Reliability Engineering and System Safety 194 (2020) 106418

Contents lists available at ScienceDirect

Reliability Engineering and System Safety

journal homepage: www.elsevier.com/locate/ress

Review

Addressing human error when collecting failure cause information in the oil and gas industry: A review of ISO 14224:2016

Jon T. Selvik[a,*], Linda J. Bellamy[b]

[a] *University of Stavanger, Norway*
[b] *White Queen BV, The Netherlands*

ARTICLE INFO

Keywords:
Failure causes
Reliability
Human error
Data collection
Standardization
Quality

ABSTRACT

The international standard ISO 14224 provides key guidance on how to achieve quality information about equipment failures for decision-making in the oil and gas industry, including specific guidance on data collection concepts and how to record and categorize failure causes. The third edition, issued in September 2016, is still focusing mainly on equipment failures, but has a higher focus on human errors than previously. It provides a 'human error' definition, currently the only one in an ISO standard, and a link to several types of error used in failure cause classification. In this article, the authors study the value of this added focus on human errors by assessing the definition and effect on failure cause classification, discussing the benefits and challenges. It is concluded that the standard has provided a clear distinction between the terms 'error' and 'human error' while being consistent in the use of the term 'error'. However, it gives limited guidance on how to separate and collect different types of human error, such as mistakes, slips and lapses, making this largely an interpretation issue. Nevertheless, applying ISO 14224 will provide data for learning about the role of human error in equipment failure on a sound expandable basis.

1. Introduction

1.1. Background

Information about reliability performance normally receives significant attention in design, operation and maintenance of equipment in the oil and gas industry, particularly for safety critical systems. To support decision-making in this industry it is common, and sometimes required, to collect and analyse information about the underlying (root) causes of failures that have occurred on similar systems in the past. Information about failure causes is considered to be a key to the modelling of how human and technological elements could threaten reliability performance and safety. As stated in the classic book, "*Learning from accidents*" [1], the underlying causes must be analysed in order to identify recommendations on how to prevent reoccurrence of the same or similar events. Recording reliability data offers a way to achieve structured information regarding the causes in a format suited to such analysis.

This article examines a main guidance document for how to achieve quality reliability data in the oil and gas industry, the international standard on data collection and exchange, ISO 14224 [2]. This standard, which was recently revised (third edition was issued in September 2016), provides guidance on how to record the failure causes of the equipment failures occurring in the industry. Naturally, the focus is on understanding the equipment behaviour in terms of reliability performance, but inherently there is also a relation to the human factor. Human errors could be seen as a subset of the failure causes (see [3]). This may seem like a very old story for those involved in risk assessment of hazardous systems (nuclear, oil and gas, chemical). However, this relationship is largely ignored in previous editions of the standard. Consequently, it has been difficult to establish a clear link between the ISO 14224 [2] failure causes and possible human errors identified from root cause analysis, RCA (see IEC 62740 [4]; see also 2.2). Finally, in the third edition a step is taken to bridge the equipment reliability performance with human factors.

The rationale is simple enough as there exists, for a variety of equipment, some relationship between technological and human performance (see e.g. [5]). To what extent the equipment reliability data collection is an appropriate arena to capture such relationships is not that simple as the data focus is strongly on equipment functionally. Nevertheless, an examination of how successful the attempt is to capture also the human contribution is missing in current literature. Refer to similar studies performed for e.g. air traffic management (ATM); with reference to 'human error in ATM taxonomy' (HERA); see [6].

---

[*] Corresponding author.
E-mail address: jon.t.selvik@uis.no (J.T. Selvik).

https://doi.org/10.1016/j.ress.2019.03.025
Received 11 September 2018; Received in revised form 22 January 2019; Accepted 7 March 2019

Refer also to a second 'HERA', i.e. the 'human event repository and analysis' system as a relevant database collecting human error data in the nuclear industry (see [7,8]). As both the ATM and nuclear HERA reports point out, there is a certain amount of stigma associated with employing the term "human error". Authors like Dekker [9] have served to reinforce the stigma, suggesting a "new view" on error that addresses the underlying contexts in which errors arise. The importance, and difficulty, of collecting context related information that influences human performance has in fact long been recognised as critical to data collection and is also emphasised in both HERAs. If it were a question of accountability, a different data framework would be required. Here the interest is in human performance data in relation to failure.

The inclusion of the definition of 'human error' in ISO 14224 [2] and the linking of this to different failure cause categories raises several unanswered questions. Firstly, on a conceptual basis how to understand 'human error' - what is the appropriate definition to use for this context?

The definition used in ISO 14224 [2] is as follows:

human error: "discrepancy between the human action taken or omitted and that intended".

Other definitions in [2] for related terms used in this article are:

error: "discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition"

failure (of an item):" loss of ability to perform as required"

failure cause, root cause: "set of circumstances that leads to failure"

failure mechanism: "process that leads to failure"

It is not obvious that the human error definition is in line with other reliability terminology. As the definitions provided by ISO 14224 are widely adopted in the industry, there is a need to clarify whether the 'human error' definition is consistent with the general understanding of the term 'error', and also whether it provides a consistent understanding when applied in a broader reliability engineering context. For example, how does the definition compare with the ones applied in root cause analysis (RCA) and in reliability modelling of safety systems? An objective of this article is to examine this.

Given the definition, there is also a question regarding how to build on this foundation, to add knowledge on how human performance influences equipment failures. This is basically a question of whether this attempt to link failure causes and human errors is adding value; is it appropriate in a standard focusing on equipment reliability performance? It is another important issue to examine, although some advocates of 'resilience engineering' perspectives might claim that it is of limited value to invest in any failure cause analysis and human error data (refer to the different perspectives outlined in Section 3.3).

The research question examined in this article is:

Is the current ISO framework for reliability data collection, exchange and analysis appropriate for capturing the information needed to achieve high quality human error data for use in decision-making in the oil and gas industry?

To examine this, a key is the strength of the human error foundations and how these relate to a better understanding of equipment performance. The findings of this examination are not only of interest for the quality of the standard and future revisions of the standard, regarding how to build on them and where to go next. It is also of interest for possible standardisation initiatives in the future, as well as already issued ones that may need adjustment, also outside the oil and gas industry. Besides, the findings are of high interest regarding how to use the ISO 14224 [2].

1.2. Structure of the article

The rest of the article is organised as follows. Before addressing the definition in ISO 14224 [2], Section 2 describes the framework for recording and analysing failure causes and human errors, including the role of RCA as a possible source. This section clarifies the general link between failure cause identification and the reliability data collection. Section 3 describes further the process of identifying human errors and different ways of expressing these. Section 4 addresses the ISO 14224 'human error' definition and its rationale by comparing it with use in RCA and reliability modelling, including cross-referencing to the ISO/TR 12489 [10] on reliability modelling. The section also provides a discussion of the relationship between 'human error' and the different types of 'error' used in the ISO 14224 standard. Section 5 then discusses the data achieved by adopting the proposed definition. The section addresses the effects of this increased attention on human errors, and discusses the general ability of the ISO 14224 [2] to capture human errors and the decision-making related to error management in general, where both the current data quality and alternatives for human error data collection and findings are discussed. Finally, Section 6 discusses the findings and Section 7 gives some concluding remarks and recommendations.

2. Framework for collecting failure cause and human error data

2.1. ISO 14224 and error data collection

The ISO 14224 is an international standard prepared by the working group *Reliability Engineering and Technology* (ISO TC67/WG4). It was first issued in 1999, was strongly influenced by experiences from e.g. the OREDA and WellMaster reliability data collection projects (see e.g. [11]), and has become a key document for reliability management within the oil and gas industry. For example, the Safety Authorities Norway (PSA) specify in the "Guidelines regarding the Management regulations" ([12]: Section VI) that the companies operating on the Norwegian Continental Shelf should use the ISO 14224 standard to achieve reliability and maintenance data for risk analyses in the health, working environment and safety area.

The standard specifies a standardised format for the reporting of reliability data associated with all equipment failures. As part of the guidance, it provides definitions of key terms, and specifies the classification of failure causes for use in data collection, regardless of equipment type or hierarchy level. In this third edition, compared with the second edition [13], definitions of 'human error' and 'human fatigue' are added. There are only small changes to the failure cause categories. The word 'error' is replaced with 'failure' as is more appropriate for the fabrication-related failure causes: fabrication and installation "failure". In the standard these two causes are not considered to be errors and are not linked to human errors.

