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Standardized risk assessment techniques: A review in the framework of occupational safety

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ABSTRACT: The publication in 2018 of ISO 45001 is the first international ISO standard in the field of occupational health and safety management systems. ISO 45001 is the result of an international consensus on the subject and describes the best international preventive practices and incorporates the requirements of a management system aligned with the so-called High-Level Structure of the ISO standards of management systems. Simultaneously, ISO/IEC 31010:2009 provides for the selection and application of systematic techniques for risk assessment. However, this standard does not address safety in a specific way. It is a generic standard for risk management and any reference to safety is simply informative. Thus, the main objective of the present work is to identify and classify the main techniques included in the ISO/IEC 31010:2009 standard applicable in the field of occupational safety and in line with the requirements for the ISO Standard 45001. As a secondary objective, it is sought in the same context to identify the main non-standard techniques of new or emerging nature. This process of identification and classification has been carried out by means of a systematic review of the scientific literature specialized in the matter. The results have been classified according to bibliometric indicators in the following groups: (a) Main standard techniques for application to occupational safety; (b) Main techniques developed through specific standards (such as: IEC 61882:2016 – Hazard and operability studies [HAZOP studies] – Application guide; IEC 61025:2006 – Fault Tree Analysis [FTA]); (c) Main non-standard techniques of a new or emerging nature for application to occupational safety. Finally, the results obtained by the classification mentioned above have been analyzed in order to determine the degree of coverage and standardization of the main risk assessment techniques applied to occupational safety.

1 INTRODUCTION

The European Agency for Safety and Health at Work together with the International Labour Organization has estimated of the cost of poor occupational safety and health. Such estimation reveals (EU-OSHA, 2017): Worldwide work related injury and illness result in the loss of 3.9% of GDP, at an annual cost of roughly € 2680 billion; Work-related illnesses account for 86% of all deaths related to work worldwide, and 98% of those in the EU; 123.3 million DALY (disability-adjusted life years) are lost globally (7.1 million in the EU) as a result of work-related injury and illness. Of these, 67.8 million (3.4 million in the EU) are accounted for by fatalities and 55.5 million (3.7 million in the EU) by disability; and in most European countries, work-related cancer accounts for the majority of costs (€ 119.5 billion or 0.81% of the EU's GDP), with musculoskeletal disorders being the second largest contributor.

In order to combat the problem, ISO has developed a new standard, ISO 45001, Occupational health and safety management systems—Requirements, that will help organizations reduce this burden by providing a framework to improve employee safety, reduce workplace risks and create better, safer working conditions, all over the world. This standard follows other generic management system approaches such as ISO 14001 and ISO 9001 (ISO, 2017).

The current version ISO/DIS 45001.2:2017, contemplates in its section 6.1.2.2 that the organization must establish, implement and maintain one or several processes to assess the risks for safety and health at work from the identified hazards, taking into account legal requirements and other requirements and the effectiveness of existing controls (the concept of organization, include among others, a company, firm, enterprise, etc.). Nevertheless, this standard does not specify the techniques or methodologies to assess the occupational safety and health risks.

Simultaneously, the standard ISO/IEC 31010:2009 provides for the selection and application of systematic techniques for risk assessment.

However, this standard does not address safety in a specific way. It is a generic standard for risk management and any reference to safety is simply informative.

Thus, the main objective of the present work is to identify and classify the main techniques included in the ISO/IEC 31010:2009 standard applicable in the field of occupational safety in a way in line with the requirements for the risk assessment included in the ISO Standard 45001 (Currently, ISO/IEC 31010 is under review. For the moment, ISO/IEC/DIS 31010: 2017 is published under development)

As a secondary objective, it is sought in the same context to identify the main non-standard techniques of new or emerging nature.

2 METHOD

We conducted a systematic search in the occupational safety literature. A systematic review of the literature is typically based on a detailed and comprehensive plan and search strategy derived a priori in order to reduce bias (Uman, 2011). We aim to present an overview of techniques addressed in both quantitative and qualitative research on occupational safety, and their general direction (e.g. Cornelissen et al., 2017). Below, we will elaborate on our systematic selection process and analysis.

