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Review

Human reliability analysis: Exploring the intellectual structure of a research field

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ABSTRACT

Humans play a crucial role in modern socio-technical systems. Rooted in reliability engineering, the discipline of Human Reliability Analysis (HRA) has been broadly applied in a variety of domains in order to understand, manage and prevent the potential for human errors. This paper investigates the existing literature pertaining to HRA and aims to provide clarity in the research field by synthesizing the literature in a systematic way through systematic bibliometric analyses. The multi-method approach followed in this research combines factor analysis, multi-dimensional scaling, and bibliometric mapping to identify main HRA research areas. This document reviews over 1200 contributions, with the ultimate goal of identifying current research streams and outlining the potential for future research via a large-scale analysis of contributions indexed in Scopus database.

1. Introduction

Human Reliability Analysis (HRA) is the discipline that provides methods and tools for qualitatively and quantitatively predicting human errors in systems in which people have monitoring and control functions. The roots of HRA are in equipment reliability engineering, from which it derives its central concepts and methods [1,2]. The first systematic assessments of human reliability were initiated in the military domain and were conducted in particular for predicting and quantifying the probability of human errors in nuclear weapon assembly (the work of Swain and Guttman at the Sandia National Lab); these assessments resulted in the development of the early versions of the THERP [3]. The second main driver came from the development in the nuclear power industry of Probabilistic Risk Assessment (PRA), a technique for quantifying the risks posed to the public by a serious core-melt accident at a nuclear power plant. The WASH-1400 report [4], considered a pioneering work, used the THERP to identify potential operator errors and to systematically estimate their probability.

Applications in the military domain were focused on well-defined assembly tasks in which the physical environment paced the operator, allowing only a known sequence of subtasks for correct performance. In the context of such repetitive, lower-level processing and predictable tasks, operators could be readily modelled as components that either acted as required by the system or deviated from the requirements. Early applications in the nuclear industry maintained the assumption of the operator as a component performing a set of assigned functions. This allowed for a single reliability engineering framework to be applied to the entire human-machine system for which failure probabilities were required. However, it was later recognized that instead of a modelling of technical components, a more detailed human modelling was needed. Unlike equipment such as valves and pumps that have very specific functions in response to limited inputs and outputs, operators in nuclear power plants interpret the inputs according to the goals they are pursuing and autonomously decide among a vast array of strategies or subtasks to achieve the same results. In addition, human performance is strongly influenced by variations in task and workplace conditions as well as individual and cognitive aspects.

The need for a proper treatment of the human element in the total system led to research and development efforts that continue to this day. Through an examination of the publications included in HRA literature during a period covering over 50 years, the present review explores the intellectual structure of the field.

Tightly linked to bibliometrics, the scientometrics perspective ("quantitative study of science […]" [5]) has been adopted. A

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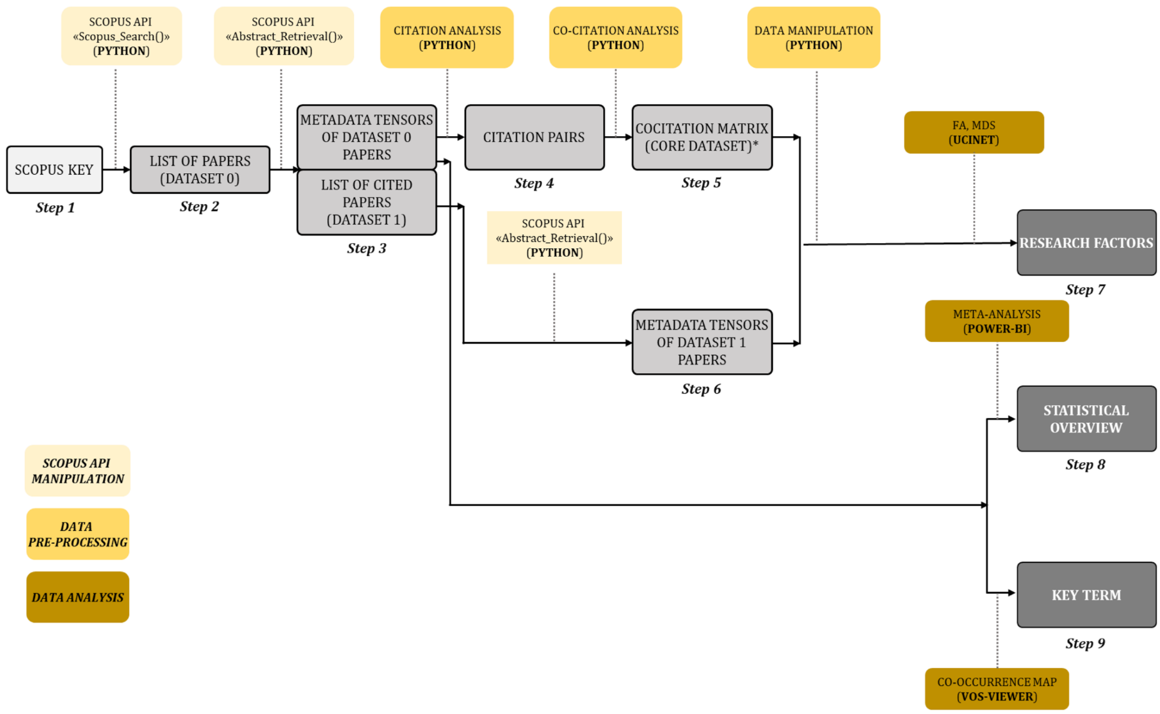