An overall level of five 'failure cause' categories are listed, i.e. failure causes related to: design, fabrication, operations & maintenance, management, and also a miscellaneous category is specified, which includes the failure causes; 'combined cause' and 'common cause'. The standard also gives a further subdivision of each category, using different types of errors; for example, management error (refer to definition of 'error' in 4.1). Out of the subcategories, there are three specific ones that are linked to human error:

- Operating error (operation/maintenance-related)
- Maintenance error (operation/maintenance-related)
- Documentation error (management-related)

However, one could also imagine human contributions beyond the specified ones. For example, a failure could have been traced to a slip in the design of the equipment for particular operating conditions.

Obviously, at the time when the data collection is performed, there are the typical challenges that key information might be missing, the failure cause might not be known, and there could be significant costs associated with the acquisition of the information. Nevertheless, ISO 14224 [2] provides some guidance on which information must be acquired. This is a realistic approach compared to attempting to create some exhaustive list of context relevant factors.

2.2. The link to root cause analysis (RCA)

According the ISO 14224, RCA is to be performed for failures of high consequence, high repair or down time cost, or failures occurring significantly more frequently than what is considered “normal” for this equipment unit class (“worst actors”). As a key source, RCA is a natural starting point and part of the foundation for the process of reaching recommendations concerning reliability improvements and error management (see [4]). The principles of RCA have long been recognised in fields such as engineering, quality control and environmental management, as well as in safety management [14].

In the RCA, a broad analysis of the failure causes is performed, normally based on the information acquired from the failure investigation. The overall objective is to identify why the events have occurred by using the full spectrum of human, organisational and technological related failure causes. Every cause uncovered by RCA must be backed up by factual evidence and these conclusions derive from careful analysis of “what happened” and “why” [15, p.74]; see also [16].

The dependability standard IEC 60050-192 [17] defines RCA as a: “systematic process to identify the cause of a fault, failure or undesired event, so that it can be removed by design, process or procedure changes”. The key is to establish a complete picture of what occurred and why, in a timeline, as a basis for understanding how the failure event could have been prevented and whether there is a chance for this happening again or frequently. For example, to conclude that ‘human error’ (refer to definition used in the RCA context; see 3.2) is the main failure cause is in principle not sufficient. As Noland and Anderson [15 p.75] point out, the RCA should go beyond this by asking what exactly was the error committed and why it happened. To achieve the useful RCA information, Tomlinson [18] suggests that the RCA analysis is driven toward answering two main questions:

1) If the identified root causes are corrected, can this incident happen again?
2) Will the countermeasures developed to correct the root causes really correct them?

In the literature, RCA is sometimes labelled as human error identification, HEI. Stanton et al. [19] give an overview of different HEI methods (see also [20]). Often some logic tree structure is used to determine the relevant failure causes (see e.g. [21]). For example, a fishbone/Ishikawa diagram [22] could be used to illustrate the relationship between the different causes and the failure event (see e.g. [23, p. 26]).

RCA processes often identify human error as a main failure cause. Vinnem et al. [24] indicate that more than 50% of hydrocarbon leaks on offshore installations in the Norwegian sector are caused by human intervention. Studies of accidents and incidents in other sectors show that this is not special to the Norwegian sector. For example, a study of 67 offshore incidents occurring in the British sector in the period 2004 to 2008 linked to earlier studies (see [25]) indicates a significant fraction of failures associated with human error. According to a report for the British HSE (Health and Safety Executive) [26], post-2001 more than 60% of maintenance-related incidents were identified as human factors related. Similar numbers are also found in other and more recent studies. According to Boschee [27] and Aas [28], human error is identified as a root cause in the majority (between 60% and 80%) of industrial accidents and incidents. Kariuki and Lowe [29] provide even higher numbers; suggesting that over 80% of failures in the chemical and petro-chemical industries implicates human error (see also [30]). Based on this, results from analysis of human performance using root cause analysis should receive high attention (e.g. in the aftermath of major accidents). However, despite the acknowledgement that the human error contribution is usually significant and important to consider, many textbooks and publications on system reliability fail to give proper attention to human aspects and focus mainly on the equipment hardware failures, e.g. [31,32].

To make the picture somewhat even more complicated, the analysis in hindsight of major industrial accidents, such as e.g. Three Mile Island (1979), Challenger (1986), Macondo/Deepwater Horizon (2010), often explains the cause of failure as a combination of human and technical aspects. Due to the dependencies between these aspects, it may not be appropriate to point to one failure cause only. Such a combination could be revealed through the RCA. According to the IEC 62740 [4], RCA processes normally conclude with one of the following results:

(1) a single root cause (root cause is defined in [4] as a: “causal factor with no predecessor that is relevant for the purpose of analysis”; and where a casual factor is a: “condition, action, event or state that was necessary or contributed to the occurrence of the focus event” set of circumstances that leads to failure”), where elimination of this will prevent the failure event from occurring;
(2) multiple root causes in which the elimination of any cause will prevent the failure event from occurring;
(3) root causes which are contributory factors where elimination will change the likelihood of the failure event occurring but not directly prevent it. For example, poor monitoring design may influence maintenance activities such that frequent testing must be performed, which may indirectly be the cause of maintenance-induced failures.

The ISO 14224 [2], which plays a key role in the collection and use of the root cause information, does not distinguish between root cause and failure cause and regards these two terms as synonymous. Both are dealing with circumstances associated with design, manufacture, installation, use and maintenance. The two terms are defined in this standard as:

failure cause (root cause): “set of circumstances that leads to failure”.

The failure causes revealed from the RCA are key pieces of information to be captured by a systematic reliability data collection process (see [2]), as illustrated in Fig. 1. The data collection places the information in a data format that makes it applicable for decision-making purposes, such as e.g. technical system design, operations and maintenance planning, and also error management in general.

Furthermore, the ISO 14224 [2] points to the importance of recognizing the intended use of the collected reliability data. It clarifies the necessity of considering carefully that the data types are consistent with the intended purpose, such as e.g. for assessment of possible improvements based on the RCA process and identification of root causes. It describes typical data requirements, including different areas of application and types of analyses. RCA (with reference to the IEC 62740 [4]) is then one of the analysis types specified, and it is clarified that the framework described in ISO 14224 supports this specific type of analysis. In some situations, to achieve useful data, it may be required to perform a RCA analysis prior to the reliability data collection to further investigate the root causes. Normally, the possible human errors identified from a RCA/ human performance analysis are likely to be presented on a more detailed level than simply “human error.”

Refer to discussion in Section 5 in this article and ISO/TR 12489 [10] on reliability modelling for further details on the link between reliability data and analysis; see also e.g. Rausand and Høyland [32]. See also [33–35] for a review of human reliability assessment (HRA) methods.

In conclusion, root cause analysis is a systematic way of making the link between human error and the human error context. Context in this

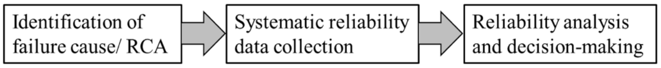

Fig. 1. Typical failure cause information flow in reliability informed decision-making.

sense is the "set of circumstances" referred to in the analysis.

3. Identification and interpretation of human error

3.1. Identification of the human errors

Focusing on the human errors, a root cause analysis (formal or informal) may identify a broad spectrum of failure causes associated with failure events. Different ways of analysing and classifying human errors exist, leading to problems in consistency, harmonization and validation [36,37]. The choice of classification may be industry specific or generic, external or internal reference in relation to the human (e.g. workplace or task related versus cognitive related) and based on different concepts of failure.

Classification frameworks for data collection and statistical analysis of incidents, such as HFACS – *Human factors analysis and classification scheme* [38,39] based on Reason's [3] human error concepts, where four or five levels are considered for the analysis of the human error: i.e. unsafe acts (level 1), preconditions for unsafe acts (level 2), supervision (level 3) and organizational influences (level 4); sometimes a fifth level 'legislation and government' is considered after the organizational influences. Another framework is the *Storybuilder* [40] based on a safety barrier and barrier management model. One aspect of the model is that it is used to collect data on human performed tasks related to the failure of specific safety barriers in accidents. The *Storybuilder* model is looking for patterns of causes within the system of safety barriers. The data collection structure is not necessarily the same as for other approaches to the quantification of human reliability (see e.g. [41,42], which are based on an analysis of critical tasks, identification of opportunities for error and calculation of the probability of error per opportunity. Nonetheless, the two frameworks are interrelated because human reliability assessment (HRA) methods require data sources for calibration and validation.

