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Definition of reliability and maintenance concepts in oil and gas – validity aspects

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ABSTRACT

International standards have a key role in establishing consistent terminology. Amongst these is the recently published and revised ISO standard on reliability and maintenance data collection and exchange, i.e. ISO 14224:2016. This particular standard guides the petroleum, petrochemical and natural gas industries on how to achieve quality data for decision-making. It represents a main reference document for these activities and strongly influences how key terms are interpreted and used in practice. To serve this purpose, it provides a glossary that defines basic concepts or terms within the reliability and maintenance discipline, including new definitions of the key terms ‘safety critical equipment’ and ‘uncertainty’. This article addresses the new definitions given in ISO 14224:2016 and, in particular, the two mentioned above. A common understanding of the concepts is important from an analysis perspective, as it strongly influences the way both reliability and risk are assessed, managed and communicated. Some clarification of the meaning of each definition is proposed, and comparisons with definitions from other international standards are made, such as the definition of ‘uncertainty’ given in ISO 31000:2018. A main purpose of the article is to discuss the validity of the definitions with reference to different sub-criteria that should be satisfied, and provide recommendations concerning the use of the concepts and definitions studied.

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KEYWORDS ISO 14224; reliability; maintenance; data collection; safety critical equipment; uncertainty; validity

1. Introduction

This article discusses some new definitions within the reliability and maintenance (RM) area, in relation to data collection, exchange and analysis. The

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definitions have an influence on data quality and are therefore important to consider for analysis purposes and for informed decision-making. Furthermore, the quality strongly depends on the way the data is collected and analysed (Rausand 2011, p. 187; Rausand & Høyland, 2004, p. 569). To achieve a sufficiently high quality requires a standardised format for data collection and exchange. Having precise and valid definitions of key terms is an important part of this equation.

A main reference – to guide such activities to meet the objectives, and which is developed for and applied within the petroleum, petrochemical and natural gas industries – is ISO 14224:2016. See reference to applications in, for example, Barabady et al. (2015), Braaksma et al. (2011), Selvik and Bellamy (2017) and Guillén et al. (2016). The document deals specifically with the collection, exchange and analysis of RM data. It provides a comprehensive guidance that describes data collection, analysis principles and basic concepts. In particular, this international standard defines a 'reliability and maintenance language', by providing definitions and interpretations of key terms and measures that are of significant importance to how reliability and maintenance data is applied within the industries mentioned.

Reference to this international standard is also made in regulatory documents, such as the regulations issued by the Petroleum Safety Authorities Norway (PSA). For example, the 'Guidelines regarding the management regulations' (PSA, 2016a), state that '*The ISO 14224 standard should be used for RM data for risk analyses in the health, working environment and safety area*'. In general, RM data has a broad area of application with links to both cost and safety issues, which partly explains why there is a strong focus on how to achieve and use high-quality data. It also explains the recent interest in revising the ISO 14224 document.

The third edition of ISO 14224, issued in 2016, provides several new definitions, including 20 completely new ones: 'new' meaning that they were not given in any of the previous editions of this international standard, i.e. that either the 'old' definition was modified, or a new term is introduced. Of the total of 98 definitions in the 2016 edition, 67 have a 'new' status. Of these new definitions, almost 50 were adopted from other documents, mostly from the closely linked IEC standard on dependability, IEC 60050-192:2015; see complete overview in Table 1.

Table 1. Number of definitions given in ISO 14224.

Edition	1: 1999	2: 2006	3: 2016
No. of terms defined (in ISO 14224, Clause 3)	31	51	98
No. of new terms defined in this edition	31	24	47
No. of new definitions in this edition	31	31	67
No. of new definitions with ISO 14224 as source	13	21	20
No. of new definitions with IEC 60050-191:1990 (or -192:2015) as source	18	10	27
No. of new definitions with other sources	0	0	20

One of these completely new definitions is the one given to the term 'uncertainty'. Uncertainty is a much-used term within the RM discipline and is mentioned several times in the ISO 14224 document. The standard has a specific subsection in one of the annexes linked to this concept, i.e. in item C.6.4 of the standard: 'Handling of uncertainty'. But, unfortunately, this subsection, while relevant enough and pointing to the importance of discussing uncertainty, does not give an in-depth interpretation of the term 'uncertainty', nor does it go into detail on how to use it in practice. Nor is the proposed definition, given in Clause 3 of the standard, able to provide sufficient clarity concerning these issues.

'Uncertainty' is clearly an important term within the RM discipline. At the same time, it is also a challenging term to which different interpretations can be attributed (see, for example, de Rocquigny et al., 2008, p.7). It is therefore highly relevant to include a definition of this term for clarification, as is finally done in the ISO 14224:2016. However, while a variety of interpretations are indicated by the notes to the entry following the definition, some further clarification beyond what is currently written in the standard is required for in-depth understanding of how to use this definition in practice.

It is the same situation for the concept 'safety critical equipment', which is often confused with 'safety critical elements'. A discussion on the interpretation and use of this term is important, as there is currently limited, if any, literature that discusses the applicability and robustness of this new definition from a standardisation perspective. The revised ISO 14224 also includes other new definitions of terms that require some clarification.

In general, this article raises some general questions concerning the validity of definitions; with focus on those given in ISO 14224:2016. In particular, the overall validity is questioned, as it is not clear how to assess this. It is, for example, questioned whether the definition holds, or whether there are other alternative definitions that should have been selected instead of creating new ones. An objective of the article is to suggest a way to identify and assess aspects of relevance. As the definitions are influential, and widely used within the RM disciplines, it is important that the different aspects are clarified.

The remainder of this article is organised as follows. Section 2 presents the key principles for the definition of key terms followed in the ISO 14224 revision process. Section 3 then provides an overview of the new definitions. These are briefly discussed in Section 4, before two of them, the terms 'safety critical equipment' and 'uncertainty', are studied in Sections 5 and 6, respectively, in greater detail. Section 7 offers some concluding remarks.

2. Terms and definitions in ISO and IEC documents

2.1. Main principles

The revision of ISO 14224 has followed the main principles for producing quality ISO and IEC documents outlined by the ISO/IEC Directives – Parts 1 and 2 (ISO/IEC, 2016a, 2016b). A main objective, as specified in ISO/IEC (2016b), is to ensure that produced documents contribute effectively to the consistent and interdependent body of knowledge that ISO and IEC produce. The ISO/IEC Directives also outline the rules and principles for terms and definitions, specifying that consistency is particularly important to: 'help the user understand documents or series of associated documents' (ISO/IEC, 2016b, p. 8). For consistency purposes, the two points below should be followed:

a. Identical wording should be used to express identical provisions
b. The same terminology should be used throughout. The use of synonyms should be avoided.

In addition, there is a requirement that the concept relates specifically to the document in which it is defined. It is not permissible to define relevant concepts that are not used in the document (except in the 'Guides', for example in ISO/IEC Guide 51:2014). Furthermore, if a term may refer to different concepts, for example 'die', it should be given a separate entry in the definition section (Clause 3), and the domain where it is applicable should be specified. Additional information clarifying the definition may be given in the notes to the entry.

