yes
REPCON	No	No	No	No	No	No	No	No	No	No	No
WFLLC	No	No	No	No	No	No	No	No	No	No	No
Seahealth	No	No	No	No	No	No	No	No	No	No	No
MARS	No	No	No	No	No	No	No	No	Yes	No	Yes
Insjo	Partial	No	No	No	No	No	No	No	Yes	No	Yes
UPLOADS	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	Partial	Yes
NID	No	Yes	No	No	No	No	No	No	Yes	No	Yes

Table 6: Summary of evaluation results - Protection

	Evaluation Criteria related to Protection (see Table 1 for details of criteria)										
System	1P – Actors and Factors across system	2P – Multiple factors	3P – Relations between factors	4P – Vertical Integration in purpose	5P – Communication factors	6P – System Migration in purpose	7P – Influences on normal work	8P – Work level migration in purpose	9P – Work migration factors	10P – Erosion of controls in purpose	12P – Prevention actions
ASRS	No	No	No	No	No	No	No	No	No	No	Yes
SERCURITAS	No	No	No	No	No	No	No	No	No	No	Yes

CHIRP	No	No	No	No	No	Partial	No	No	No	No	No
CHIRP-MEMS	No	No	No	No	No	Partial	No	No	No	No	No
DANMP	No	No	No	No	No	No	No	No	No	No	Partial
MERS-TM	No	No	No	No	No	No	No	No	No	No	Yes
UTCCRS	No	No	No	No	No	No	No	No	No	No	Partial
NFFNMRS	No	No	No	No	No	No	No	No	No	No	Partial
C3RS	No	No	No	No	No	Partial	No	No	No	No	Yes
CIRAS	No	No	No	No	No	No	No	No	No	No	No
LEONM	No	No	No	No	No	No	No	No	No	No	No
EVENT	No	No	No	No	No	No	No	No	No	No	Yes
PSRS	No	No	No	No	No	Partial	No	No	No	No	Yes
REPCON	No	No	No	No	No	Partial	No	No	No	No	No
WFLLC	No	No	No	No	No	No	No	No	No	No	No
Seahealth	No	No	No	No	No	Partial	No	No	No	No	Yes
MARS	No	No	No	No	No	No	No	No	No	No	Yes
Insjo	No	No	No	No	No	Partial	No	No	No	No	Yes
UPLOADS	No	No	No	No	No	No	No	No	No	No	No
NID	No	No	No	No	No	No	No	No	No	No	No

None of the reporting systems fully met all the 22 criteria. None of the reporting systems collect data on protective factors. All but one system is able to fulfil multiple evaluation criteria. The highest number of criteria met by a system was 9 (MERS-TM), the lowest was 0 (WFFLC) with a median number of met criteria of 5. The details of each criterion are listed next, with examples for each ‘yes’ and ‘partial’ rating.

Criterion 1 – Causation (C) and 1 – Protection (P): System gathers information on decisions or actions from actors across the overall sociotechnical system. This includes those decision or actions which create the potential accident trajectory and those which create the protective trajectory.

One reporting system fully met this criterion for causation factors, as the contributing factor categories allowed for the identification of actors and/or decisions at all levels of the RRMF (UPLOADS). Seven systems partially met this criterion as the contributing factor categories allowed for the identification of actors and/or decisions at the staff and management levels (MERS-TM, UTCCRS, NFFNMRS, CIRAS, LEONM, EVENT, Insjo).

Criterion 2C and 2P: System gathers information on multiple contributing factors, rather than only on a root or primary cause. This includes those factors which create the potential accident trajectory and those which create the protective trajectory

Eight reporting systems fully met this criterion for the ability to select multiple contributing factors for causation. One reporting system fully met this criterion by allowing reporters to identify multiple contributing factors throughout the RRMF (UPLOADS). Five systems fully met this criterion by allowing reporters to identify multiple contributing factors at the work, staff, and management levels (MERS-TM, UTCCRS, NFFNMRS, LEONM, EVENT). Two systems fully met this criterion by allowing reporters to identify multiple contributing factors at the work and staff levels (DANMP, NID).

Criterion 3C and C3P: System gathers information on relationships between contributing factors. This includes those relationships contributing to the potential accident trajectory and those which contribute to the protective trajectory.

Two reporting systems fully met this criterion for causation factors. One reporting system (UPLOADS) fully met this criterion by allowing reporters to identify relationships between contributing factors across the RRMF. One system (MERS-TM) fully met this criterion by allowing reporters to identify relationships between contributing factors at the work, staff, and management levels.