Another relevant technique for identification and evaluation of human errors is the *Systematic human error reduction and prediction approach* (SHERPA). The technique employs so-called hierarchical task analysis together with the error classification by covering a variety of errors in action, retrieval, checking, selection and communication [43]. See also [44,45].

Key features of the classification systems are the contexts in terms of factors affecting performance viewed from different sociotechnical system aspects – organisational processes and culture; management, resourcing and supervision; human factors and ergonomics of the workplace, task design, human performance; cognitive factors such as memory, attention and awareness.

A key reference to the human error classification is the IEC 62740, which frames the analysis of human performance. The starting point is the identification of the 'error mode'; i.e. the external manifestation of the error (what is observed to have, or not have, been done) such as actions omitted or wrong actions. The next step is categorization (classification) and analysis of the mechanisms and causes leading to the identified error modes. The 'error mechanism' is in this context understood as the process leading to the error, in line with the common interpretation of 'failure mechanism' being the apparent observed cause of the failure. For equipment this might be some material failure such as breakage, fatigue, or overheating, which may then be explained by the failure causes (the root causes). According to the IEC 62740 [4], the following could then be relevant for this analysis:

(a) The internal error mode and error mechanism. This is the reason behind the error in psychological meaningful terms e.g. for an error mode of 'took a wrong turn in car', the internal error mode and mechanism might be incorrect decision due to habit intrusion.
(b) Inherent problems of the task, e.g. conflicting goals, planning problems, constraints, cognitive demands etc.
(c) Performance shaping factors. These are the conditions of the technical or organizational environment or internal to a person which affect how well a task will be performed. See IEC 62508 [46].
(d) The flow of information and feedback without which correct judgements are unlikely to be made.

After the identification of the error modes, the mechanisms are generally clarified before starting the identification of the underlying reason for the mechanism and why the human error was made, using for example the two frameworks mentioned above. The IEC 62740 [4] refers also to the *Technique for retrospective and predictive analysis of cognitive errors* (TRACEr), described in Shorrock and Kirwan [47].

3.2. Interpretation of human error based on IEC 62740 and IEC 60,050-192

How should one deal then with all these different views of human error? Based on the incentives to record human error information revealed through RCA, the definition proposed in the IEC 62740 [4] offers a key. Human error is a generic term used to describe all those occasions where a planned sequence of mental or physical activities fails to achieve its intended outcome, and when these failures cannot be attributed to outside intervention [3]. Senders and Moray [48] in addition place a set of rules and the external environment into the equation, by stating that it is: "not intended by the actor; not desired by a set of rules or an external observer; or that led the task or system outside its acceptable limits". In both, 'intention' is a key to the understanding. Without intention, there could be no 'human error' – meaning implicitly that human error relates to skill, e.g. slips, and to knowledge dimensions, e.g. mistakes. There are several ways, which are dealt with later in this article, to define and understand this term, some of which also include the rule (requirement) dimension, as is also done in the RCA standard IEC 62740 [4]. This standard adopts the definition of 'human error' from the dependability standard IEC 60050-192 [17]:

human error: "discrepancy between the human action taken or omitted, and that intended or required".

By including the "or required" part, a human error could be in any situation where an operator is not following a given operational procedure. According to the definition, it does not matter what the person was trying to accomplish, i.e. the person's intent, which could be different from for example the required procedure. One example is violations, i.e. deliberately failing to comply with the procedure (see [49, p.288]). Hence, the 'human error' concept could include the activity of deliberately performing wrongly such that a failure occurs. Although this being clearly a human failure linked to human performance, deliberately breaking rules is according to Reason [50,51] not per se a 'human error'. Only those failures where individuals generate (through actions or decisions or omissions based on their individual skills, knowledge and reasoning) unintended results, should classify as 'human error' (see [3, p.207]) – the *Generic error modelling system* (GEMS), which is based on the following triplet:

- Skill-based failures (slips and lapses)–e.g. attentional failures (slips) or memory failures (lapses)
- Rule-based mistakes–either applying good rules incorrectly or applying a bad rule
- Knowledge-based mistakes–lack of relevant (incomplete/incorrect) knowledge

A main distinction between 'slips and lapses' and 'mistakes' categories, is that the former are execution type failures generated from intended actions that fail to achieve their intended result, whereas the latter are a type of planning failure which by character are more difficult to detect.

The discussion of whether violations are part of the 'human error' concept, relates also to what is the meaning of an 'error', which is dealt with further in 4.1.

A key to understanding the definition given in IEC 62740 [4] is the interpretation of the combination "intended or required". Basically, by covering both elements, the definition is saying that the result of the human action could be labelled as a human error in all situations where a human is involved in the mechanism of equipment failure; i.e. it is a matter of assessing whether based on the human contribution, if the failure could have been avoided. Any 'unsafe act', to use the terminology of Reason [3,51], then classifies as a 'human error'.

Such an interpretation, that is linking human performance closely to failure events, is strongly criticized by several, which regard the human contribution to failures more as an effect or symptom of deeper problems. For example, Dekker [52] labels this as the 'new way of thinking', where focus is rather on how the tools, tasks and working conditions influence human performance. The rationale is that this 'influence' is the key to the understanding and successful management of human performance. For example, a human error in relation to offshore oil and gas activities could be caused by stress, exhaustion or fatigue resulting in decreased speed in cognitive processing, causing an increase in reaction times, inattentiveness and lower vigilance (see [53]). Ideally, these influences would be identified through the RCA, and would then be more relevant than simply 'human error'.

3.3. *Different perspectives regarding the human contribution*

In the world of safety, Hollnagel [54] refers to the approach of focussing on (human) failure as the Safety I perspective, which he abandons in favour of Safety II. Safety II focusses instead on successful performance, a perspective which has mostly attracted attention in the health sector and in aviation. While Safety I focuses on causes, Safety II is focussed on resilience in handling variability and recovering from change that threatens or disrupts normal operation. Safety II invokes much disagreement that the human contribution should be labelled as a failure cause. Some argue that labelling the human contribution as a cause of failure is both naive and overly simplistic [39, p. 60]. Dekker [9] was already moving in this direction in what he called the "new view" on human error; people are just doing what makes sense to them at the time [52]. Nonetheless, having information about the occurrence of human "error" could be highly useful for the management of equipment reliability and safety in the oil and gas industry. People are part of safety critical systems. It is a reason why after critical failure events, and especially those with accident potentials, that it is important to identify the possible human contribution, and not to restrict attention to technical systems. However, the way in which we label this contribution is important.

Even if there is a dispute as to whether human beings "fail", equipment certainly does fail and sometimes the failure cause involves a human contribution. For example, a failure in calibration, using the wrong equipment part, making a typing error in a procedure can all be a contributing underlying cause to equipment failure [55,56]. When these types of occurrence are not recovered, they can remain latent in the system. Other types of contribution are "errors of judgement", which do not fall into the classical consideration of human error [57]. When human failures are recovered it is unlikely that their occurrence is recorded, for example if there is no incentive to report or for fear of blame. It is not clear to what extent the actual collection of data from equipment failures in the oil and gas industry captures this human part. Despite being acknowledged as important, it might be seen as far more convenient to ignore the human contribution and focus on the software and hardware systems. A similar conclusion is reached in Johnsen et al. [58], stating that although human factors (HF) has been accepted as a discipline in the Norwegian oil and gas industry, the importance of HF work has not been sufficiently prioritized in practice from safety authorities, management and engineering. Nonetheless the oil and gas industry does address this topic, such as on using human factors in risk assessment [20].

In HRA human error is defined as any member of a set of human actions or activities that exceeds some limit of acceptability, this being an out of tolerance action or failure to act where the limits of performance are defined by the system [41]. The human contribution seen from an engineering or risk assessment perspective is something that has an effect on the model parameters, and building in the human component requires quantitative data. For example, it might be an initiating event which puts a demand on a safety system, or a test interval for safety critical systems, or the possibility that testing or maintaining a safety critical system could introduce a human-induced failure besides the intended monitoring and repair functions.