The standardisation process should, in line with terminology standards ISO 704:2009 and ISO 10241-1:2011, avoid producing new definitions when acceptable ones already exist in other ISO or IEC documents. It is thus important that the experts in charge of the standardisation work consider both applicability issues and the reuse of existing definitions given in other relevant documents issued by ISO or IEC. Besides, definitions should be given only where the concept defined would not be understandable from the use of the term in general language or where an existing standard definition is not applicable (ISO/IEC 17000:2004). Definitions of common terms, which qualified users should already know, should therefore be avoided.

Furthermore, the definitions should be produced from a collaborative and consensus-based process that does not favour any particular stakeholder. The products should, in general, target optimal benefit for society as a whole. Consensus concerning the technical content of the standard, where relevant parties are involved, is therefore considered an important aspect. The same applies to transparency. The process should be in an open format, which allows interested parties to contribute in a constructive manner, as has been the situation for the ISO 14224 revision. The information concerning technical content is discussed by interested parties, has undergone widely announced ballot processes, and is properly archived by ISO management systems.

2.2. Validity

The issue of validity concerns both consensus and transparency in the way that the definitions should have a foundation within the discipline in which they are meant to be applied. The definition should be true to the concept it is purporting to interpret, which is a main aspect when deciding whether there is a need to produce a new definition, as opposed to the option of using an existing one.

To meet the requirement of validity, the proposed definition should give a precise description of the concept it is attempting to describe. This means that the application area, thus the RM area in relation to ISO 14224, plays a key role in whether the definition is appropriate.

Aven and Heide (2009) interpret 'validity' in a similar way, albeit by discussing the term in the context of risk analysis. They give a definition of 'validity' in line with the interpretation given above, i.e. '*the degree to which the risk analysis describes the specific concept it is trying to describe*'. In addition, they give four more specific and detailed sub-criteria (interpretations), which must be satisfied for the analysis to be acceptable from a validity perspective. The set of sub-criteria used in Aven and Heide (2009) is, however, not considered transferable and applicable when the focus is on terms and definitions.

The ISO/IEC Directives provide no such interpretation. Therefore, this article proposes several new ones that are appropriate to the context. Hence, when focussing on the new terms and definitions in ISO 14224:2016, instead, the five sub-criteria (V1 to V5) given in Table 2 are applied.

For a definition given in an ISO or IEC standard to be valid, all the five sub-criteria given in Table 2 should be satisfied. These are discussed in the current paper in relation to the new definitions given in ISO 14224:2016; see Sections 4 to 6.

3. The new definitions in ISO 14224:2016

3.1. Aligning of terms and definitions

The alignment of terms and definitions represented a key activity of the ISO 14224 revision process. The revision was managed by a working group from the ISO technical committee (TC) 67, called 'Reliability engineering

Table 2. Validity sub-criteria.

Sub-criteria (V)	Description
V1– Axiomatic:	The degree to which the definition per se qualifies as a definition, i.e. is reasonable, replaceable, avoids circularity and avoids the use of opposites when defining the concept
V2 – Completeness:	The degree to which the definition allows for a precise interpretation of the concept, i.e. sets out the essential attributes of the concept
V3 – Understandable:	The degree to which the meaning of the definition is clear and reasonable (i.e. given in a comprehensible form)
V4 – Balanced:	The degree to which the definition is in line with other associated concepts (i.e. sound relationship to other concepts)
V5 – Applicability:	The degree to which the definition is needed and appropriate when it is used within the relevant application areas

and technology' (WG4). The group includes expert members with a wide area of expertise, several of whom are from international oil and gas companies, which again allows for shared experience with different industrial reliability and maintenance data collection projects such as e.g. the OREDA and WellMaster projects and associated analysis. The link provided valuable feedback on the need for changes based on the application of the international standards in these industries.

For the ISO 14224 revision, the formal liaison between ISO TC67 and IEC TC56 – Dependability enables associated sub-committees to communicate relevant documents, such as on relevant definitions and interpretations of key terms and measures, as outlined by ISO/IEC (2016a, Clause 16). This allows for a close relationship to IEC 60050-192:2015 (replacing IEC 60050-191:1990; see Table 1).

A main activity in the ISO 14224 revision process was to establish consistent and aligned definitions of basic concepts within the reliability and maintenance disciplines. In particular, there was a call to include several new definitions, within the reliability discipline, of terms not defined in the 2006 edition.

A need was identified to align several of the definitions in the 2006 edition with definitions in cross-referenced international documents, in particular with: IEC 60050-192:2015 on dependability vocabulary, ISO/TR 12489:2013 on reliability modelling, and ISO 20815:2008 on production assurance. These are three key documents with wide application, but which have several definitions not in line with those in ISO 14224:2006.

An important part of the revision process was therefore to achieve consistency between the terms defined and those used in these international standards and technical reports, and for such to be in line with the principles outlined in Section 2.1.

3.2. New terms and definitions – an overview

The 2016 edition shows an increase of 47 definitions, compared with the 2006 edition. In total, this edition introduces 47 new terms in Clause 3, i.e. the terms and definitions of the standard. The increase in the number of definitions from the 2006 edition to the 2016 edition is significant, as shown in the total number given in Table 3. The meaning of a 'new' definition is that it is not included in the previous edition of the standard, i.e. either the 'old' definition was modified, or a new term is included. Of the definitions in the 2016 edition, 68% are considered 'new'. The notes to the entry linked to the definitions are not checked.

The distribution given in Table 3 shows that about half of the definitions for all three of the editions are produced from the ISO 14224 project teams. The terms having new definitions in ISO 14224:2016 are further studied in Sections 4 to 6, including the two terms mentioned in the introduction, i.e. 'safety critical equipment' and 'uncertainty'. These are considered important terms within the RM discipline, but they are also terms that may be given different interpretations, depending on the context.

4. Assessment and discussion of the new definitions

A validity score assessment of the definition of terms is suggested using the following qualitative score for each sub-criterion given in Table 2:

- Strong (S): Significant arguments in favour of the definition
- Medium (M): The argumentation is in favour of the definition; however, some arguments are not in favour (i.e. overall the definition is acceptable)
- Weak (W): Significant arguments not in favour of the definition

The five validity scores give an indication of the strength of each definition, without producing an overall score. The main objective is not to reject the definition in any way but, rather, to provide a screening of the definitional aspects that could lead to unintended or ambiguous use of the term

Table 3. Distribution of sources to terms and definitions in ISO 14224.

Edition	1: 1999	2:2006	3:2016
ISO 14224	13	25	48
IEC 60050-191:1990	18	26	30
ISO 20815:2008	–	–	4
ISO/TR 12489:2013	–	–	13
Other sources	–	–	3
Total	31	51	98

and, thus, could justify modification of the definition in the next revision of the international standard.

Table 4 provides a rubric for use in the evaluation of a definition's validity. Each sub-criterion (V1 through V5) is evaluated as either 'strong', 'medium' or 'weak', depending upon which associated collection of attributes most closely characterises the definition.

Table 4. Rubric for definition validity.