Criterion 4C and 4P: One of the purposes of the system is to monitor vertical integration across levels of the sociotechnical system. This includes vertical integration mismatches which contribute to the potential accident trajectory and vertical integration matches which contribute to the protective trajectory.

None of the reporting systems met this criterion for either causation or protection.

Criterion 5C and 5P: System gathers information on communication (e.g. contributing factor categories enable the capture of information about communication both across and within levels of the system). This includes contributing factor categories of both effective and ineffective communication which contribute to the potential accident trajectory and those which contribute to the protective trajectory.

Eight reporting systems fully met this criterion for causation factors. One reporting system (UPLOADS) fully met this criterion, with contributing factor categories reflecting communication throughout the RRMF. Five systems fully met this criterion, with contributing factor categories reflecting communication at the work, staff, and management levels (UTCCRS, NFFNMRS, CIRAS, LEONM, EVENT). Two systems fully met this criterion, with narrative prompts reflecting communication (CHIRP, CHIRP-MEMS).

Criterion 6C and 6P: One of the purposes of the system is to monitor the migration of the work system towards the safety boundary. This includes system migration leading to a potential accident trajectory and system migration leading to a protective trajectory.

None of the reporting systems fully met this criterion for either causation or protection. Two systems (ASRS, LEONM) partially met this criterion for protection through having prevention of accidents in their purpose. Seven systems (CHIRP, CHIRP-MEMS, C3RS, PSRS, REPCON, Seahealth, Insjo) partially met this criterion for protection, through including the enhancement of safety or safety awareness as part of the purpose of the system.

Criterion 7C and 7P: System includes specific fields relating information on the influence of external and internal pressures for increased safety, cost effectiveness, and work efficiency on the work system (e.g. why are current work practices considered normal).

None of the reporting systems met this criterion for either causation or protection.

Criterion 8C and 8P: One of the purposes of the system is to monitor the migration of work practices (i.e. the behaviour of individuals throughout the sociotechnical system). This includes migration at all levels of the system, not just the system or organization as a whole.

None of the reporting systems met this criterion for either causation or protection.

Criterion 9C and 9P: System includes specific fields on migration of work practices (e.g. contributing factor categories capture information on influences to work practices).

Thirteen reporting systems fully met this criterion for causation. One reporting system (UPLOADS) fully met this criterion by including contributing factor categories related to work practice migration (e.g. time pressure, financial constraints, funding and budgets) for actors throughout the RRMF. Three systems (MERS-TM, CIRAS, LEONM) fully met this criterion by including contributing factor categories related to work practice migration (e.g. management priorities, policy, culture) for actors at the management, staff, and work levels. Nine systems fully met this criterion by including contributing factor categories related to work practice migration (e.g. workload, fatigue, task allocation) for actors at the staff and work levels (CHIRP, CHIRP-MEMS, DANMP, UTCCRS, NFFNMRS, EVENT, MARS, Insjo, NID).

Criterion 10C and 10P: One of the purposes of the system is to monitor changes in the effectiveness of defences.

Six of the reporting systems partially met this criterion for causation. One reporting system (MERS-TM) partially met this criterion through a narrative prompt on the barriers breached by the incident. Three systems (SECURITAS, ASRS, C3RS) partially met the criterion by identifying unsafe acts or conditions is part of the systems' reporting criteria/definition. Two systems (UTCCRS, UPLOADS) partially met the criterion through the identification of errors indicated in the purpose or reporting criteria/definition.

Criterion 11C: System gathers information on where, why, and how the potential accident trajectory was initiated (i.e. triggering events).

Eleven reporting systems fully met this criterion for causation factors, through narrative prompts for information regarding how an incident was initiated (ASRS, SECURITAS, MERS-TM, UTCCRS, C3RS, LEONM, PSRS, MARS, Insjo, UPLOADS, NID).

Criterion 12P: System gathers information on where, why, and how the incident was prevented from becoming an accident (i.e. identifying and evaluating potential accident trajectories and protective trajectories).

Nine reporting systems fully met this criterion for prevention factors. Two reporting systems fully met this criterion through including narrative prompts or contributing factor categories to gather information on both how the incident was prevented and on how to prevent a future occurrence (Insjo, EVENT). Seven reporting systems fully met this criterion through including narrative prompts for information regarding how the incident was prevented (ASRS, SECURITAS, MERS-TM, C3RS, PSRS, MARS, Seahealth). Three reporting system partially met this criterion through including narrative prompts on possible future avoidance strategies (DANMP, UTCCRS, NFFNMRS).