Human errors might be recovered before they have any effect, which is a problem if one wants to quantify them, but not from a success perspective. Safety II proponents would say one needs to be looking more at these successes than at the failures. Recovery by humans is an important part of the reliable system but this has been given little attention in human reliability assessment [59]. Another issue of collecting data on human error is that some actions leading to failure are intentional and are referred to as violations. Violations occur where successful performance is intended by deliberately breaking the rules of the normative system of controls. In fact, some systems can only operate effectively through routine rule violation as has been reported to occur in aircraft maintenance for example [60]. The definition of human error in the ISO 14224 standard [2] (see Sections 1.1 and 4.1 in this article) does not include violations but in practice a violation may look like a human error when in fact it is not.

A further discussion on pros and cons of adopting Safety I versus Safety II is beyond the scope of this article (refer to Reason [50]).

4. Rationale for the human error definition used in ISO 14224

4.1. *The nexus between the terms 'error' and 'human error'*

For the definition of 'human error' to be appropriate, it should fit with the general concept of 'error'. In ISO 14224 [2], error is defined as a *"discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition"*.

Following the definition, by relating to what is the true, specified or correct value (or condition), the term is considered applicable for hardware, software and human errors. Consequently, when defining 'human error' from this perspective, it relates to a discrepancy. Reason [3] identifies a link between error and intention. The definition given in IEC 62508 [46] is consistent with this and is adopted in ISO 14224 [2] (see human error definition below).

There exist several definitions of 'error'. A systematic search through definitions given in published ISO standards using an online browsing platform (OBP) reveal that as many as 900 hits includes the key word 'error'. There are currently 45 ISO standards specifically defining the term 'error'. Of these, four use the definition given above. The term 'human error', on the other hand, ignoring the IEC standards for a moment (where definitions exist), is not to be found in any other ISO standard document. However, the term indirectly links to the associated term 'mistake', which has two existing definitions identified through the OBP:

(a) "human action or inaction that can produce an unintended result" (ISO/IEC 2382 [61]);
(b) "human action that produces an incorrect result" (ISO/IEC/IEEE 24765 [62]).

Both is about action leading to a 'wrong' result somehow, where a) also refers to the aspect of intention. The 'intention' is part of the framework set by the IEC 60050-192 [17], and makes the term 'human error' to be interpreted in the ISO 14224 [2] as a subset or special case of the term 'error'. It is defined as a "*discrepancy between the human action taken or omitted and that intended"*. This restricts the definition of human error entirely to the cognitive dimension.

This definition is compatible with the technical definition of 'error' given in [17] in the sense that it is a discrepancy. This is in line with the concept of error developed by Reason [3]. We refer also to discussion in Le Coze [63], where this relationship is discussed using the theories of Jens Rasmussen. If the intention is inappropriate it is a mistake. If the intention is appropriate but wrongly carried out or an action omitted it is a slip or lapse. This differs from what is termed a violation, which is an act where there is a conscious deviation from the rules or procedures and which therefore cannot be considered to be part of the error definition. Routine violations are regular occurrences that have become accepted or ignored by management, exceptional violations are atypical one-off occurrences such as in a crisis, and situational violations are induced by workplace conditions or task design encouraging violation of the rule or procedure such as when something is difficult to access or there is not enough time. To complete the human reliability picture, violations could be included but are incompatible in contexts that are intended to lead to success and may often do so e.g. a driver must edge forward through a red light to let an ambulance through. On the other hand, a driver may accelerate through a light that has just changed to red and collide with a driver at the crossroads who anticipates their light changing to green. The issue is thus also related to the outcome, success or failure. The violation could be identified as a root cause of failure but, by the 14224 definition, not as a 'human error'.

The human error definition in IEC 60050-192 [17] is virtually identical to that suggested in ISO 14224 [2] except that it says "…and that intended *or required*" (italics ours). Consequently, it is also slightly different from the definition provided by the IEC 62740 [4], which is adopting the exact same definition as in [17]. This IEC definition therefore does not solely require there to be a discrepancy with intention to define error and takes error outside the cognitive dimension by also including actions or inactions that do not meet requirements. One could also here consider what is meant by "required" in relation to human action. Is it only specified requirements or could it mean a more general reference to professional behaviour? It would also include violations, these being a discrepancy with formal requirements. The definition of human error in IEC 62508 [46] on human dependability is however the same as in [2] but also includes a separate definition of violation, including that it is deliberate, subsuming this and human error under 'human failure'. The types of human errors and violations that would fit this definition of human failure would be ones where there is "*a deviation from the human action required to achieve the objective, regardless of the cause of that deviation*" with a note that this is human errors and violations which lead to system failures or hazardous outcomes. ISO/TR 12489 [10] on reliability modelling only considers random failures. Violations would therefore be out of scope. In this respect excluding violations from ISO 14224 [2] would be consistent with this standard. The earlier ISO/TR 12489 [10] does however refer to rule violations when considering human performance and error in an informative annex on the human factor. Important aspects for further classifying error data which are referred to in [10] are:

(i) whether the task is a skill-based, rule-based, or a knowledge-based task as this affects the likelihood of failure.
(ii) the ease with which signals can be detected and recognized and the decision made to act upon them (hits, misses, correct rejections and false alarms) as this reflects the strength and quality of the information, the sensitivity of people to the signals and the decision criteria. For example, signal detection is an important aspect of inspection and can also be important in error recovery e.g. detecting a typing error in a document, detecting an error in maintenance.

Given the opportunity for an error or violation, performance shaping factors can influence the chance of making them, increasing or decreasing the probability of occurrence through such factors as the quality of procedures, level of competence, and ergonomics of the workplace and task design. Bellamy et al. [40], for example, define eight management "delivery systems" in the *Storybuilder* model which can influence task performance: Plans and procedures, competence, communication and collaboration, availability of sufficient people, ergonomics, motivation to work safely/risk awareness, resolution of conflicts (pressures to go beyond the safe boundary), and having the right equipment (tools, spare parts, personal protective equipment, etc.). According to Mosleh and Chang [64], it is important that models-based HRA methods have a core focusing on the cognitive causal link between behaviour and the measurable factors. Refer also to [65] for discussion on how to evaluate the effect of performance shaping factors on the human error probability.

4.2. Relationship to other 'error' types

Throughout the ISO 14224 [2] document, the term 'error' is used in several places, and always combined with other words, not only in the section specifying the possible failure causes. For example, software error is defined as erroneous result produced by the use of software product and is listed as a 'failure mechanism' (i.e. the process that leads to failure) rather than a 'failure cause'. The different 'error' concepts could be appearing on different levels in the failure reporting. There are examples of human errors seen as part of the failure mechanisms. Huang [66], as one example, addresses software fault defence based on prevention of so-called 'human error mechanisms' in the cognitive errors of software practitioners and by that not making any clear distinction between the circumstances or process leading to the failure. Another example is Pandya [67], who in a radiotherapy context use 'failure mechanism' (as the means by which a function may fail) to explain why the failure causes (termed 'proximate causes' of the task failure) occur, as is the opposite of the interpretation and hierarchy given in ISO 14224 [2] and IEC 62740 [4], where the 'failure cause' has no predecessor that is relevant for the RCA (identification of root cause).

Using combinations that include the word 'error', allows for more specificity on how these relate to hardware, software and human aspects. The combination 'human error' is, in the document, the far most frequent one.

Furthermore, by studying the overall distribution of 'error' use in [2], one finds that there is limited reference to error types other than human and those already mentioned in the table of failure causes [2, Table B.3]. Some few references are made to errors related to calibration, computing, design, and software, but these are sparse. In fact, several of the error types labelled with more specificity, i.e. not referred to as 'human error' in the 2006 edition, are in the 2016 edition changed to 'human'. The ISO 14224 [2] uses the term 'human error' a total of 28 times, whereas in the 2006 edition 'human error' was only used twice, indicating the higher attention now being given.

In the literature and in RCA processes in general, as mentioned in 2.2, it is common and clearly relevant to use a somewhat more detailed classification of the human errors. One of the subcategories frequently used, and one also used in the ISO 14224 [2], is 'mistake', which is retained from the 2006 version. Despite not being defined, 'mistake' is used in the standard to further clarify the meaning of 'operating error' and 'maintenance error'. Both error types are described as follows: "Human error: Mistake, misuse, negligence, oversights, etc. during operation (e.g. due to human fatigue)". For example during inspection or testing. There is no use of other human error or unsafe act subcategories such as 'lapses', 'slips', or 'violations' in the document.