Sub-criteria	Strong (S)	Medium (M)	Weak (W)
Axiomatic (V1)	Qualify as a Definition • substitutable for term • self-evident meaning • concise and practical • logical explanation • reasonable description • audience appropriate	Qualify as a Definition • adequate equivalence • sensibly framed • slightly terse or verbose • fairly logical • suboptimal word choice • audience restricted	Qualify as a Definition • circuitous reasoning • uses antonyms • inappropriate size • illogical description • convoluted and blurry • directed at wrong group
Completeness (V2)	Focus on Concept Essence • covers critical concepts • details boundaries • precise interpretation • essential attributes • indispensable ideas • crucial points	Focus on Concept Essence • acceptable coverage • slightly broad/ restrictive • satisfactory explanation • obvious and on point • missing something • satisfactory emphasis	Focus on Concept Essence • core issues missing • arbitrary treatment • awkward interpretation • inconclusive traits • incomplete and sketchy • peripheral focus
Understandable (V3)	Connote the Aim • clearly communicated • accurate true meaning • flawless word choice • singular interpretation • appropriately flexible • lucid explanation	Connote the Aim • adequately explained • reasonable meaning • imperfect word choice • varied interpretation • flexible to some extent • plausible explanation	Connote the Aim • unclear explanation • incomprehensible • inferior word choice • misleading • distorted and confused • obscure explanation
Balanced (V4)	Link to other Concepts • agrees with other terms • closely connected • sound relationship • corresponds well • in accordance with • includes full definitions	Link to other Concepts • partial association • adequately connected • limited relationship • conditional agreement • suitable with loose ties • needs clarifying notes	Link to other Concepts • conflicts with other terms • disconnected • differing perspective • incompatible • obvious discordance • contradictory wording
Applicability (V5)	Use in Applications • fits all application areas • consistent meaning • pertinent and required • vital and indispensable • strong compatibility • germane and relevant	Use in Applications • variable application fit • meaning differs by use • usually appropriate • functional limitations • restricted application • marginally relevant	Use in Applications • obvious fit conflicts • inconsistency issues • inappropriate • erroneous • incompatible • irrelevant

Table 5 gives an overview of the new definitions developed for ISO 14224:2016 and, thus, not adopted from other sources. Some definitions, i.e. of 'downstream', 'midstream', 'petrochemical', 'upstream' and 'trip', were previously given in the Appendix section of the 2006 edition and moved into the definitions section (i.e. Clause 3) for the 2016 edition, without any further changes being made. A complete list of all the new definitions provided in ISO 14224:2016 is given in the Appendix of this paper.

For example, the term 'turnaround' as 'planned event wherein an entire process unit is taken off stream for revamp or renewal' is one of the terms that is added in the 2016 edition. This term is evaluated as 'strong' for all criteria, except for the 'understandable' (V3) criterion that is scored as 'medium'. It can be claimed that the word '*revamp*' is too informal, giving a reasonable but not accurate meaning, and that another wording would be preferable. Nevertheless, the definition of this term reflects the industry interpretation of the term, and this specific definition that could be found, for example, within refining; see for example Awonusi and Oamen (2014).

Overall, the validity of definitions in ISO 14224 should assume a high score that reflects the thorough assessments and quality assurance process they pass through. All definitions are reviewed and approved through the international ballot process, as required before publication of an international standard. Such a quality is confirmed from Table 5, where the majority of the definitions are given the 'strong' score, and only two cells out of the 75 are assigned the score 'weak'. On the other hand, only a third of the definitions are given a 'Strong' score on all five of the validity sub-criteria, which also indicates that it is not straightforward to define these terms. Other new definitions with validity scores different from 'strong' are addressed below.

The only term given the score 'weak' is the term 'equipment type', which scores low on two sub-criteria, i.e. the 'axiomatic' (V1) and the 'understandable' (V3) criterion. The main reason for this is that there is something ambiguous about the way it is phrased. It refers to a particular feature of a design which should be different from another design. This does not quite match the meaning of the term. It is a key term used in the Appendix to categorise each of the equipment classes. For example, the equipment class 'Piping' is given types based on the type of material, i.e. carbon steel, stainless steel, etc. These may be referred to as features of the design. However, the definition should also state something about why this feature is selected, i.e. it should reflect the characteristics of the equipment. Furthermore, the definitions refer to different designs within an equipment class but ignore the possibility of similar features within these. By so doing, the term becomes the same as 'design class', but where the features could be the same across the different designs. This is not considered to be sufficiently clear. A note to entry or

Table 5. Assessment of the validity of new definitions given in ISO 14224:2016.

		Validity sub-criteria				
Term	Definition	V1	V2	V3	V4	V5
Active repair time	effective time to achieve repair of an item	M	M	M	M	S
Detection method	method or activity by which a failure is discovered	M	S	M	S	S
Equipment type	particular feature of the design which is significantly different from the other design(s) within the same equipment class	W	M	W	M	M
Integrity	ability of a barrier to function as required when needed	S	S	M	M	M
Mean cycles to failure	expected number of cycles before the item fails	S	S	S	S	S
Mean number of cycles	expected number of cycles per time unit	S	S	S	S	S
Mean elapsed time between failures (METBF)	expected elapsed time between successive failures of a repairable item	S	S	S	M	S
Mean time to repair (MTTR)	expected time to achieve the repair of a failed item	S	S	M	M	S
Mobilisation time	time to get all necessary resources available to execute maintenance	S	S	S	S	S
Predictive maintenance	maintenance based on the prediction of the future condition of an item estimated or calculated from a defined set of historic data and known future operational parameters	S	M	M	M	M
Safety critical equipment	equipment and items of permanent, temporary and portable equipment playing an important role in safety systems/functions	S	M	M	S	S
Software error	erroneous result produced by the use of software product	S	S	S	S	S
Tag number	unique code that identifies the equipment function and its physical location	S	S	S	S	S
Turnaround (revision shutdown)	planned event wherein an entire process unit is taken off stream for revamp or renewal	S	S	M	S	S
Uncertainty	inability to determine accurately what is or will be the true value of a quantity	S	M	M	M	M

definition of ‘design class’ would be useful. Nevertheless, the meaning of the term is implicitly understood from the tables in the document in which it is used.

In general, ISO 14224:2016 has strengthened the focus on maintenance terms, as these were not adequately described in the previous editions. As can be seen from Table 5, several terms relate to maintenance actions. One of these is the 'mobilisation time', which is a 'new' definition in ISO 14224:2016. This is a term much used in reporting of maintenance activities, and it is important that it is defined appropriately, which it appears to be according to the scores given in the table.

Another maintenance-related term is the 'active repair time'. This is defined as '*effective time to achieve repair of an item*', and is defined in addition to 'active maintenance time', i.e. '*duration of maintenance action, excluding logistic delay*'. One could argue that 'effective time' refers to the time observed, and thus should include logistic delays. Furthermore, some industries, for example the nuclear industry (see ISO 8107:1993), consider these two terms as synonyms, as '*the part of the maintenance time during which active work is carried out on the item*'. Although definitions of the two terms are justified, it is considered difficult to separate them based on the definitions given in the revised ISO 14224. There is a definition of 'maintenance' (adopted from IEC 60050:2015) as '*combination of all technical and management actions intended to retain an item in, or restore it to, a state in which it can perform as required*', while on the other hand 'repair' is not defined although understood as the part of maintenance where the item is '*being worked on*'. This indicating that 'active repair time' being a part of 'active maintenance time', but this could be better expressed in the current definitions and notes to entry. The distinction is important, as the expectation of the 'active repair time' is also listed as a key performance indicator.