Discussion

The aim of this review was to define the required characteristics of near miss reporting systems from a systems perspective and evaluate whether current systems capture this type of information about near miss incidents. To achieve this, Rasmussen's seven tenets of accident causation were extended to describe the factors contributing to potential accident trajectories and protective trajectories. Criteria were then derived to evaluate industry-wide near miss reporting systems.

The reviewed reporting systems fulfil a limited number of criteria, with no system meeting more than 9 of the 22 derived criteria. Additionally, only one system (UPLOADS) is able to identify contributing factors at all levels of the RRMF; it was the only system which explicitly identifies factors beyond the management level. These results indicate that the reviewed systems are not capturing the type of information that is needed to understand near misses from a systems perspective. One caveat to this conclusion is that all systems ask for a narrative description of incidents. Therefore, it is possible that qualitative information is collected regarding all the systems thinking-based characteristics of near misses.

In order to determine the extent to which the reviewed systems may capture information on all the systems thinking-based characteristics, the results are discussed in the context of the principles of a systems approach discussed earlier. First, only two reviewed systems (UPLOADS, MERS-TM) are able to address interactions by specifically collecting information about relationships between contributing factors across the system. UPLOADS allows reporters to connect any two contributing factors across the system. MERS-TM uses a causal fault tree diagram to describe a linear flow of error propagation. As the emergence of properties such as safety are the outcome of interactions throughout the system (Dekker, Cilliers, and Hofmeyr 2011; Leveson 2011), this result indicates that the capacity of current near miss reporting systems to identify emergence is broadly lacking and signifies a large gap in the ability of these systems to collect data on the relational factors leading to potential accident trajectories and protective trajectories. As emergence is one of the fundamental concepts of accident causation in sociotechnical systems (Leveson 2004; Rasmussen 1997), this research-practice gap highlights how near miss reporting systems have not yet fully engaged with the systems approach.

Second, eight of the reviewed systems may be able to address non-linearity by allowing reporters to identify multiple contributing factors within their applicable levels of the RRMF. However, only one (UPLOADS) is explicitly underpinned by a systems approach. The others are underpinned by linear accident causation models; this effects the reporting systems' capacity to provide information on the effects of contributing factors on the system as a whole (Dekker 2012; Lundberg, Rollenhagen, and Hollnagel 2009; Leveson 2011). These linear based systems collect information at the most proximal levels (e.g. management, staff, and work). As it has been argued that addressing contributing factors at higher systems levels is important to understanding incidents in sociotechnical systems (Johnson and de Almeida 2008; Cassano-Piche, Vicente, and Jamieson 2009b; Salmon et al. 2017; Newnam and Goode 2015b), this suggests that near miss reporting systems may have limited capacity to capture information on systemic causes of near misses in sociotechnical systems.

Third, none of the reviewed system are able to fully address normal work variability, through identifying system migration, internal and external pressures defining normal work, or monitoring work practices as purposes of the system. Accidents are frequently the effect of systemic migration of behaviours due to internal and external pressures (Rasmussen and Svedung 2000; Dekker 2012; Hollnagel 2009; Leveson 2004; Rasmussen 1997). Consequently, while several systems capture information through contributing factor categories regarding influence on work practices, these categories are focussed primarily on the 'sharp end' of work processes (e.g. worker fatigue) in all but one system (UPLOADS) and do not address the systemic factors driving migration. These results indicate that a fundamental construct of the systems approach is not yet being fully applied in the study of near miss incidents and represents a significant gap in the capacity for these systems.

Finally, in relation the near misses as successful outcomes, twelve of the reviewed systems collect information on how the accident was prevented. However, no system collects information on factors which led to the successful outcome (i.e. what went right) or address normal work, vertical integration, or system migration. Although error recovery has been identified as an important component of near misses (Kessels-Habraken et al. 2010; Kanse et al. 2005; Battles et al. 1998) and it has been argued that it is more productive to focus on strategies for recovery than study error (Rasmussen and Svedung 2000), no system directly addresses protective factors.

Overall, the results of the review indicate that near miss reporting systems capture the appropriate information to understand how decisions, actors, and factors at the work, staff, and management levels underlie near misses. However, the purpose of near miss reporting systems is not currently aligned to the characteristics of systems thinking and the reviewed systems do not collect information on the factors which lead to protective trajectories. Similar to results from Lundberg, Rollenhagen, and Hollnagel (2009) regarding accident investigations, the majority of near miss reporting systems appear to be limited by their underpinning accident causation models. As systems approaches are increasingly understood as the most appropriate for the study of accidents (Salmon, Cornelissen, and Trotter 2012; Reason 1990; Stanton, Rafferty, and Blane 2012), the lack of near miss reporting systems capacity to identify systemic contributing factors is a potentially significant research-practice gap in their ability to capture information on near misses with contributing factors beyond the management level.