4.3. Conclusions on the rationale

It should by now be clear that the term human error has been far from being a simple and clear-cut category for collecting and analysing human performance events in a system sensitive to failure because it depends on how it is defined. The term is made even more complex by its association but lesser role within a framework for collecting and analysing equipment failures. While the definition is now consistent in ISO 14224 [2] with the concept of error and is quite precise, data collection and analysis in practice is still left with the issue of identifying the context or set of circumstances. It restricts the definition to the cognitive aspect of human performance and does not restrict it to those occurrences solely resulting in failure, even if the interest is only in failure causes.

5. Appropriateness of the ISO 14224 framework

5.1. Challenges and opportunities

The appropriateness of the way human error is included in ISO 14224 [2] relates to the link between failure cause identification and the data collection illustrated in Fig. 1 (see 2.1). A main challenge discussed in this article is that it is difficult to see a clear link between the ISO 14224 failure causes and possible human errors identified from root cause analysis, RCA [4]. For example, rule violations could also be relevant to collect and analyse data on, but these cannot be regarded as error in the human error definition in [2]. It also may be difficult to break the failure causes down into the skills and knowledge dimensions identified by Reason [3] and Rasmussen [68] and which are used in ISO/TR 12489 [10] to frame human performance considerations in the context of reliability modelling.

The two guidance documents ISO 14224 [2] and ISO/TR 12489 [10], provide a link between the data collection and exchange on the one hand and the application in reliability modelling and assessments on the other. They allow for a common 'reliability language' and framework to be applied throughout the process illustrated in Fig. 1 (see 2.1). It is largely a matter of establishing a taxonomy that is applicable to and consistent throughout all the steps. Several studies, as pointed out in Di Pasquale et al. [69], underline that use of taxonomies to classify data is a potential solution to produce meaningful information from different types of source using the same framework. A similar discussion is provided in Lam et al. [70], in a medical context, where it is claimed that the lack of a common and relevant taxonomy for radiation treatment errors influences the ability to describe important characteristics of radiotherapy incidents.

The link to 'reliability analysis and decision-making' also provides some clarity regarding limitations of the data that is collected and considered for use. This accounts for what is not covered by the data collection. For example, the ISO 14224 [2] gives a clear description for each of the specified failure causes, which should increase the likelihood that the analyst in reliability assessments interprets the failure causes in the same way as the data collector. There is normally limited room for producing new failure cause data at the time of analysis as the building of reliability databases takes time. Besides, the change of taxonomy requires understanding of the cascading effects (e.g. influence on other data collection projects). Hence, the analyst's effort is typically focused on optimizing the use of the existing data.

Another challenge is the importance of understanding the data collection process. The selected format for data collection may not be open for multiple failure causes associated with the failure event studied. The data collector may thus have to choose between human and technical aspects. The ISO 14224 [2] gives sparse advice on how to deal with the situation of multiple failure causes, except from using a specific failure cause labelled 'combined causes' or selecting the dominant 'failure cause'. For example, when some data collector decides on what is the appropriate failure cause(s) of a failure event, there can be software restrictions allowing only one failure cause to be entered for each of the failure events. The structured reliability data collection is typically not able to capture the full picture identified through RCA processes. The failure cause registered for a given failure event is considered as the dominating failure cause in situations where there also could be multiple failure causes. It is thus likely that the reliability analyst fails to account for human errors ignored in the reliability data collection. Besides this there is the question as to what extent the data collector is capable of making an unbiased decision about which cause is the dominating one. Should the data collector in addition be placed in a situation where also the operator intent (related to a failure event) must be considered, the incentives and competency of the data collector is obviously challenged with respect to ensuring high data quality.

The ISO 14224 [2] indicates clearly which of the failure causes involve human error, but does not in general guide a further breakdown, as we have clarified. It is then a task for the analyst performing the reliability assessment to consider the link between the specified failure cause and the underlying types and levels. Although such underlying information about the failure causes may be desirable, and in some situations also available from a RCA process, it is usually not done. It is typically more practical and cost-efficient to only perform in depth analysis, such as RCA, for selected failure events of complex or safety-critical nature, as recommended by the ISO 14224 [2].

A problem is, if one intends to study the human errors in depth, e.g. in a HRA, then the classification specified in [2] is not sufficiently detailed to make clear inferences about the type of human error detailed in 3.2. The ISO/TR 12489 [10] specifies that human error is generally considered to be of three types, i.e.; (i) memory and attention lapses and action slips, (ii) mistakes in action planning, and (iii) rule violations. In addition, there are specified three performance levels that may be considered, i.e. skill-based, rule-based and knowledge-based. Although information about such types and levels might be attractive from a human error perspective, there are obvious consistency challenges when such information is collected for all failures, and might not be achievable using the ISO 14224 classification. For example, in recording the causes of a failure, one data collector could specify management, whereas another would rather prefer to specify an operator error (e.g. documentation error - some typing error). This means obviously that there could be some inconsistency between the data needs and the data collection on human error related failure causes. Considering the three steps in Fig. 1; both the first and last step is referring to subsets or classification of human error, but the middle step is not following this up.

Furthermore, the classification suggested from the RCA [4] and the reliability data collection [2] suggests that rule violations are not part of the 'errors', although it represents relevant information on decision-making related to possible unsafe acts. Nevertheless, 'rule violations' are clearly linked to the non-technical aspects and human performance. ISO/TR 12489 [10] specifically states that it is appropriate to omit actions performed outside the demands of the task when considering commission errors (doing things wrongly) in human error modelling; "commission errors not associated with a requirement for the operator to act and acts of sabotage are generally not modelled". However, this does not necessarily apply to rule violations. E.g. deliberately going through a red light is a rule violation in response to a demand to stop and might be modelled in an RCA of going through a red light. However, deliberately driving on the pavement instead of the road is unlikely to be modelled.

The ISO/TR 12489 [10], although not including a definition of 'human error' in the document, frequently refers to this term when guiding reliability modelling and calculations. One of the measures described in [10] and that is commonly used in human error modelling, is the 'human error probability' (HEP), which addresses the number of human errors divided by the number of opportunities for error. Assessment of HEP is typically a key activity of HRA. To apply such a measure, it is typically necessary to analyse a wide range of failure causes in order to achieve the overall number of human error events and identification of opportunities for errors. The analyst will then have to decide on which of the failure causes relate to human errors. ISO 14224 [2], largely accommodates this task, and specifies that the three failure causes, operating error, maintenance error and documentation error, specifically relate to human errors.

These are all failure causes that, for example, might be associated with human fatigue, i.e. loss of physiological and psychological function as a result of extended wakefulness, heavy work, excessive stimulation, illness or stress [71]. For example, loss of function could be a decrease in attentional capacity, which could increase the chance of making attentional slips. Other types of ‘error’, such as ‘management error’ are open to interpretation, as in many situations they will not be classified as a human error according to the definition given in the ISO 14224 [2].

It has traditionally, however, been a challenge to achieve the experience data for HEP calculations and, because of that, a number of HEP generating methods have been developed in the past, such as e.g. the classic *Human error assessment and reduction technique* (HEART), the *Human error rate prediction* (THERP) methods (see e.g. [44]). There is also a HRA method developed particularly for the nuclear industry called *a technique for human error analysis* (ATHEANA) issued in 1996 in NUREG/CR-6350 [72]. The variety of methods developed is a response to the missing ‘human error’ focus in general reliability data collection, where the relevant data is not collected or available in the standardized format.

Probabilistic analysis, such as the use of the HEP measure mentioned above, raises also the question of whether or not the human errors are randomly distributed, as assumed by the ISO/TR 12489 [10]. For example, Berry et al. [73] claim quite the opposite; that neither errors nor violations are random events. It is an important issue as it relates to the time to failure, but the discussion on this it is considered outside the scope of the current article.

5.2. Overview of pros and cons

The main pros and cons identified in the subsection above are summarized in Table 1.