There is also a related new definition of 'mean time to repair', defined as the '*expected time to achieve repair of a failed item*'. Where, in the notes to entry for this, there is reference to '*expectation of the time to restoration*'. However, there is no note on the relationship to the 'mean active repair time', although it indicates a distinction between 'efficient time to repair' and simply the 'repair time' when the item is '*being worked on*'. Overall, the differences between the two and the 'restoration time' are not particularly clear.

Regarding the assessment of the validity of 'active repair time', it indicates a definition that should be reconsidered in the next revision. Validity sub-criteria V1 to V4 are assigned 'medium' scores. One reason is the difficulty in separating it from 'active maintenance time'. The 'active maintenance time' does not include logistic delay, but includes technical delays related to repair planning and preparation for start-up, while the 'active repair time' does not. Time for run-down or start-up is included in neither of them. Here, the wording '*effective time*' could be misleading as it indicates time that is observed for repair, which in some situations could include also logistic delays. Due to this lack of specificity, notes to the entry are added to clarify this.

One of the maintenance-related terms that could require some further attention is 'predictive maintenance', which scores particularly low on the 'completeness' criterion (V2). The main problem is that it fails to communicate the basic attributes. The term ‘predictive maintenance’ should relate more strongly to the actual ‘condition’ of the equipment as basis for the maintenance planning. This is information achieved through condition monitoring, which is key information in modelling how the equipment will degrade in the future, and in assessing when maintenance action is needed. This is not clearly communicated. The prediction of the ‘*future condition*’, as referred to in the current definition, could in theory be performed by using only generic data combined with some fixed system information, and does not fully reflect the essence of this term. The focus on the actual ‘condition’ of the equipment, is what makes ‘predictive maintenance’ different from ‘preventive maintenance’, as the assessment then relies on condition data rather than some ‘*historical data*’ (generic expected life or failure statistics), to predict when maintenance should be performed. Hence, the definition should capture the fact that it refers to maintenance strategies that is selected based on information acquired from measuring the condition of equipment, which are used to assess the time to failure, and, based on this assessment, appropriate actions are taken to mitigate the consequences of the failure.

Another new term is ‘integrity’. Which scores ‘medium’ on the V3 to V5 criteria. The reason for that is basically the use of the word ‘barrier’, which is lacking a clear interpretation. Hence it is difficult to compare it with the definition of availability (defined as ‘*ability to perform as required*’), and it is also a bit vague how to express the ‘*ability*’ of the ‘integrity’. A note to the entry, added on this would be beneficial.

The ISO 14224:2016 has made adjustments to the former ‘mean time between failure’, which is currently expressed by the term ‘mean elapsed time between failures’. In a note to entry, it is stated that the IEC 60050-192:2015 define the ‘mean operating time between failures’, yet no further clarification is provided the relationship between the two. A definition is given on ‘operating time’ in ISO 14224:2016, but not on ‘elapsed time’. The validity is therefore given a ‘medium’ on the ‘balanced’ (V4) criterion. The other four sub-criteria are given a ‘strong’ score.

The terms ‘safety critical equipment’ and ‘uncertainty’ have already been mentioned as being highly important within the RM discipline. These two require a more in-depth discussion; see Sections 5 to 6. A summary of the recommendations identified in Section 4, is summarised in the concluding remarks (Section 7).

5. Terms and definitions: safety critical equipment

5.1. General discussion

The term ‘safety critical equipment’ is defined in ISO 14224:2016, 3.84, as:

'*equipment and items of permanent, temporary and portable equipment playing an important role in safety systems/functions*'. No notes to this entry are provided.

This is an important term, especially for RM assessments concerning safety systems or systems with safety functions, as it points to a group of equipment requiring special attention. For example, monitoring of such equipment is often linked to several key performance indicators (KPIs) making use of RM data, such as percentage of outstanding maintenance actions or fraction of unacceptable tests. As a response to the Macondo blowout (the Deepwater Horizon accident) of April 2010, Skogdalen et al. (2011) suggest improvements regarding the use of indicators such as, specifically, the technical condition of safety critical equipment (e.g. digital positioning and power generation). The identification and management of such equipment is a key activity regarding the safety level (see e.g. Tremblay et al., 2007; Bell & Al Busaeedi 2015). Campos et al. (2015) succinctly state that '*the process of monitoring critical equipment aims to increase safety, availability and operational efficiency*'. See further examples of KPIs referring to such equipment in ISO 14224:2016 (in Table E.3 of the standard) and EN 15341:2007.

A term commonly confused with 'safety critical equipment' and frequently used within barrier management, is 'safety critical elements'. For example, both the Petroleum Safety Authorities Norway's (PSA) report on barrier management principles (PSA, 2013) and the industry standard NORSOK Z-008 (2011) on risk-based maintenance and consequence classification use the two terms, but without providing any definition, nor clarifying whether the terms are distinct from each other. In addition, both terms may use the abbreviation 'SCE'.

The Health and Safety Executive UK (HSE) defines the term 'safety critical elements' in the safety case regulations (HSE, 2015) as '*such parts of an installation and such of its plant (including computer programs), or any part thereof*:

1. *the failure of which could cause or contribute substantially to; or*
2. *a purpose of which is to prevent, or limit the effect of, a major accident.*'

A couple of definitions of the term are also provided in ISO documents related to the management of structures. ISO 19906:2010 on Arctic offshore structures offers the following definition: '*item of equipment, procedure or structure whose failure can lead to a major accident or whose purpose is to prevent or limit the consequences of a major accident*'. ISO 19901-3:2014 on the requirement for offshore topside structures provides the following definition: '*item of structure, piping or equipment, the failure of which can result in major accidents or which is provided to prevent or mitigate against them*'.

These are examples of two definitions that do not necessarily have to be placed in a barrier perspective, and which are quite similar to the definition given to 'safety critical equipment'.

Reference is also made to the term 'barrier elements', such as in the industry standard NORSOK D-010 (2013), where, for example, typical safety critical equipment such as downhole safety valves (DHSVs) are labelled 'barrier elements'. Similarly, Hauge and Øien (2016) refer to 'safety critical equipment' in relation to technical barrier elements, when dealing with the verification and evaluation of barrier performance. Reference to barrier elements is also made by the PSA in their annual survey of the risk level on the Norwegian continental shelf, the so-called RNNP study (see for example PSA 2016b), in which a link is established between equipment failures and the level of safety by pointing to important safety-related equipment having the potential for accidents, and therefore requiring specific attention. The identification and follow-up of such equipment is thus considered a key activity.

The link between 'safety critical equipment' and safety performance (barriers) is also captured by the definition given by Oil Companies International Marine Forum (OCIMF, 2018) as: 'a*n individual piece of equipment, control system or an individual protection device which in the event of a single point of failure may: result in a hazardous situation which could lead to an accident; or, directly cause an accident that results in harm to people or the environment*'. A similar definition was given in the previous version of the NOROG Guideline 122 (2012), which defined 'safety critical equipment' as: '*equipment that is critical and required if the barrier is to fulfil its intended function during a hazardous event*' [note that the term is not used in the revised guideline (NOROG Guideline, 2017)]. These definitions indicate that the failure of barrier items can lead to a hazardous event, and hereby provides no clear distinction between barrier items or elements and 'safety critical equipment'. Furthermore, it is assumed, from the definition, that the term is strongly linked to the functionality of the equipment, i.e. a relationship to possible equipment critical states.