2.1 *Literature search*

As indicated by Goerlandt et al. (2017), in traditional indexing systems such as Scopus and Web of Science, risk analysis is not considered as a separate category in the scientific research areas. Instead, contributions related to risk are typically listed under "mathematics", "social sciences" or "engineering". Hence, general searches in those systems on terms such as "risk analysis", "validation" and "QRA" results in many hits, with low relevance to the above stated aims.

Therefore, another review method has been applied (November, 2017). To do this, we chose a literature search using broad search terms as a starting point. To this end, we selected as search criteria the use of the keywords "risk" and "review" in the journal title. In addition, we delimited the search in "engineering" and "chemical engineering" fields using ScienceDirect databases. The results were the following: Engineering field: 90 records published all years (1995–2018); Chemical engineering field: 48 records published all years (1988–2017).

With these criteria, the journal principals identified in the work of Reniers and Anthone (2012) have been included, except Journal Risk Analysis. These authors found that the most well-respected journal by expert opinion was the Journal of Loss Prevention in the Process Industries. However, taking into consideration both the respondents' results and the citation-based results into consideration, the Journal of Hazardous Materials is the most influential journal, followed by Reliability Engineering and System Safety, Risk Analysis, Accident Analysis and Prevention and Safety Science.

2.2 *Article selection*

The further selection of articles was performed in steps, as depicted in Figure 1.

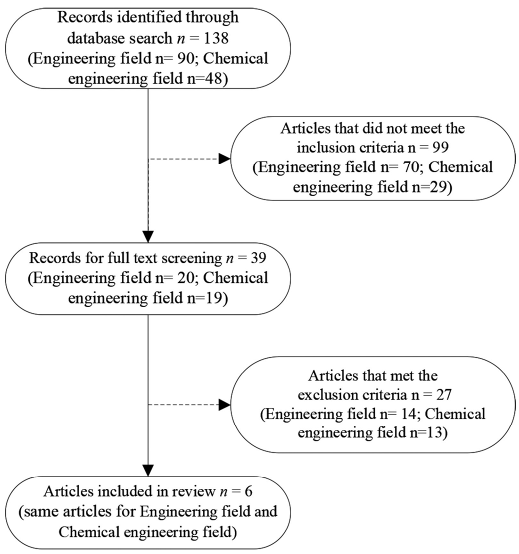

Figure 1. Flow diagram of study selection.

First, the titles were evaluated and articles that did not meet the following inclusion criteria were marked: (a) describe safety in an occupational setting; (b) focus on the application, study or analysis of techniques of identification, analysis or risk assessment applied to occupational safety; (c) conducted in the construction, manufacturing, offshore, or petrochemical sector; (d) published in a peer-reviewed journal; and (e) be written in English.

Second, the full text of the articles obtained after the application of the previous step, were analyzed. In this regard, the following exclusion criteria were applied: (a) only one specific technique is applied; (b) collect several techniques only by way of example; (c) conducted on driving or transportation; (c) conducted on risks in natural disasters.

Third and finally, the articles obtained were included in the review process. In this regard, both the Engineering field and the Chemical engineering field obtained the same 6 results (Table 1).

2.3 *Analysis*

The analysis of the articles was developed as follows.

a. Articles that contain a classification or set of techniques related to standard ISO/IEC 31010: 2009. First, each article has been analyzed with the aim of identifying those techniques that coincide with the list of techniques included in Annex A of ISO/IEC 31010: 2009. Second, those techniques that are developed through specific standards have been identified. To do this, the reference documents of the standard have been analyzed (ISO/IEC 31010: 2009 and ISO/IEC/DIS 31010:2017). In addition, each technique has been checked if it has been developed through any standard published by any of the following standardization bodies: International Organization for Standardization (ISO), European Committee for Standardization (CEN) and International Electrotechnical Commission (IEC).
b. Articles containing other techniques not collected to ISO/IEC 31010. The main techniques have been identified.

Table 1. Articles included in review (n = 6).