6. Discussion

In the current article, the authors address whether the current ISO framework for reliability data collection, exchange and analysis are appropriate for capturing the information needed to achieve high quality human error data for use in decision-making in the oil and gas industry. To assess this, they have studied thoroughly the guidance provided by the two key international standards available on the issue, i.e. the ISO 14224 [2] and the IEC 62740 [4], as well as the dependability standard IEC 60,050-192 [17], which is highly relevant also within the oil and gas industry.

Basically, the appropriateness relates to two related issues; firstly, whether the current framework is sound and can provide adequate data quality; and secondly, whether key information is unavailable through the current framework, which then should be considered for inclusion. Regarding the first issue, ISO 14224 [2] suggests the following five key characteristics that characterize high quality data:

1. Completeness of data in relation to specification
2. Compliance with definitions of reliability parameters, data types and formats
3. Accurate input, transfer, handling and storage of data (manually or electronic)
4. Sufficient population and adequate surveillance period to give statistical confidence
5. Relevance of the data to the need of the users

Collectability issues are obviously a key here, being covered by quality points 1, 3 and 4. The current classification of failure causes is simple to interpret and use in practice. The prioritization might be a challenge, but it is normally quite clear whether a failure cause is to be part of one category (e.g. operating error or maintenance error). For a possible in-depth categorization of the human errors, it is not that obvious. In particular, it might be difficult to specify the human intentionality i.e. how to establish what the person intended. For example, say an equipment inspector supposedly made an omission in inspecting a piece of equipment was this because the inspector intended to inspect the component but forgot about it (attentional slip) or maybe they identified the wrong equipment (mistake) or the inspector had little time and just assumed it was working adequately (violation), or perhaps it would have been inspected if it had not been accidentally omitted from the checklist (a documentation error). Obtaining, verifying and recording this kind of information might be highly resource demanding if there are not already systems in place that can be used for obtaining it.

Aside from the collectability issues, high quality is about relevance and intended use, and about the overall consistency of the data, which by increasing usefulness is clearly adding value to the data collection. Achieving consistency is naturally a key objective, i.e. to have a common platform for collecting and exchanging reliability data, where it is important that the data can be analysed and compared in a consistent way. A main challenge regarding consistency in the data on failure causes is the different ways of presenting the human errors depending on different objectives and methods, as outlined in Sections 2 and 3, and captured by the quality points 2 and 5 above. These objectives and methods can motivate the need for more detailed data; however, deciding on an appropriate breakdown applicable to reliability data collection seems to be difficult from a standardization perspective. Despite there being many classifications, it is not easy arriving at a satisfying and unambiguous definition and classification of human error, and literature provides little guidance on how to systematically classify an event into error categories [69]. The intended use may obviously vary and in the current edition of the ISO 14224 [2], there is no attempt in the structured reliability data collection to provide any in-depth human error information beyond the specified general failure causes, despite the increased attention to the human contribution

Another consistency issue, addressed in both Sections 3.1 and 4.2, is the ambiguous distinction between failure mechanism and error, which

Table 1
Pros and cons of the human error inclusion in ISO 14224 [2].

Pros	Cons
The consistency of the definition and taxonomy of human error makes it possible to achieve meaningful information for different analysis purposes.	Difficulty identifying when error according to the definition occurs (what was the intention).
The link to RCA makes it feasible to consider human errors in more depth, as well as violations even if the latter are not included in the standard.	No guidance on further breakdown of the failure causes into knowledge-, rule- and skill-based dimensions are provided.
Provides a clear interpretation of the specified failure causes, and identifies clearly which failure causes relate to human error (operating, maintenance & documentation human errors).	Although being an equipment-oriented standard, there could be more focus on the human performance aspects, particularly defining relevant contexts/sets of circumstances.
It is achievable to collect the human error data with high quality using the current classification.	Too much focus on what is the dominating failure cause, possibly creating bias towards the exclusion of human error
Allows for different ways of data collection, as it is often more practical and cost-efficient to perform in depth analysis for selected equipment/ failure events.	The current framework might not be appropriate to collect the full set of information needed to calculate HEP; data quality on the number of opportunities for error could be increased as well as on the cognitive aspects of the errors.

links to whether different types of error should belong to the same classification hierarchy; e.g. ‘human error’ being linked to failure causes and ‘software error’ linked to failure mechanisms. However, the interpretation of a failure mechanism is clear enough–the process leading to failure, which is explainable by the underlying failure cause(s). That classification of failure mechanisms sometimes uses the word ‘cause’ could be confusing, e.g. ‘combined causes’ or ‘no cause found’ could be relevant for both failure mechanisms and causes. One would then expect a similar relationship between different error mechanisms and causes, although this is not explicitly defined in the international standards.

Concerning the intended use, there are many examples that can demonstrate mismatch between collected reliability data and use in reliability modelling. Also for hardware failures there should be examples of proper motivation for a more detailed collection of failure causes. To some extent, the adopted classification of failure causes is a trade-off, but one where focus is clearly not restricted to human errors. We find it reasonable that the ISO 14224 [2], as an international standard focusing on equipment reliability performance and the circumstances influencing this performance, presents a wide picture of the failure causes. Nevertheless, we see a clear link between the depth of human error information and the relevance and value of the data. Just identifying that there is a human contribution, when considering the high fraction of such failures (depending on how one classifies it), is perhaps not providing the relevant information; or in the words of Trevor Kletz: “*To say accidents are due to human failing is like saying that falls are due to gravity. It is true but does not help us prevent them*” [74, p. 230].

One may then question whether the current classification of failure causes should aim for showing a broader picture as needed for assessing and identifying reliability recommendations concerning human errors. It could be useful to have in-depth data on the task level within which the error took place, i.e. skill-based, rule-based, and knowledge-based according to the classification in Reason [3]. The analyst could then use these data to calculate HEP values for different performance levels. Given a probability distribution for each of the levels, performance shaping factors could then be applied to e.g. predict future performance or for human resource management. The main problem is not the relevancy, which is clearly there, but rather that the detailed information might be difficult to obtain, as outlined above. For example, if both an operator and a hardware sensor is failing to detect a fault (i.e. a redundancy failure); which of the two should be attributed the detection failure? Perhaps then it is better to focus on the relationship between the human and the technical system, e.g. through systemic analysis or signal detection theory (SDT). By doing that, more attention is placed on the human factors, the quality of information and criteria for acting/making decisions/responding. In that case it might be more appropriate to build the classification around the ‘signal quality’.

Whilst it is clear that the ISO 14224 framework seems incapable of capturing all failure causes at the required level of detail, with underlying causes likely to be ignored, the new ISO 14224 [2] is largely capturing which of the failure causes are linked to human errors compared with the withdrawn 2006 edition. This is both useful and relevant information in human reliability assessments, e.g. when calculating the HEP measure. The basic need of real data for the HEP calculations is largely covered by the increased specificity of ‘human error’ in collection of ‘failure causes’. However, there is still a need to capture the number of demands, which is not fully in place yet. The number of demands, while being an attractive piece of information, is more a collectability issue, as the number of demands could be quite high and uncertain.

7. Conclusions and research needs

To conclude the discussion and give some remarks on how to consider failure causes from a human error perspective, the ISO 14224 [2] presents a solid guidance for which failure causes are to be applied in data collection. It may not be able to capture the full human error picture identified through a RCA process, but will normally present the dominant failure cause.

The ISO 14224 [2] clarifies specifically that three specific failure causes relate to human errors, i.e. operating, maintenance and documentation error, but does not provide any guidance on a further breakdown. Each of these, and others such as fabrication, installation and general design failure causes, could all be further broken down (e.g. to knowledge, rule or skill dimensions) but this is not in the current framework for structured reliability data collection. Other failure causes such as ‘combined causes’ may also deal with human errors, but no direct link is given concerning this failure cause.

To achieve appropriate information for human reliability assessment (HRA) decision-support, it is beneficial in some situations to perform additional data collection. In-depth analysis, as through RCA, is advised for selected failure causes relating to human errors to identify which elements are dominant. For example, it is highly interesting to study the extent of the influence of human errors in the collected data on maintenance. For this purpose, we believe that it could be useful and reasonable to include a separate part, perhaps a new annex, in the next edition of the ISO 14224, which provides clear guidance of how additional and in-depth data collection of human errors could be performed in an appropriate way so that such initiatives are based on a common framework. It is important that this part is synchronized with the RCA output guided by the IEC 62740 and other international standards that might be developed for activities around this issue. The development of such a part should also be based on experience in the industry and could be supported by empirical research in this area.