A main issue, therefore, is the interpretation of 'critical', which is the principal aspect separating the term from 'safety equipment' or 'safety-related equipment' (see Vinnem, 2010). The ISO 14224 definition appears to consider 'critical' as a synonym for 'important role', which is somewhat open to interpretation and could be challenged. Consequently, the type of failures considered could guide the interpretation, meaning that any equipment that can experience 'safety critical failures' could be classified as 'safety critical equipment'.

For example, an emergency shutdown (ESD) system may consist of different types of equipment, such as control logic units, valves, etc. All of these are included because they have a role to play within the system, although not necessarily a safety-related one. Say that a redundant component, which is safety related, fails. What then? This failure, isolated, may have no immediate effect on safety. The failure is then not considered safety critical, but one could, nevertheless, argue that the equipment (the component) should be labelled 'safety critical' if the situation of both components failing significantly increases the risk of major accidents. Hence, there could be different aspects, such as functionality, possible consequences, likelihood, etc., influencing the interpretation and labelling of 'safety critical equipment'. See a similar discussion in Selvik and Signoret (2017) on different aspects associated with criticality that could influence such an interpretation related to the term 'safety critical failures'.

One could take this one step further and pursue the meaning of 'safety system'. This meaning is discussed in Selvik and Signoret (2017), where it is shown that there are differences concerning what are the consequences or unacceptable risk aspects defining such a system. The criticality could relate to both the severity of the positional consequences of failures and the possibility that some failure brings down the safety system.

5.2. Validity aspects of the 'safety critical equipment' definition

To clarify the validity of the definition given in ISO 14224:2016, the five sub-criteria given in Table 2 are considered. See also the summary of the validity assessment in Table 5.

5.2.1. V1– Axiomatic

An IEC/ISO definition should be composed such that it is replaceable with the 'term', when used in any text in which the term is used, as is clearly possible with the definition of 'safety critical failure'. It is a definition that is considered to be reasonable in the sense that there appear to be no logical problems with the way it is formulated from an axiomatic perspective, although there are reasons to question some of the wording.

For example, one may challenge the use of the 'equipment' element from the 'safety critical equipment' term, as the definition 'items of equipment' is also included, i.e. subunits, components/maintainable items or parts. Although, it can be questioned whether the '*and items …*' should instead refer to '*or items …*', as the latter sub-set is necessarily part of the first. Nevertheless, an 'item' refers to the subject being considered and gives little specificity as to what taxonomic level one is dealing with, meaning that the definition is basically applicable for any type of item, given that it is associated with a safety system or a safety function.

One may also question whether the set of '*permanent, temporary and portable equipment*' is necessary, as it appears that any type of equipment used within the relevant industries is covered by the definition.

5.2.2. V2 – Completeness

To satisfy the completeness sub-criterion, the definition should specify a precise set of equipment, meaning that the term should neither cover unintended equipment nor leave intended equipment out.

The current definition covers a broad spectrum of equipment. One could easily argue that the spectrum is too broad, due to the inclusion of any item playing an '*important role*' for the safety system or functions, which is somewhat vague. Hence, one may question whether the definition should be formulated more precisely. What equipment is captured relates to the understanding of the wording, therefore *Completeness* overlaps with *Understandable*.

5.2.3. V3 – Understandable

In IEC/ISO documents, any word that may challenge the understanding of the definition should be further clarified, for example in the notes to the entry or by the use of other definitions, such as is done for the term 'items' and 'safety system'.

Key, in relation to this sub-criterion (V3), is the understanding of '… *plays an important role* … ', which is a main aspect of the definition. For example, it should be sufficiently clear what an 'important role' is, such that one avoids, for example, two analysts interpreting the term differently and thus performing an inconsistent classification of safety critical equipment. As it is, this is not necessarily the case. 'Important role' can be interpreted synonymously with any influence on the safety performance. This complicates the definition, as any equipment whose potential failure could hinder the system in any way to perform some safety function may be labelled 'safety critical equipment'. But it is also possible to claim that only the equipment that could lead to 'safety critical failures' should be included, as one may be more focussed on the safety level or the effects or consequences of a potential failure than on the functionality of the equipment.

As indicated, some clarification is already provided through the definition of 'safety system'. The term is defined as a '*system which is used to implement one or more safety functions*' (ISO 14224:2016: item 3.86), meaning that the 'important role' may be closer to the functionality than the effects/consequences. But, then again, the inclusion of 'safety system' (i.e. '… *safety systems/functions*') instead of simply 'safety functions' indicates that this is not always the situation and gives the definition some flexibility.

One may then again argue that the definition leaves a flexibility that allows different companies to apply different principles regarding what is 'critical'. This openness is perhaps needed for the industries and involved companies to agree on one definition. However, from a pure data collection and analysis perspective, it is difficult to argue that this is any advantage, as it complicates the analysis (e.g. comparison and benchmarking) of such equipment.

5.2.4. V4 – Balanced

The term is closely related to the definitions of 'safety system'. Any change in the meaning of this definition would also influence the meaning of 'safety critical equipment'.

A clear distinction is normally made between the terms 'safety critical equipment' and 'barriers'. In situations where barriers are labelled 'safety barriers' or subdivided into 'safety critical elements', the distinction is somewhat less evident, as all refer to the ability of the equipment to mitigate risk from a safety perspective. However, a critical failure of a barrier element, while being undesirable, is generally not a safety critical failure, unless other barrier elements are also down. It simply refers to the situation of one of the barriers going down. The fundamental principle of barriers is that one should have one or more layers of protection (i.e. barriers) to avoid safety critical failures. Hence, only the final failure of a barrier (which is then composed of one or several barrier elements or safety critical elements), i.e. the one that makes it possible to penetrate the whole barrier system, is considered safety critical. However, the failure of some safety critical equipment may not relate to any barriers. The equipment may be unprotected in a sense that any critical failure may also be safety critical. Nevertheless, safety critical equipment would normally, although not always, be included as part of the safety barrier system, as such equipment has an '*important role in safety systems/functions*'. Hence, there should be no conflict between the use of the terms, 'safety barrier', 'safety critical element' and 'safety critical equipment'.

5.2.5. V5 – Applicability

Currently, the definition of 'safety critical equipment' is the only one issued in ISO documents. Hence, there are obviously no conflicting ISO/IEC definitions of this term that could have been selected instead. However, there are several interpretations of what 'safety critical elements' mean in existing ISO documents (see Section 5.1 above), which could also be appropriate for use in ISO 14224, given that one would be willing to change the labelling of the term from 'equipment' to 'elements'. However, as 'safety critical elements' are strongly associated with barrier management, it is considered more appropriate to introduce and formulate a new definition of 'safety critical equipment', as this is a term much used within the industries. See further recommendations in the concluding remarks (Section 7).