Nr	Paper citation	Field of application	Journal
1	Kjellén and Sklet (1995)	Offshore industry	SS
2	Tixer et al. (2002)	Risk analysis on an industrial plant	JLPPI
3	Marhavilas et al. (2011)	Work sites	JLPPI
4	Dallat et al. (2017)	Safety management, (risks that may lead to accidents)	SS
5	Villa et al. (2016)	Chemical and process Industries	SS
6	Yang et al. (2017a)	Petroleum activities	SS

SS: Safety Science; JLPPI: Journal of Loss Prevention in the Process Industries.

3 RESULTS

The results presented in this section follow the scheme accordingly for the analysis of the articles included in the review.

3.1 *Main standard techniques for application to occupational safety*

Table 2 lists the existing relations between the techniques identified in the reviewed articles (1–4) and the techniques included in Annex A of ISO/IEC 31010: 2009.

The following results can be observed in the Table 2: 18 techniques are collected in a single reference (Nr Paper citation); 7 techniques are collected in two references; 3 techniques are collected three references; and 3 techniques in four references.

3.2 *Main techniques developed through specific standards*

Those techniques that are developed through specific standards have been identified in the Table 3.

Thus, 10 techniques of the 31 collected by ISO/IEC 31010: 2009 are identified. Comparing these 10 techniques with the results of Table 2, it can be observed: 4 techniques are collected in a single reference (techniques Nr 11, 12, 24 and 25); 1 technique is collected in two references (13); 3 techniques are collected in three references (6, 20 and 22); and 2 techniques (14 and 15), in four references.

Of the 10 techniques listed in Table 3, all of them except Reliability centered maintenance (RCM), have also their correspondence with European Standards (ENs) published by the European Committee for Standardization (CEN, 2017).

3.3 *Main non-standard techniques of a new or emerging nature for application to occupational safety*

Tables 4 and 5 list the existing relations between the techniques identified in the reviewed articles (5–6).

Table 2. Relations between techniques identified in reviewed articles and Annex A of ISO/IEC 31010: 2009.

Nr	Annex A ISO/IEC 31010/2009	Nr Paper citation 1	2	3	4
1	Brainstorming	N	N	N	Y
2	Interviews	N	N	N	Y
3	Delphi technique	N	Y	N	Y
4	Check lists	N	Y	Y	Y
5	Preliminary Hazard Analysis (PHA)	N	Y	N	Y
6	Hazard and operability studies HAZOP	N	Y	Y	Y
7	Hazard analysis and critical control points HACCP	N	N	N	Y
8	Environmental Risk Assessment (ERA)	N	N	N	Y
9	Structured what if technique SWIFT	N	Y	Y	Y
10	Scenario analysis	N	N	N	Y
11	Business Impact Analysis (BIA)	N	N	N	Y
12	Root Cause Analysis (RCA)	N	N	N	Y
13	Failure Modes and Effect and Analysis (FMEA)	N	Y	N	Y
14	Fault Tree Analysis (FTA)	Y	Y	Y	Y
15	Event Tree Analysis (ETA)	Y	Y	Y	Y
16	Cause consequence analysis	N	N	N	Y
17	Cause and effect analysis	N	N	N	Y
18	Layers of Protection Analysis (LOPA)	N	N	N	Y
19	Decision tree	N	N	N	Y
20	Human Reliability Analysis (HRA)	N	Y	Y	Y
21	Bow tie analysis	N	N	N	Y
22	Reliability Centered Maintenance (RCM)	N	Y	Y	Y
23	Short cut risk analysis (SCRAM)	N	Y	N	Y
24	Markov analysis	N	N	N	Y
25	Monte Carlo analysis	N	N	N	Y
26	Bayes analysis and Bayesian networks	N	N	N	Y
27	F/N diagrams	N	N	Y	Y
28	Risk índices	N	N	N	Y
29	Consequence likehood matrix	N	N	Y	Y
30	Cost-benefit analysis	N	N	N	Y
31	Multi criteria analysis (MCDA)	N	N	N	Y

Y (YES): The technique (Nr) is collected by the Paper (Nr) (NOT): The technique (Nr) is not collected by Paper (Nr).