Furthermore, as part of the input to future standardization work, the ISO/TR 12489 should clearly be aligned in the next revision of this, such that the document considers ‘violations’ in the same way as the ISO 14224 [2] and IEC 62740 [4].

In summary, the new ISO 14224 standard moves the focus in reliability data collection closer to ‘human errors’. It clarifies for both data collectors and analysts which failure causes relate to such errors and provides a consistent reliability language linking the terms ‘error’ and ‘human error’ in an appropriate way. It restricts the term human error to a discrepancy with intention: *“discrepancy between the human action taken or omitted and that intended”*. This avoids any connection with blame or any generalised all-encompassing catch-all for attributing anything that fails to human root causes. The standard can thus to a larger extent ensure consistency of ‘human error’ data within the oil and gas industry, such that high quality can be achieved in reliability assessments, for example, when identifying recommendations on how to prevent reoccurrence of the events or the occurrence of human error related events.

As for the clarification of how to guide additional data collection on human errors, there is generally a need for human factors experts to contribute more to the standardization process related to the activity of e.g. the ISO TC67/WG4 – *Reliability Engineering and Technology* and the IEC TC 56 - *Dependability*. In the ballot concerning the final draft of the 2016 edition of the ISO 14224, which received 343 comments, none of the comments were about ‘human errors’ or how to capture the human contribution. Some research on how to improve support for the collecting of human error data in practice by non-human factors specialists, as well as how to better integrate human factors in equipment reliability questions, could be undertaken. By this is meant better communication and transfer and integration of professional knowledge and understanding rather than more development of classification systems. This is quite a challenge as in any multi-disciplinary undertaking. Impediments to integrating expertise on the organisational and cognitive aspects of human performance, such as those found in the Norwegian petroleum sector [58], need to be overcome by prioritising the integration of such human factors expertise in the data collection for and analyses of safety critical systems and the supporting standards.

Acknowledgements

The current article builds on the paper “On the use of the international standard ISO 14224 on reliability data collection in the oil and gas industry: How to consider failure causes from a human error perspective” [75], presented at the European Safety and Reliability (ESREL) conference in Glasgow, 25–29 September 2016. The authors are grateful to earlier comments given from two anonymous reviewers on how to improve the quality of the paper for journal publication. Both authors are currently members of the ISO TC67/WG4, however the views expressed in this article are solely those of the authors.

References

[1] Kletz T. Learning from accidents. Third ed. New York, USA: Routledge; 2001.
[2] ISO 14224. Petroleum, petrochemical and natural gas industries–collection and exchange of reliability and maintenance data for equipment. Third ed. Geneva Switzerland: ISO - International Organization for Standardization ISO; 2016.
[3] Reason J. Human error. Cambridge, UK: Cambridge University Press; 1990.
[4] IEC 62740. Root cause analysis (RCA). Geneva, Switzerland: IEC - International Electrotechnical Commission; 2015.
[5] Boring RL. Defining human failure events for petroleum applications of human reliability analysis. Proc Manuf 2015;3:1335–42.
[6] EUROCONTROL. Technical review of human performance models and taxonomies of human error in ATM (HERA). Technical Report No. HRS/HSP-002-REP-01. Brussels, BE; 2012.
[7] NUREG/CR-6903/Vol.1. Human event repository and analysis (HERA) system, Overview (NUREG/CR-6903, Volume 1). July 2016. U.S. Nuclear Regulatory Commission: https://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6903/v1/.
[8] NUREG/CR-6903/Vol.2. Human event repository and analysis (HERA): the HERA coding manual and quality assurance. (NUREG/CR-6903, Volume 2). July 2006. U. S. Nuclear Regulatory Commission: https://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6903/v2/.
[9] Dekker SWA. Reconstructing human contributions to accidents: the new view on error and performance. J Saf Res 2002;33:371–85.
[10] ISO/TR 12489. Petroleum, petrochemical and natural gas industries–reliability modelling and calculation of safety systems. Geneva. Switzerland: International Organization for Standardization ISO; 2013.
[11] Molnes E, Strand G-O. Application of a completion equipment reliability database in decision making SPE 63112 Proceedings of the SPE annual technical conference and exhibition held in DallasTexas: Society of Petroleum Engineers (SPE); 2000. p. 1–4. October.
[12] PSA . Petroleum Safety Authority Norway. Guidelines regarding the management regulations. 18 December 2017 http://www.psa.no/management/category406.html.
[13] ISO 14224. Petroleum, petrochemical and natural gas industries–collection and exchange of reliability and maintenance data for equipment. Geneva, Switzerland: ISO; 2006.
[14] HSE - Health & Safety Executive. Root causes analysis: literature review. Contract research report 325/2001 http://www.hse.gov.uk/research/crr_pdf/2001/crr01325.pdf.
[15] Nolan DP, Anderson ET. Applied operational excellence for the oil, gas, and process industries. Oxford, UK: Elsevier Inc; 2015.
[16] Been J, Bloomfield E, Jacob Y. Root cause analysis of an upstream pipeline failure indicating the contribution and interaction of multiple factors NACE-2017-9742 Proceedings of the corrosion 2017 conferenceMarch 2015. p. 26–30.
[17] IEC 60050-192. International electrotechnical vocabulary–part 192: dependability. Geneva, Switzerland: IEC–International Electrotechnical Commission; 2015.
[18] Tomlinson R. Root-cause analysis–analyze, define & fix. Prof Saf 2015:52–3. September. www.asse.org.
[19] Stanton NA, Salmon PM, Walker GH, Baber C, Jenkins DP. Human factors methods: a practical guide for engineering and design. Ashgate: Aldershot; 2005.
[20] OGP – International Association of Oil & Gas Producers. Risk assessment data directory–human factors in QRA. OGP Publications; March 2010. OGP report no. 434-5.
[21] Ferjencik M. IPICA_lite–improvements to root cause analysis. Reliab Eng Syst Saf 2014;131:1–13.
[22] Ishikawa K. Guide to quality control. Tokyo, Japan: Asia Productivity Organization; 1986.
[23] Duphily RJ. Root cause investigation best practices guide The Aerospace Cooperation; 2014. Report no. TOR-2014-02202 http://aerospace.wpengine.netdna-cdn.com/wp-content/uploads/2015/04/TOR-2014-02202-Root-Cause-Investigation-Best-Practices-Guide.pdf.
[24] Vinnem JE, Seljelid J, Haugen S, Husebø T. Analysis of hydrocarbon leaks on offshore installations. In: Aven T, Vinnem JE, editors. Risk, reliability and societal safety. London: Taylor & Francis Group; 2007. p. 1559–66.
[25] Hare J, Johnson M. Underlying causes of offshore incidents Health & Safety Laboratory; 2009. FP/09/21 http://www.hse.gov.uk/offshore/offshore-incidents.pdf.
[26] Vectra Group. Human factors guidance for selecting appropriate maintenance strategies for safety in the offshore oil and gas industry UK: Health & Safety Executive; 2004. HSE report no. 213.
[27] Boschee P. Improving human performance–tackling the challenges to develop effective safety culture. Oil Gas Facil 2014;3(3):18–23.
[28] Aas AL. The human factors assessment and classification system (HFACS) for the oil & gas industry IPTC 12694 Proceedings of the international petroleum technology conference in Kuala LumpurDecember 2008. p. 3–5.
[29] Kariuki SG, Lowe K. Integrating human factors into process hazard analysis. Reliab Anal Syst Saf 2007;92(12):1764–73.
[30] Brauer RL. Safety and health for engineers. Hoboken, New Jersey: John Wiley & Sons, Inc; 2016.
[31] Tobias PA, Trindade DC. Applied reliability. Boca Raton, USA: CRC Press; 2012.
[32] Rausand M, Høyland A. Systems reliability theory–models, statistical methods and applications. Hoboken, New Jersey: Wiley Series in Probability and Statistics; 2004. John Wiley & Sons, Inc.
[33] HSE - Health & Safety Executive. Review of human reliability assessment methods. Research report RR679 Bell, J., Holroyd, J. at the Health and Safety Laboratory for the Health and Safety Executive. 2009. http://www.hse.gov.uk/research/rrpdf/rr679.pdf.
[34] Boring RL, Hendrickson SML, Forester JA, Tran TQ, Lois E. Issues in benchmarking human reliability analysis methods: a literature review. Reliab Eng Syst Saf 2010;95(6):591–605.
[35] Di Pasquale V, Iannone R, Miranda S, Riemma S. An overview of human reliability analysis techniques in manufacturing operations. In: Schiraldi M, editor. Operations Management. Intech; 2015https://www.intechopen.com/books/operations-management/an-overview-of-human-reliability-analysis-techniques-in-manufacturing-operations.
[36] Olsen NS. Reliability studies of incident coding systems in high hazard industries: a narrative review of study methodology. Appl Ergon 2013;44:175–84.
[37] Moura R, Beer M, Patelli E, Lewis J, Knoll F. Learning from major accidents to improve system design. Saf Sci 2016;84:37–45.
[38] Shappell, S., Wiegmann, D. The human factors analysis and classification system (HFACS). Federal aviation administration, Report No. DOT/FAA/AM-00/7. Office of Aviation Medicine: Washington, DC. 2000.
[39] Shappell S, Wiegmann D. Applying reason: the human factors analysis and classification system (HFACS). Hum Factors Aerosp Saf 2001;1:59–86.
[40] Bellamy LJ, Mud M, Manuel HJ, Oh JIH. Analysis of underlying causes of investigated loss of containment incidents in Dutch Seveso plants using the storybuilder method. J Loss Prev Process Ind 2013;26:1039–59.
[41] Kirwan B. A guide to practical human reliability assessment. UK: Taylor & Francis; 1994.
[42] Bell J, Holroyd J. Review of human reliability assessment methods. RR679 Research report for the UK Health and Safety Executive; 2009http://www.hse.gov.uk/research/rrpdf/rr679.pdf.
[43] Dadgar P, Tehrani GM, Borgheipour H. Identification and assessment of human error in CNG stations with SHERPA technique. Int J Environ Sci Educ 2017;12(2):253–65.
[44] Di Pasquale V, Miranda S, Iannone R, Riemma S. A simulator for human error probability analysis (SHERPA). Reliab Eng Syst Saf 2015;139:17–32.
[45] Hughes CM, Baber C, Bienkiewicz M, Worthington A, Hazell A, Hermsdorfer J. The application of SHERPA (Systematic Human Error Reduction and Prediction Approach) in the development of compensatory cognitive rehabilitation strategies for stroke patients with left and right brain damage. Ergonomics 2015;58(1):75–95.
[46] IEC 62508. Guidance on human aspects of dependability. Ed. 1.0 2010-06. Geneva, Switzerland: IEC.International Electrotechnical Commission; 2010.
[47] Shorrock S, Kirwan B. Development and application of a human error identification tool for air traffic control. Appl Ergon 2002;33:319–36.
[48] Senders JW, Moray NP. Series in applied psychology: human error: cause, prediction, and reduction. Hillsdale, NJ, USA: Lawrence Erlbaum Associates, Inc; 1991.
[49] Mason S. Procedural violations–causes, costs and cures. In: Redmill F, Rajan KJ, editors. Human factors in safety critical systems. Oxford, UK: Butterworth-Heinemann; 1997. p. 287–318.
[50] Reason J. The human contribution–unsafe acts, accidents and heroic recoveries. Farnham, UK: Ashgate Publishing Ltd; 2015.
[51] Reason J. Managing the risks of organizational accidents. Aldershot, UK: Ashgate Publishing Ltd; 1997.
[52] Dekker S. The field guide to understanding ‘Human error’ Third ed. Farnham, UK: Ashgate Publishing Ltd; 2014.
[53] Mathisen GE, Bergh LIV. Action errors and rule violations at offshore rigs: the role of engagement, emotional exhaustion and health complaints. Saf Sci 2016;85:130–8.
[54] Hollnagel E. Safety-I and safety-II: the past and future of safety management. Farnham, UK: Ashgate; 2014.
[55] Bellamy LJ, Geyer TAW, Astley JA. Evaluation of the human contribution to pipework and in line equipment failure frequencies. Bootle: HSE: Health and Safety Executive; 1989. ISBN 0717603245. HSE Contract Research Report 15/1989. 1989 http://www.hse.gov.uk/research/crr_pdf/1989/crr89015.pdf.
[56] Bellamy LJ, Geyer TAW. Organisational, management and human factors in quantified risk assessment - Report 1. HSE Contract Research Report 33/92; 1992http://www.hse.gov.uk/research/crr_pdf/1992/crr92033.pdf.
[57] Paté-Cornell E, Bea RG. Management Errors and system reliability: a probabilistic approach and application to offshore platforms. Risk Anal 1992;12(1):1–18.
[58] Johnsen SO, Kilskar SS, Fossum KR. Missing focus on human factors–organizational and cognitive ergonomics–in the safety management for the petroleum industry. J Risk Reliab 2017;231(4):400–10.
[59] Jang I, Kim AR, Jung W, Seong PH. An empirical study on the human error recovery