6. Terms and definitions: uncertainty

6.1. General discussion

'Uncertainty' is a commonly used concept relating to possibilities, typically described by a probabilistic expression, regarding what is the result or outcome of an activity or situation. It has a wide range of applications, including RM and associated disciplines, such as decision analysis, risk analysis, safety engineering, structural analysis and planning. When used within these applications, it may take at least one of the three interpretation categories below as a basis for uncertainty quantification:

1. Stochastic (or aleatory) uncertainty; SU: A measure related to variation (inherent variability; see e.g. ISO 2394:2015)
2. Epistemic (or subjective) uncertainty; EU: A measure related to lack of knowledge (see e.g. ISO 2394:2015)
3. Measurement uncertainty (errors); MU: A measure related to accuracy (see. e.g. Taylor, 1997; and Salicone, 2007)

Within the scope and content of ISO 14224, all these categories may be relevant. For example, reduced uncertainty in decision-making is mentioned in this international standard as one of the benefits of the application that could create business and industry value. Such 'uncertainty' could relate to all three categories. More specificity is needed, to identify which is the most appropriate one.

Hence, there is clearly a need for a definition to clarify the specific meaning. The following definition is given (ISO 14224:2016, item 3.95):

> inability to determine accurately what is or will be the true value of a quantity.

This is an interesting and new definition not currently given in any other international standard or guide. The use of the word 'accuracy' may indicate that the definition relates to 'measurement uncertainty', although this is not obvious from the note to this entry. This states that '*uncertainty can have different meanings within reliability data collection and exchange. It can be used as a measure of variability within a population, which is a type of uncertainty often referred to as stochastic (or aleatory) uncertainty. Uncertainty can also have a subjective meaning (epistemic uncertainties)*'.

Reliability data collection is often occupied with what is the correct value when specifying equipment-specific data or data from failure and associated maintenance events. For example, the data collector must specify the active maintenance time, which relates to accuracy.

The ISO 14224:2016 definition questions the ability to determine some value in an accurate manner. Following the traditional meaning of accuracy as the closeness between the produced value and the specified reference value (ISO 5725-1: 1994), the main focus is on the error, i.e. the discrepancy between a computed, observed or measured value or condition and the true, specified or theoretically correct value or condition (IEC 60050-192:2015).

As an example, say that a data collector is to specify the active maintenance time: X. Then, the uncertainty relates to some inability to produce an accurate estimate of X, i.e. X* (see Figure 1). The main challenge is then to say (determine) whether this estimate is within some accuracy range and how wide this range should be. However, it is difficult to see whether this inability is due to lack of knowledge or variation, although the latter is perhaps indicated through the link to 'classical' statistical theory by stating that the uncertainty of the estimate may be presented as a 90% confidence interval with a lower limit and an upper limit (see ISO 14224:2016, p. 216).

This way of defining the term relates specifically to the concept of 'uncertainty', whereas the aspect of what the inability refers to is rather a matter of how the uncertainty is described. A similar distinction is made with respect to risk (see for example ISO/IEC Guide 73:2009).

Nevertheless, there are also several other ISO definitions, as shown in Table 6, some of which could be considered appropriate for ISO 14224. Although this is not a complete list, it indicates a lack of consensus on a definition suiting all applications. A separate column is included for the categorisation of the uncertainty interpretations.

As perhaps expected, the definition most frequently referred to and used in ISO documents is the one given in ISO/IEC Guide 99:2007, *International vocabulary of metrology – Basic and general concepts and associated terms* (VIM), and ISO/IEC Guide 98-3:2008, *Uncertainty of measurement – Part 3: Guide to the expression of uncertainty in measurement* (GUM). These are two key documents dealing with measurement uncertainty. This definition is applied in about 60% of the ISO documents dealing with 'uncertainty', i.e. 57 out of 91 definitions of this term. In addition, there are

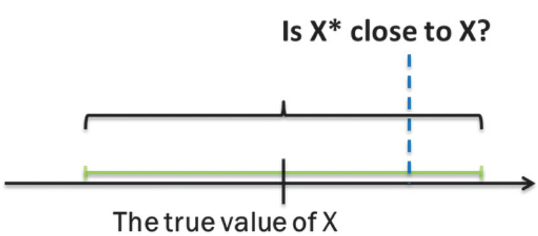

Figure 1. Illustration of the accuracy of a measurement X* given the true value X.

Table 6. Sample of different definitions of 'uncertainty' given in ISO documents.

Definition	Category	Source
inherent variability typically associated with the loading environment, the geometry of the structure, and the material properties	AU	ISO 2394:2015
condition appearing when a value cannot be determined during consultation, or a fact or a rule in the knowledge base remains in doubt	EU	ISO/IEC 2382:2015
lack of knowledge that, in principle, can be reduced by measurements or improved theories	EU	ISO 2394:2015
estimate characterising the range of values within which the true value of a measurand lies	MU	ISO 4006:1991
An estimate attached to a measurement result, which characterises the range of values within which the true value is asserted to lie	MU	ISO 14111:1997
quantification of systematic and random error in data, variables, parameters, or mathematical relationships or of failure to include a relevant element	MU	ISO 16732-1:2012
parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand	MU	ISO/IEC Guide 98-3:2008

also definitions of combined terms in which 'uncertainty' is included, such as 'expanded uncertainty', 'model uncertainty', 'overall uncertainty' and 'standard uncertainty'. In total, 383 hits are produced from the population of ISO documents defining some variant of 'uncertainty'.

Descriptions of the term also exist in definition notes to the entry, not included in the count above. One of these is in the ISO Guide 73:2009, 1.1 – Note 5 to entry, where 'uncertainty' is explained below the definition of risk ('*effect of uncertainty on objectives*'), as: '*the state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequence, or likelihood*'.

Furthermore, Note 4 to the entry in the same document also links uncertainties to a probabilistic interpretation, by stating that risk is '*often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated likelihood of occurrence*'. Hence, the interpretation given from ISO/IEC Guide 73:2009, although it could be considered applicable with respect to categories Nos. 1 and 2 above, would not be particularly appropriate for No. 3, dealing with measurement uncertainty. Measurement uncertainty may relate to a deficiency of information and may also be handled through a probabilistic framework (as in e.g. Salicone, 2007), but then normally by focussing on the past or current situation and not with future events.

Finally, there are also other definitions of 'uncertainty', such as the definitions developed by the Society of Risk Analysis (SRA, 2015), as one example out of many sources not linked to a standardisation organisation. These could have been applicable, given an appropriate IEC or ISO definition was not available. However, preferably, an existing ISO or IEC definition should be used.

6.2. Validity aspects of the uncertainty definition

As in Section 4, the five sub-criteria given in Table 2 are used to study the validity of the uncertainty definition. See also the summary of the validity assessments in Table 4.

6.2.1. V1– Axiomatic

There should be no axiomatic problems with the current definition. Axiomatic-wise, it is considered sound.

6.2.2. V2 – Completeness

The term 'uncertainty' could be attributed to limitations in available information or to the inherent nature of the activity such as variation or error. To what extent the essential attributes are given by the definition is thus a matter of interpretation. Based on the sample of definitions given in Table 6, clearly there could be some missing attributes. In particular, the ISO 14224:2016 definition does not specify whether uncertainty is a state, condition, parameter or estimate, which is clearly specified by some of the other definitions. However, one could also argue that such specificity is not needed.