Implications and research agenda

The implications for near miss reporting system design are clear from the review. A system that fully incorporates all the tenets of systems thinking does not currently exist. This means that the current understanding of accident causation is not being applied to the study of near misses within industry. This represents a significant research-practice gap. In turn, it is questionable whether organizations are currently extracting appropriate lessons from near miss incidents. Given that they provide such rich data this represents a significant missed opportunity.

A research agenda designed to bring near miss reporting systems in line with the systems approach must address both near miss reporting systems specifically and the role for these reporting systems within the context of a broader organizational approach to safety. To address the latter, it would be valuable to evaluate the whole of industrial safety management systems (SMS) from a systems perspective; within which near miss reporting systems are one of several aspects. To address the former, an agenda for near miss reporting systems in line with the systems approach, several questions must be addressed.

In looking at near miss reporting systems specifically; first, what does a systems-based theoretical approach to near misses look like? Second, how should near miss reporting systems capture information which describes near misses from a systems perspective? Third, what is an appropriate analysis method for learning from near misses? Finally, how can this perspective to near misses be implemented in near miss reporting systems?

In order to address the first issue, further validation of the proposed characteristics of near misses is needed. This should include the evaluation of existing near miss reporting system datasets to identify to what extent these characteristics appear in reporter narratives. If the proposed characteristics of near misses are validated, an associated issue with existing near miss reporting systems is their underlying purpose and reporting criteria. No reviewed reporting system seeks to understand the issues of system migration, migration of work practices, or influences. Addressing this research-practice gap is a significant challenge (Underwood and Waterson 2013) and requires engagement with and understanding of the issues faced by practitioners. This should include outreach and education to potential user groups as well as practitioner feedback.

The next category of issues relates to the development and implementation of applying a systems approach to the reporting and analysis of near misses. Data collection tools must support the capture of information which meets the proposed characteristics of near misses. Once appropriate data is collected, a method of analysis must be available to practitioners in drawing out lessons from the data and informing prevention efforts across the sociotechnical system. There is a well-known research-practice gap in the use of systems methods (Underwood and Waterson 2013; Read, Salmon, and Lenné 2013; Salmon, Cornelissen, and Trotter 2012). To address this, practitioners should be included throughout the stages of developing a near miss reporting system underpinned by the systems approach. Finally, the identification and analysis of systemic factors should drive the development of countermeasures and prevention strategies throughout the sociotechnical system (Goode et al. 2016). These countermeasures should address both increasing the number of ‘what went right’ events as well as decreasing the number of ‘what went wrong’ events.

Limitations

This review does have some limitations. Only near miss reporting systems with publicly available resources were reviewed; therefore, there are likely to be other industry-wide incident reporting systems that were not reviewed. In addition, only publicly available resources were reviewed, internal resources to the reporting systems were not accessed.

Conclusion

This paper extends Rasmussen's seven tenets of accident causation to include near misses and reviews existing near miss reporting systems against derived evaluation criteria to determine the extent to which near miss reporting systems align with the systems approach. Based on the review, it is concluded that near miss reporting systems are not yet fully engaged with systems thinking as it applies to near misses in complex sociotechnical systems. While these systems clearly provide an important resource for industry, their power to understand emergence and system migration is limited.

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Table 1: Extension of Rasmussen's Seven Predictions of accident causation applied to near misses and evaluation criteria (Cassano-Piche, Vicente, and Jamieson 2009b; Vicente and Christoffersen 2006)