Theoretical and practical limitations affecting results of hazard identification suggest the need for an improvement of current techniques (Paltrinieri et al., 2016). Yang et al. (2017a) indicated that several aspects of operational decision making creates a need for different risk analyses compared to the traditional Quantitative Risk Analysis (QRA) with principles and guidelines described in standard ISO 31000:2009, which are developed more for design purposes.

Yang et al. (2017a) reviewed 11 risk influence-frameworks that integrate organizational and human factors in a structured way (Table 4). The intention was to evaluate how these frameworks

Table 3. Techniques included in Annex A of ISO/IEC 31010: 2009 that are developed through specific standards.

Nr	Annex A ISO/IEC 31010/2009	Specific standards
6	Hazard and operability studies HAZOP	IEC 61882:2016
11	Business Impact Analysis (BIA)	ISO TS 22317:2015; ISO 22301:2012
12	Root Cause Analysis (RCA)	IEC 62740:2015
13	Failure modes and effect and analysis (FMEA)	IEC 60812:2006
14	Fault Tree Analysis (FTA)	IEC 61025:2006
15	Event Tree Analysis (ETA)	IEC 62502:2010
20	Human Reliability Analysis (HRA)	IEC 62508:2010
22	Reliability Centered Maintenance (RCM)	IEC 60300-3-11: 2003
24	Markov analysis	IEC 61078:2016; IEC 61165:2006; ISO/IEC 15909-1:2004
25	Monte Carlo analysis	IEC 62551:2012; ISO/IEC Guide 98-3-SP1:2008

Table 4. Risk influence frameworks (techniques) that integrate organizational and human factors in a structured way (adapted from Yang et al., 2017a).

Technique	Paper citation	Field of application
Model of Accident Causation using Hierarchical Influence Network (MACHINE)	Embrey (1992)	General
WPAM		Nuclear
System Action Management (SAM)	Paté-Cornell and Murphy (1996)	General
ω-factor model	Mosleh et al. (1997); Mosleh et al. (1999)	Nuclear
Integrated Risk (I-RISK)	Papazoglou et al. (2002)	Chemical
(Organizational Risk Influence Model (ORIM)	Øien (2001a, 2001b)	Oil & Gas
Barrier and Organizational Risk Analysis (BORA)	Aven et al. (2006)	Oil & Gas
RISK_OMT	Vinnem et al. (2012)	Oil & Gas
Hybrid Causal Logic (HCL)	Røed et al. (2009)	Oil & Gas
Socio-Technical Risk Analysis (SoTeRiA)	Mohaghegh et al. (2009); Mohaghegh and Mosleh (2009)	General
Phoenix	Ekanem et al. (2016).	General

and identified Risk Influencing Factors (RIFs) can be used for activity related risk analysis.

Real-time data and periodical risk evaluation may be considered as a key improvement to allow for effective decision-making support (Bucelli et al., 2017). However, being static QRA precludes any possible update and integration of the overall risk figures, due to the actual real world ever-changing environment or later improvements based on new risk notions. To overcome this limit, during the last decade several efforts have been devoted to the development of novel approaches to risk assessment and management, which can be considered the dynamic evolution of conditions, both internal and external to the system, affecting risk assessment (Paltrinieri and Scarponi, 2014). The main purpose of dynamic risk assessment is the development of an appropriate technique that allows for the effective aggregation of heterogeneous information and provides risk estimation over time reflecting the current condition of the system (Yang et al., 2017b).

Villa et al. (2016) reported a brief description of the most relevant methodologies and applications of dynamic approaches to risk analysis in the chemical process industry.

Table 5 shows a list of these dynamic methodologies. These methodologies (or techniques) have evolved over time according to Villa et al. (2016) describe in detail. In this way, the list of techniques

Table 5. List of the most relevant methodologies (techniques) of dynamic approaches to risk analysis in the chemical process industry (adapted from Villa et al., 2016).