The given definition might be considered to have a weak spot concerning the meaning of '*inability*', which is a key attribute. Failing to specify what this inability refers to makes it possible to interpret the term within all three categories mentioned above; i.e. it may refer to lack of knowledge, variability or errors, although one could see 'errors' as part of the 'lack of knowledge' interpretation. For example, uncertainty due to limitations in measuring device could be attributed to 'lack of knowledge' (see for example Salicone, 2007).

The definition also refers to a '*true value X*' as a value that is realised at present or at a time in the future. Hence, the definition is not valid for situations such as whether a failure will occur during the next month, which is formulated as a 'yes or no' question. Hence, the text, '*reduced uncertainty in decision-making*', might not be fully covered by the definition. Uncertainty as 'confidence in the decision taken' is not covered by the definition in ISO 14224:2016, which strictly covers values and the ability to somehow produce the correct ones.

6.2.3. V3 – Understandable

Compared to the other definitions of uncertainty given in Table 4, the one proposed adds complexity by introducing an 'accuracy' aspect, whose interpretation is not straightforward. This is dependent on the definition of accuracy, which is not explicitly referred to in ISO 142224:2016. Some further notes to this entry, giving insight into the range of use, would be beneficial.

The '*inability to determine accurately*' is an especially interesting part of the definition. It refers to the lack of information regarding what the value X is or will be. However, such information may never become available, to reveal what the true value in fact is. For measurements, one could specify some level of accuracy and precision, and thus offer some understanding related to uncertainty and what could be the variation of the true value, although further clarification is required to specify which values are inside the accuracy area (See Figure 1), i.e. where the estimate or prediction of X is sufficiently close to the true X. Currently, the definition leaves it to the assessor to determine which values are considered accurate.

Similarly, within an epistemic uncertainty framework, a subjective probability may be produced to express the degree of belief concerning some observable value or quantity. The uncertainty then reflects the assessor's knowledge, instead of expressing the inherent limitations of some measuring device. The assessor may produce the correct value by, for example, guessing but is not able to specify the one value with full certainty.

6.2.4. V4 – Balanced

The use of the term 'accuracy' makes the definition applicable to multiple uncertainty aspects of relevance within the RM discipline. At the same time, by introducing a definition of uncertainty with the concept of 'accuracy', the ISO 14224 adopts a definition clearly different from the way 'uncertainty' is expressed in e.g. the ISO 31000:2018. Obviously it could make sense to adopt one or several definitions from other IEC/ISO documents, but by introducing this new one, it signal that an appropriate one is not found. The much used definition from ISO/IEC Guide 99:2007, is a relevant alternative, where uncertainty is a '*non-negative parameter characterising the dispersion of the quantity values being attributed to a measurand, based on the information used*'. This is adopted for several IEC document (see IEC, 2019), and is a definition that could have been adopted, but would fail to cover any epistemic aspects. At the same time, is seems clear that if the term were defined this way in the IEC 60050-192:2015, then this definition of uncertainty would most likely have been adopted by the ISO 14224:2016.

The type of uncertainty expressed as the most relevant for the ISO 14224 document, and the application of it, is the stochastic uncertainty

(SU) type, which expresses variation of the values. Some would prefer to label this type simply as 'variation' (see for example Begg et al., 2014), to avoid the link to uncertainty and thus limit different types. Besides, except for the part in the text linking uncertainty to decision-making, all the applications of uncertainty in RM data collection and the use described in ISO 14224 appear to concern the SU type. Currently, in this international standard, no specific definition is given of the SU, nor EU, as the one definition proposed in the document is assumed applicable for all applications.

Furthermore, the section on the handling of uncertainty inside the documents gives little indication that there is a need to interpret uncertainty in any new way, compared to how it is used in previous editions or in industry. Based on this section, it seems sufficient to cover the SU aspects.

However, although the definition in ISO 14224:2016 might be applicable to both SU and EU situations, and thus is not in conflict with other types of uncertainty, it provides limited insight into what the '*inability*' refers to. This would be clearer if, instead or in addition, the SU or EU terms were specifically applied. This is also why it is important to include the given note to this entry; '*uncertainty can have different meanings within reliability data collection and exchange. It can be used as a measure of variability within a population, which is a type of uncertainty often referred to as stochastic (or aleatory) uncertainty. Uncertainty can also have a subjective meaning (epistemic uncertainties)*'. The note specifies the distinct meaning of the two, although, according to the IEC/ISO principles, it would be better to include full definitions of all these terms, instead of including them somewhat hidden in the notes to the entry.

6.2.5. V5 – Applicability

This new definition of uncertainty is not in any way in conflict with traditional ways of handling uncertainty. It allows for all three of the types listed at the beginning of Section 5. One could claim that it covers all of them at a conceptual level, although it clearly also has some limitations regarding being restricted to true values.

From an applicability perspective, some clarification is required as to what the '*inability*' refers to. This provides important information about the source of the uncertainty, i.e. whether this is due to inherent system aspects or the knowledge of the assessors. If not clarified, one could easily see that the assessors interpret the definition in different ways and use it inconsistently. This part is inadequately described in the document and should be improved in the next revision of this international standard.

It could be questioned whether, instead, distinct definitions of 'uncertainty', capturing the description aspects and thus the different types listed in Section 6.1, should have been included in this international standard, or whether the one that is included is sufficient because it captures all application areas. Some recommendations are suggested in the Section below (section 7). Currently, the one proposed is also used in several places and with different meanings. Hence, the notes to the entry are highly relevant, as justification is given to the different aspects.

7. Concluding remarks

Besides, discussing the quality of the new ISO 14224:2016 definitions, a main objective and contribution of the paper is to demonstrate a way to assess validity of definitions by using the five sub-criteria introduced. These are applicable also to other standards or technical documents, as they are generic and in no way specific to one discipline or application area.

Applying these sub-criteria support the claim that the ISO 14224:2016 includes useful definitions for use in RM data collection and exchange within the petroleum, petrochemical and natural gas industries. Being the key document to provide extensive guidance, it has a strong influence on how to communicate RM information for analysis purposes associated with decision-making within these industries. Hence, it is important that the vocabulary, including the terms and definitions, in general has strong validity, which, based on the assessment shown in this paper, is, overall, the situation for the new definitions proposed in the revised ISO 14224. This article also identifies some new definitions introduced that could benefit from modification, such as for example the term 'equipment type', which has a couple of weak aspects and are not given a high validity score from the assessment shown in Table 4. This scoring may be used to identify both the strength of the validity and the need for clarification or modification of the terms for the next revision of ISO 14224 and when these are adopted for use in other IEC/ISO documents.

The definition proposed for the term 'safety critical equipment' is considered acceptable from a validity perspective, although some clarification regarding the meaning of '*important role*' would add more specificity to, and could improve, the definition. Furthermore, this is a much-used term within the industries mentioned above. Including it places emphasis on the distinction between 'safety critical equipment' and 'safety critical elements'. Hence, it is an important term to define in ISO 14224.