	Prediction applied to accident causation	Prediction applied to near miss	Criteria derived from prediction for a near miss reporting system
1	Safety is an emergent property of a complex sociotechnical system. It is impacted by the decisions of all of the actors-politicians, managers, safety officers, and work planners-not just the front-line workers alone.	Near misses are emergent in complex sociotechnical systems. The potential accident trajectory results from decisions and actors throughout the system. Similarly, protective trajectories result from decisions and actor throughout the system.	[1] System gathers information on decisions or actions from actors across the overall sociotechnical system. This includes those decision or actions which create the potential accident trajectory and those which create the protective trajectory.
2	Threats to safety or accidents are usually caused by multiple contributing factors, not just a single catastrophic decision or action.	Potential accident trajectories are usually caused by multiple, interacting contributing factors. Similarly, the protective trajectories are usually caused by multiple, interacting contributing factors.	[2] System gathers information on multiple contributing factors, rather than only on a root or primary cause. This includes those factors which create the potential accident trajectory and those which create the protective trajectory. [3] System gathers information on relationships between contributing factors. This includes those relationships contributing to the potential accident trajectory and those which contribute to the protective trajectory.
3	Threats to safety or accidents can result from a lack of vertical integration (i.e. mismatches) across levels of a complex sociotechnical system, not just from deficiencies at just one level.	Potential accident trajectories can result from a lack of vertical integration across levels of a sociotechnical system, rather than from one level alone. Protective trajectories can result from vertical	[4] One of the purposes of the system is to monitor vertical integration across levels of the sociotechnical system. This includes vertical integration mismatches which contribute to the potential accident

		integration (i.e. matches) across levels of a sociotechnical system, not just from decisions at just one level.	trajectory and vertical integration matches which contribute to the protective trajectory.
4	The lack of vertical integration is caused, in part, by a lack of feedback across levels of a complex sociotechnical system. Actors at each level cannot see how their decisions interact with those made at other levels, so the threats to safety are far from obvious before an accident.	Potential accident trajectories are caused, in part, by a lack of feedback across levels of a sociotechnical system where actors cannot see how their decisions interact with those made at other levels. Protective trajectories are supported by feedback across levels of a sociotechnical system. Controls (propagated downwards) and feedback (propagated upwards) allow actors to see how their decisions interact with those made at other levels.	[5] System gathers information on communication (e.g. contributing factor categories enable the capture of information about communication both across and within levels of the system). This includes contributing factor categories of both effective and ineffective communication which contribute to the potential accident trajectory and those which contribute to the protective trajectory.
5	Work practices in a complex sociotechnical system are not static. They will migrate over time under the influence of a cost gradient driven by financial pressures in an aggressive competitive environment and under the influence of an effort gradient driven by the psychological pressure to follow the path of least resistance.	Practices leading to potential accident trajectories in sociotechnical systems are not static. They migrate over time under the influence of cost gradient driven by financial pressures in an aggressive competitive environment and under the influence of an effort gradient driven by the psychological pressure to follow the path of least resistance. Practices leading to protective trajectories are not static. They migrate over time under the influence of a safety gradient	[6] One of the purposes of the system is to monitor the migration of the work system towards the safety boundary. This includes system migration leading to a potential accident trajectory and system migration leading to a protective trajectory. [7] System includes specific fields relating information on the influence of external and internal pressures for increased safety, cost effectiveness, and work efficiency on the work system (e.g. why are current work practices considered normal).

		driven by social pressures and individual psychological pressures to do no harm.	
6	The migration of work practices can occur at multiple levels of a complex sociotechnical system, not just one level alone.	The migration of work practices leading to both potential accident trajectories and protective trajectories occur at multiple levels of a complex sociotechnical system, not just at one level alone.	[8] One of the purposes of the system is to monitor the migration of work practices (i.e. the behaviour of individuals throughout the sociotechnical system). This includes migration at all levels of the system, not just the system or organization as a whole. [9] System includes specific fields on migration of work practices (e.g. contributing factor categories capture information on influences to work practices).
7	Migration of work practices can cause the systems' defences to degrade and erode gradually over time, not all at once. Accidents are released by a combination of this systematically-induced migration in work practices and a triggering event, not just by an unusual action or an entirely new, one-time threat to safety.	Migration of work practices can result in the degradation of defences over time. Similarly, migration can result in the introduction of new defences over time. Potential accident trajectories are released by a combination of systematically-induced migration and a triggering event. Protective trajectories are released by identifying and evaluating potential accident trajectories and triggering protective factors.	[10] One of the purposes of the system is to monitor changes in the effectiveness of defences. [11] System gathers information on where, why, and how the potential accident trajectory was initiated (i.e. triggering events). [12] System gathers information on where, why, and how the incident was prevented from becoming an accident (i.e. identifying and evaluating potential accident trajectories and protective trajectories)

Table 2: Example of Rasmussen's Seven Predictions of accident causation and near misses