failure probability when using soft controls in NPP advanced MCRs. Ann Nuclear Energy 2014;73:373–81.

[60] McDonald N, Corrigan S, Ward M. Cultural and organizational factors in system safety: good people in bad systems. Proceedings of the international conference on human-computer interaction in aeronautics (HCI-Aero). 2002. p. 205–9https://www.aaai.org/Papers/HCI/2002/HCI02-033.pdf.

[61] ISO/IEC 2382. Information technology–vocabulary. Geneva Switzerland: ISO–International Organization for Standardization ISO; 2015.

[62] ISO/IEC/IEEE 24765. Systems and software engineering–vocabulary. Geneva Switzerland: ISO–International Organization for Standardization ISO; 2010.

[63] Le Coze JC. Reflecting on Jens Rasmussen's legacy. A strong program for a hard problem. Saf Sci 2015;71:123–41.

[64] Mosleh A, Chang YH. Model-based human reliability analysis: prospects and requirements. Reliab Eng Syst Saf 2004;83(2):241–53.

[65] Podofillini L, Park J, Dang VN. Measuring the influence of task complexity on human error probability: an empirical evaluation. Nuclear Eng Technol 2013;45(2):151–64.

[66] Huang F. Human error analysis in software engineering. In: De Felice F, editor. Theory and Application on Cognitive Factors and Risk Management. Intech.; 2017. 2017 https://www.intechopen.com/books/theory-and-application-on-cognitive-factors-and-risk-management-new-trends-and-procedures/human-error-analysis-in-software-engineering.

[67] Pandya D, Podofillini L, Emert F, Lomax AJ, Dang VN. Developing the foundations of a cognition-based human reliability analysis model via mapping task types and performance-influencing factors: application to radiotherapy. J Risk Reliab 2018;232(1):3–37.

[68] Rasmussen J. Skills, rules, and knowledge: signals, signs and symbols and other distinctions in human performance models. IEEE Trans Syst Man Cybern 1983;SMC-13:257–67.

[69] Di Pasquale V, Franciosi C, Lambiase A, Miranda S. Methodology for the analysis and quantification of human error probability in manufacturing systems. Proceedings of the IEEE student conference on research and development (SCOReD). 2016.

[70] Lam C, Medlam G, Wighton A, Breen SL, Bissonnette J-P, McGowan TS, Carlone M, Milosevic MF. A practice-based taxonomy for radiation treatment errors. J Med Imaging Radiat Sci 2013;44:173–9.

[71] Moore-Ede M. The definition of human fatigue, white paper. Circadian Information Limited Partnership; 2009.

[72] NUREG/CR-6350. A technique for human error analysis (ATHEANA). U.S. Nuclear Regulatory Commission; May 1996https://www.nrc.gov/reading-rm/doc-collections/nuregs/contract/cr6350/.

[73] Berry KA, Stringfellow PF, Shappell SA. Examining error pathways: an analysis of contributing factors using HFACS in non-aviation industries. Proceedings of the fifty fourth annual meeting human factors and ergonomics society. 2010. p. 1900–4.

[74] Kletz T. An engineer's view of human error. Third ed. Rugby, UK: IChemE – Institution of Chemical Engineers; 2001.

[75] Selvik JT, Bellamy LJ. On the use of the international standard ISO 14224 on reliability data collection in the oil and gas industry: how to consider failure causes from a human error perspective. In: Walls L, Revie M, Bedford T, editors. Risk, reliability and Safety: innovating theory and practice. London: Taylor & Francis Group; 2017.