Technique	Paper Citation
Dynamic Risk Assessment Methodology (DRA)	Kalantarnia et al. (Abimbola et al., 2014; Kalantarnia et al., 2010, 2009; Khakzad et al., 2013a
Dynamic Procedure for atypical scenario identification (DyPASI)	(Paltrinieri et al., 2011, 2013a, 2013b).
Coupling of DRA and DyPASI	(Paltrinieri et al., 2014b, 2014c, 2013a, 2013b).
Dynamic risk assessment with bayesian networks	Khakzad et al. (2013b, 2011)
Risk barometer	The Center for Integrated Operations in the Petroleum Industry (Hauge et al., 2015; Paltrinieri and Hokstad, 2015; Paltrinieri et al.,2015, 2014a)

collected in Table 5 are linked to the most recent citations according to Villa et al. (2016).

4 ANALYSIS AND DISCUSSION

The results obtained can be grouped into two groups of techniques for application in the field of occupational safety: standardized and non-standard techniques of a new or emerging nature.

In relation to the standardized techniques, of the 31 techniques included in Annex A of ISO / IEC 31010, the following techniques are among the most used: HAZOP, SWIFT, HRA, FTA, ETA and RCM. In turn, these techniques are developed through specific standards (IEC-EN), except the SWIFT technique.

Regarding non-standard techniques of a new or emerging nature, new risk influence frameworks as well as new dynamic techniques are observed.

Among the first techniques, the following ones can be cited according to its closeness in time (last decade): HCL (2009), RISK_OMT (2012), SoTeRia (2009) and Phoenix (2016). In relation to dynamic techniques, stand out the following: DRA, DyPASI, DRA-DyPASI and Risk barometer.

However, the set of the foregoing results should be considered as an approximation in the framework of occupational safety. This approximation is due to the characteristics of the method followed, which are linked to three important limitations. The first limitation is due to the use of a single database; the second to the inclusion and exclusion criteria used; and the third limitation is due to the lack of differentiating and applicative criteria between the techniques used in the field of safety occupational and safety linked to major accidents.

In relation to the first limitation, it has allowed analyzing the main journals that emerge from the work of Reniers and Anthone (2012). However, these authors analyzed a total of 35 representative safety journals, of which with the present work a total of 11 journals have been analyzed.

Regarding the inclusion and exclusion criteria used, they prevent analyzing the evolution of standardized risk assessment techniques in a broader and deeper way through the scientific literature.

As for the third limitation, with this work the dividing line that exists between occupational safety and safety linked to major accidents has not been analyzed directly (for example, this important aspect can be observed in the Table 5). It is evident that both branches of the safety are interconnected and that therefore share risk assessment techniques with the aim of avoiding accidents in processes and industries.

However, such dividing line between these safety branches is diffuse, so it would be advisable to deepen the analysis of differentiating and applicative criteria. The differentiating criteria could allow a structured and interconnected risk and loss analysis. These criteria could be aligned with the results of the EU-OSHA (2017). With the application criteria, the scope, use, complexity, strengths and limitations of each technique in the field of occupational safety could be defined.

5 CONCLUSIONS

With this work the main objective consisting in identifying and classifying the main techniques included in the ISO/IEC 31010:2009 standard applicable in the field of occupational safety, was achieved. These techniques could be compatible with the current version ISO/DIS 45001.2:2017 (section 6.1.2.2).

In addition, a secondary objective has also been achieved, that is, to identify the main non-standard techniques of new or emerging nature (especially dynamic characteristics).

However, three important limitations have been identified that can point the direction of future research. Such research could focus on two objectives. The first objective concerns pursuing analyzing in greater depth the impact and degree of development of standardized techniques and non-standard techniques of a new or emerging nature. To do this, the method used must be modified to obtain results with greater representativeness. This modification should include an update of the results obtained by Reniers and Anthone (2012). The second objective concerns the focus on the analysis of differentiating and applicative criteria between the techniques used in the field of safety occupational and safety linked to major accidents.

In any case, the final publications of ISO 45001 as well as ISO/IEC 31010 should be considered, both publications being foreseen for 2018.

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