Tenet	Causation factors of the potential accident trajectory	Protection factors of the protective trajectory
1	• Adjustment to airspace under Basel Mulhouse control • Instructor controller decision to turn on unreliable radar • Instructor controller physical position • Trainee controller speech error	• Ascending pilot response to TCAS • Descending pilot response to TCAS • Instructor controller response to loss of separation
2	• Unreliable radar • Thunderstorm Cells • Trainee Controller (i.e. speech error, workload, untrained-for situation) • Instructor Controller actions (i.e. physical location making continuous direct supervision impossible and reactivating the unreliable radar) • Conventional Procedural Control	• TCAS alerts • STCA alerts • Instructor controller identified loss of separation and alerted trainee controller • Ascending flight crew actions • Descending flight crew actions
3	• Communication error between trainee controller and ascending aircraft • Initial airspace change safety paper did not identify radar capacity in risk assessment	• Radar issue communicated to all flight crews using airspace • Crew communication management between pilots and co-pilots
4	• Trainee controller lack of attention to read back on request for ascending aircraft to FL110 • Trainee controller use of unreliable radar after it was reactivated • Unclear procedure for horizontal separation in procedural control situation	• TCAS and STCA systems provided feedback to flight crews initiating recovery actions
5	• Increase in workload due to change in air space to be managed created a mismatch between the radar system and the characteristics of traffic involved • Time pressure on equipment replacement due to the delay in identifying the issue with radar capacity	• Safety study completed for transfer of air space by regulatory bodies

6	• Lack of radar requiring use of procedural controls • First cycle of shifts where instructor and trainee controllers using procedural control at airport	• TCAS procedures applied in simulator training for both pilots • Radar failure experienced in simulation training for both Trainee and instructor controller
7	• The planned defence of reliable radar was lost	• Descending pilots' previous experience at airport informed potential for loss of separation prior to TCAS

Table 3: Evaluation criteria definitions for near miss reporting systems

	Criteria derived from prediction for a near miss reporting system	Criteria for a 'Yes' Rating	Criteria for a 'Partial' Rating	Criteria for a 'No' Rating
1	[1] System gathers information on decisions or actions from actors across the overall sociotechnical system. This includes those decisions or actions which create the potential accident trajectory and those which create the protective trajectory.	[1] The reporting system contributing factor categories allow for the identification of decisions or actions at all six levels of RRMF	[1] The reporting system contributing factor categories allow for the identification of decisions or actions as 2-5 levels of the RRMF	[1] The reporting system lacks contributing factor categories or allow categories at 1 level of the RRMF
2	[2] System gathers information on multiple contributing factors, rather than only on a root or primary cause. This includes those factors which create the potential accident trajectory and those which create the protective trajectory. [3] System gathers information on relationships between contributing factors. This includes those relationships contributing to the potential accident trajectory and those which contribute to the protective trajectory.	[2] The reporting system allows for the selection of multiple contributing factor categories [3] The reporting system allows for relationships to be identified between contributing factors at all six levels of RRMF	[2] Not Applicable to this criterion [3] The reporting system allows for relationships to be identified between contributing factors at 1-5 levels of RRMF	[2] The reporting system does not allow for the selection of multiple contributing factor categories [3] The reporting system does not allow for relationships to be identified between contributing factors
3	[4] One of the purposes of the system is to monitor vertical integration across levels of the sociotechnical system. This includes vertical integration mismatches which contribute to the potential accident trajectory and vertical integration matches which contribute to the protective trajectory.	[4] The purpose of the near miss reporting system includes the identification of vertical integration (i.e. matches or mismatches) between levels of the RRMF	[4] Not Applicable to this criterion	[4] The purpose of the near miss reporting system does not include the identification of vertical integration (i.e. matches or mismatches) between levels of the RRMF

4	[5] System gathers information on communication (e.g. contributing factor categories enable the capture of information about communication both across and within levels of the system). This includes contributing factor categories of both effective and ineffective communication which contribute to the potential accident trajectory and those which contribute to the protective trajectory.	[5] The reporting system contributing factor categories include categories regarding communication	[5] Not Applicable to this criterion	[5] The reporting system contributing factor categories does not include categories regarding communication
5	[6] One of the purposes of the system is to monitor the migration of the work system towards the safety boundary. This includes system migration leading to a potential accident trajectory and system migration leading to a protective trajectory. [7] System includes specific fields relating information on the influence of external and internal pressures for increased safety, cost effectiveness, and work efficiency on the work system (e.g. why are current work practices considered normal).	[6] The purpose of the near miss reporting system specifically includes the monitoring of system migration [7] The reporting system contributing factor categories include categories regarding external and internal pressures at all six levels of RRMF	[6] The purpose of the near miss reporting system includes an aspect of the monitoring of system migration [7] The reporting system contributing factor categories include categories regarding external and internal pressures at 1-5 levels of RRMF	[6] The purpose of the near miss reporting system does not include the monitoring of system migration [7] The reporting system contributing factor categories does not include categories regarding external and internal pressures
6	[8] One of the purposes of the system is to monitor the migration of work practices (i.e. the behaviour of individuals throughout the sociotechnical system). This includes migration	[8] The purpose of the near miss reporting system specifically includes the monitoring of work	[8] The purpose of the near miss reporting system specifically	[8] The purpose of the near miss reporting system does not include the monitoring of work practices