A way to achieve a more specific definition of this term, is by establishing a stronger link to 'safety critical failures', instead of the ambiguous '*… important role …*' part. Thus, a more appropriate and recommended definition is:

> equipment or items of permanent, temporary and portable equipment, where a failure can trigger an unsafe situation and make a hazardous event possible.

The recommended definition is in line with the interpretation of 'safety critical failure' recommended in Selvik and Signoret (2017) based on discussions on how the term is used in international standards and technical reports, e.g. ISO 14224:2016 and ISO/TR 12489:2013.

The same applies to the definition of the term 'uncertainty', which is also a key term within the industries, and which requires a definition, as one was missing from the previous editions of this international standard. Some clarity regarding the meaning of '*inability to determine accurately*' would improve the definition. Some notes to entry could be added. It could also be beneficial to include separate definitions of uncertainty, to reflect and specify whether it refers to knowledge, variation or measurement aspects. This is the recommended way. As it is, these aspects are somehow merged into the one definition given. At the same time, a distinction is made between the concept and the description of uncertainty, meaning that the specificity related to the aspects may depend on the situation in which it is used.

In contrast to the definition of 'safety critical equipment', several definitions of 'uncertainty' already exist in ISO/IEC documents, although many of these are perhaps not applicable to the use proposed in ISO 14424:2016. Thus, one could expect some resistance to this new definition from the industries or academic communities in the ballot process in which the definition was approved. However, although more than 300 comments were collected for the draft (DIS) version of this international standard, none of these concerned the uncertainty definition, which implies that the definition appears acceptable for use, although it remains somewhat open as to how it holds up in practice. Further work is recommended, to test the applicability of this new definition and to see how this influences risk communication and decision-making.

Validity of also the other new definitions are assessed in this article, although main attention is given to the definitions of safety critical equipment' and 'uncertainty'. Generally the impression is that the definitions have strong validity, and all are acceptable, but also some weak points are identified. Some recommendations are given as input to the next revision of ISO 14224. A summary is given below.

- Active repair time: The distinction between active repair time and maintenance time should be expressed by the definition. This could be achieved by adding a note to entry on this.

- Detection method: When the term is referring to a 'method' it can be questioned why the definition cover '*method or activity*'. Another wording should be considered.
- Equipment type: Somewhat ambiguous definition, should be modified as it is not sufficiently clear how the term separates from 'design class'.
- Integrity: The definition is good as is, but could benefit a note to entry on whether the 'ability to function' is expressed using probabilities. A definition of 'barrier' should also be added.
- Mean elapsed time between failures: It is not sufficiently clear how 'elapsed time' compare with 'operating time'. The notes to entry should be more specific on this.
- Mean time to repair: Not sufficiently clear how this term differ from the mean active time to failure and the mean time to restoration. It should be more specific on time period included.
- Predictive maintenance: Should specify that the assessment of '*future condition*' is based on the actual condition of the item and not just '*historical data*'.
- Turnaround: Consider using another word than '*revamp*' in the definition, but generally acceptable.

In this article, focus is mainly on the new definitions of ISO 14224:2016. It should be noted that in addition several definitions are adopted from other standards and technical documents, by that achieving approval from at least two publication processes. First it is approved by the ballot of the source document when this was published, and then recently also by the ISO 14224 ballot. Obviously a definition could be then adopted according to the principle of preventing a variety of similar definitions, nevertheless, it is adopted based on the working committee considerations of this as the 'best option'. At the same time, the point that it is already published, somewhat empowers the definition, and makes it easier to reuse the definition instead of making a new one – it is already approved and there are good chances that it will pass another ballot process.

Applying the five sub-criteria presented in this article is a way to also study the validity of the remaining definitions, although this has not been the focus in this article. There are indications that also some of the ones adopted from other documents should be improved in future revisions. For example, the term 'random failure', which is adopted from ISO/TR 12489:2013 as '*failure, occurring in a random way*' is clearly circular and, thus, fails criterion V1. Thus, the definition provides limited assistance in interpreting this term within the RM context.

Generally, the five validity sub-criteria offer a way of identifying weaknesses of definitions considered. But it also gives a picture of the strength.

And generally the impression is that the definitions provided by the revised ISO 14224 is having a high quality. The findings give strong support to this standard as a key guidance document for RM data collection, exchange and analysis.

The findings also indicates the importance of having key personnel involved in standardisation work, either as part of a working committee or participating in the ballot processes. Currently, it seems that a major part of the scientific community fails to be involved in such activities. The lack of response in the ballot process, with respect to the terms and definitions, is an indication of this. For example, with the current focus on uncertainty within these industries, and also within the academic community, especially in relation to risk and reliability analysis, and with the close link established between risk and uncertainty, one would expect greater involvement and interest in the definition of 'uncertainty'. This may be partly due to disincentives such as lack of credit, cost issues, the rigid process of standardisation, and the reputation of often ending up with a product that is a consensus-based and a compromise between the involved participants.

It is an important principle for standardisation work that the technical committees should are made up of experts from a broad set of experts reflecting the possible users of the standard, such as industry, academia and consultants. This is a way to allow for a process where relevant stakeholders are taken into account. Further, there should be more openness towards external contribution. To increase involvement in the community, particularly from academic institutions, the involved expert members should also have a responsibility to consult relevant experts outside the technical committee and make these aware of ongoing technical matters and ballot processes.

The final product is highly dependent on the composition of the committee and the involvement of dedicated and competent people. Nevertheless, it is important to have expertise beyond those directly involved in the standardisation committees, to add quality and value to the products. There is a wide and shared responsibility, to ensure a high quality of the standards produced.

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This article may be relevant as contribution to standardisation work, but is not produced as part of any standardisation initiative.

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Appendix

The terms below have new definitions in ISO 14224:2016. Terms not defined in the previous edition (i.e. ISO 14224:2006) are marked with *.

- The terms defined with ISO 14224 as source: active repair time*, detection method*, downstream*, equipment type*, integrity*, mean cycles to failure*, mean number of cycles*, mean elapsed time between failures (METBF)*, mean time to repair (MTTR)*, midstream*, mobilisation time*, petrochemical*, predictive maintenance*, safety critical equipment*, software error*, tag number, trip*, turnaround*, uncertainty* and upstream*.
- The terms defined with IEC 60050-192:2015 as source: active maintenance time, availability, common cause failure, common mode failure*, condition-based maintenance*, corrective maintenance, down state, failure, failure cause, failure mechanism, failure mode, fault, human error*, idle state*, idle time, item, latent fault*, life cycle*, logistic delay, maintainability, maintenance, maintenance concept*, maintenance supportability*, operating state, planned maintenance*, preventive maintenance (PM) and up state.
- The terms defined with ISO 20815:2008 as source: design life*, performance objective*, performance requirement* and reliability data*.
- The terms defined with ISO/TR 12489:2013 as source: failure due to demand*, failure frequency*, failure on demand, failure rate*, mean active repair time (MART)*, mean overall repairing time (MRT)*, mean time to failure (MTTF)*, mean time to restoration (MTTRes)*, periodic test*, random failure*, safety critical failure*, safety system* and systematic failure*.
- The terms defined with other source: cycle* (IEC 60050-444:2002), human fatigue* (Moore-Ede, 2009) and maintenance plan* (EN 13306:2010).