	at all levels of the system, not just the system or organization as a whole. [9] System includes specific fields on migration of work practices (e.g. contributing factor categories capture information on influences to work practices).	practices at all six levels of the RRMF [9] The reporting system contributing factor categories include categories regarding influences to work practice	includes the monitoring of work practices at 1-5 levels of the RRMF [9] Not Applicable to this criterion	 [9] The reporting system contributing factor categories does not include categories regarding influences to work practice
7	[10] One of the purposes of the system is to monitor changes in the effectiveness of defences. [11] System gathers information on where, why, and how the potential accident trajectory was initiated (i.e. triggering events). [12] System gathers information on where, why, and how the incident was prevented from becoming an accident (i.e. identifying and evaluating potential accident trajectories and protective trajectories)	[10] The purpose of the near miss reporting system specifically includes the monitoring the effectiveness of defences [11] The reporting system captures information on how the incident was initiated [12] The reporting system captures information on how the near miss prevented an accident	[10] The reporting criteria, definition, or contributing factors of the near miss reporting system identify defences [11] Not Applicable to this criterion [12] The reporting system captures information of the prevention of a similar near miss in the future	[10] The near miss reporting system does not capture information on the effectiveness of defences [11] The reporting system does not capture information on how the incident was initiated [12] The reporting system does not capture information on how near miss prevented an accident

Table 4: Near miss reporting systems identified by the review

System Name	Domain / Year of Origin	Associated Papers / Grey Literature Sources
Aviation Safety Reporting System (ASRS)	Aviation (US) / 1975	ASRS (2017)
Transport Safety Board of Canada (SERCURITAS)	Marine, Pipeline, Rail, Air (Canada) / 1989 (year of CTAISBA)	SECURITAS (2017)
UK Confidential Human Factors Incident Reporting Programme (CHIRP)	Air (UK) / 1982	CHIRP (2017)
UK Confidential Hazardous Incident Reporting Programme – Maritime (CHIRP-MEMS)	Maritime (UK) / 2003	CHIRP-MEMS (2007)
Dispensing Accurately and Near Miss Program (DANMP)	Pharmacy / 2000	Dooley, Streater, and Wilks (2001)
MERS-TM	Medical – Transfusion Medicine (US) / 1998	Battles et al. (1998); Kaplan (2005); Battles and Shea (2001)
University of Texas Close Call Reporting System (UTCCRS)	Health Care (US) / 2002	Simmons et al. (2008); Martin et al. (2005)
National Fire Fighter Near Miss Reporting System (NFFNMRS)	Firefighting (USA) / 2005	Taylor et al. (2015); Taylor and Lacovara (2015); Taylor et al. (2014); Tippett Jr (2007); NFFNMRS (2017)

Confidential Close Call Reporting System (C3RS)	Rail (USA) / 2007	C3RS (2017)
Confidential Incident Reporting and Analysis System (CIRAS)	Rail and Road (UK) / 1996	Wright (2000); CIRAS (2017)
LEO Near Miss (LEONM)	Law Enforcement (USA) / 2013	LEONM (2017)
EMS Voluntary Event Notification Tool (EVENT)	Emergency Services (USA) / 2010	Gallagher and Kupas (2011); EVENT (2017)
Patient Safety Reporting System (PSRS)	Patient Safety (USA) / 2010 (in development)	PSRS (2017)
REPCON - Australian Transportation Safety Bureau (ATSB)	Air, Rail, Marine (Australia) / 2013	REPCON (2017)
Wildland Fire Lessons Learned Center (WFLLC)	Fire and Rescue (USA) / 2012	WFLLC (2017)
Seahealth	Maritime (Denmark) / 2013	Seahealth (2017)
Mariners' Alerting and Reporting Scheme (MARS)	Marine (UK) / 1992	MARS (2017)
Insjo	Marine (Sweden) / 2001	Mazaheri et al. (2015); Insjo (2017)
Understanding and Preventing Led Outdoor Accidents Data System (UPLOADS)	Outdoor Activity (Australia) / 2011	Goode et al. (2015b); Salmon et al. (2017); UPLOADS (2017)

National Incident Database (NID)	Outdoor Activity (New Zealand) / 2005	Goode et al. (2015a); Salmon, Goode, Lenné, et al. (2014); NID (2017)

Table 5: Summary of evaluation results - Causation

	Evaluation Criteria related to Causation (see Table 1 for details of criteria)										
System	**1C – Actors and Factors across systems**	**2C – Multiple factors**	**3C – Relations between factors**	**4C – Vertical Integration in purpose**	**5C – Communication factors**	**6C – System Migration in purpose**	**7C – Factors of normal work**	**8C – Work level migration in purpose**	**9C – Work migration factors**	**10C – Erosion of controls in purpose**	**11C – Triggering actions**
ASRS	No	No	No	No	No	Partial	No	No	No	Partial	Yes
SERCURITAS	No	No	No	No	No	No	No	No	No	Partial	Yes
CHIRP	No	No	No	No	Yes	No	No	No	Yes	No	No
CHIRP-MEMS	No	No	No	No	Yes	No	No	No	Yes	No	No
DANMP	No	Yes	No	No	No	No	No	No	Yes	No	No
MERS-TM	Partial	Yes	Yes	No	No	No	No	No	Yes	Partial	Yes
UTCCRS	Partial	Yes	No	No	Yes	No	No	No	Yes	Partial	Yes
NFFNMRS	Partial	Yes	No	No	Yes	No	No	No	Yes	No	No
C3RS	No	No	No	No	No	No	No	No	No	Partial	Yes
CIRAS	Partial	No	No	No	Yes	No	No	No	Yes	No	No
LEONM	Partial	Yes	No	No	Yes	Partial	No	No	Yes	No	Yes
EVENT	Partial	Yes	No	No	Yes	No	No	No	Yes	No	No
PSRS	No	No	No	No	No	No	No	No	No	No	Yes
REPCON	No	No	No	No	No	No	No	No	No	No	No
WFLLC	No	No	No	No	No	No	No	No	No	No	No
Seahealth	No	No	No	No	No	No	No	No	No	No	No
MARS	No	No	No	No	No	No	No	No	Yes	No	Yes
Insjo	Partial	No	No	No	No	No	No	No	Yes	No	Yes
UPLOADS	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	Partial	Yes
NID	No	Yes	No	No	No	No	No	No	Yes	No	Yes

Table 6: Summary of evaluation results - Protection

	Evaluation Criteria related to Protection (see Table 1 for details of criteria)										
System	**1P – Actors and Factors across system**	**2P – Multiple factors**	**3P – Relations between factors**	**4P – Vertical Integration in purpose**	**5P – Communication factors**	**6P – System Migration in purpose**	**7P – Influences on normal work**	**8P – Work level migration in purpose**	**9P – Work migration factors**	**10P – Erosion of controls in purpose**	**12P – Prevention actions**
ASRS	No	No	No	No	No	No	No	No	No	No	Yes
SERCURITAS	No	No	No	No	No	No	No	No	No	No	Yes
CHIRP	No	No	No	No	No	Partial	No	No	No	No	No
CHIRP-MEMS	No	No	No	No	No	Partial	No	No	No	No	No
DANMP	No	No	No	No	No	No	No	No	No	No	Partial
MERS-TM	No	No	No	No	No	No	No	No	No	No	Yes
UTCCRS	No	No	No	No	No	No	No	No	No	No	Partial
NFFNMRS	No	No	No	No	No	No	No	No	No	No	Partial
C3RS	No	No	No	No	No	Partial	No	No	No	No	Yes
CIRAS	No	No	No	No	No	No	No	No	No	No	No
LEONM	No	No	No	No	No	No	No	No	No	No	No
EVENT	No	No	No	No	No	No	No	No	No	No	Yes
PSRS	No	No	No	No	No	Partial	No	No	No	No	Yes
REPCON	No	No	No	No	No	Partial	No	No	No	No	No
WFLLC	No	No	No	No	No	No	No	No	No	No	No
Seahealth	No	No	No	No	No	Partial	No	No	No	No	Yes
MARS	No	No	No	No	No	No	No	No	No	No	Yes
Insjo	No	No	No	No	No	Partial	No	No	No	No	Yes
UPLOADS	No	No	No	No	No	No	No	No	No	No	No
NID	No	No	No	No	No	No	No	No	No	No	No