Fig. 1. The 9 steps of the research methodology developed for the research. The yellow boxes refer to the methodology steps (divided into Scopus API manipulation, Data pre-processing, Data analysis). Each method has been labelled and associated with the software used for its implementation (within brackets, in bold characters).

scientometrics study of a scientific field can be performed through the analysis of the field's immediate and tangible outputs (e.g.) papers, proceedings, books [6]. Consequently, to delineate research areas and thematic relationships for the definition of the field's intellectual structure, bibliometric data, such as the number of citations or the number of co-citations (i.e., the times when two documents are cited together by another document) can be analysed as proxy measures [7].

However, we offer a word of caution regarding the coverage of the present review. HRA is foremost an applied, industrial engineering discipline whose results are not necessarily published or even publishable (confidentiality issues). All HRA research and development contributions are not directly reflected in scientific indexed databases. Some important reference sources comprise proprietary research (for instance, the highly influential proprietary reports by the Electric Power Research Institute - EPRI). In other cases, the sources are publicly available but not recorded in citation databases, particularly as one moves back in time. Some examples are reports by industry bodies (e.g., the HRAG/Human Factors in Reliability Group in the UK and the Energy Institute in the US), by international organizations (e.g., IAEA, NEA/CSNI, the EU Joint Research Centers, the OECD Halden Reactor Project, and NATO) and by national regulatory and safety bodies (e.g., the U.S. NRC's NUREG reports and the HSE in the UK).

Bearing this aspect in mind, we still perform a bibliometric meta-analysis assuming that (i) the sources retrieved in citation databases are able to directly keep track of the non-recorded sources (e.g., summary papers of proprietary reports) or indirectly keep track of them (e.g., papers treating themes first raised in the non-cited reports) and that therefore (ii) the absence of the uncited sources is not expected to dramatically modify the field's overall intellectual structure.

The core concept of the review performed in this paper is the usage of bibliometric data as a main support tool for a meta-analysis aimed at exploring, clustering and categorizing the available literature. The analysis extracts information from Scopus database and adopts a multi-method approach based on different bibliometric information extracted from the articles' metadata (source, article type, date, reference list, etc.). Scopus has been identified as the reference database for two main reasons: (i) with over 5000 publishers and over 71 million records, it represents the largest database of peer-reviewed literature and is fairly balanced among the technical and social aspects of science; (ii) it allows a well-structured metadata export either through its APIs or through manageable export files (e.g., .ris, .csv) [8].

The analysis pays attention to citation and co-citation data. In particular, co-citations have been recognized as valuable data sources for examining the relationships among documents and their contribution to a research field [9–11]. The co-citation analysis in this paper relies on the assumption that if two documents are often co-cited, the same contributions have some type of semantic or conceptual link. Starting from co-citation data, Factor Analysis (FA) is used here as a multi-variate technique for data reduction to extract research factors from the literature. Research factors are intended as sets of documents that focus on a similar research topic and concern a specific sub-field. As such, they thus support the exploration and definition of the intellectual structure of the research field itself. Based on the acknowledgement of research factors as multi-faceted abstract artefacts, the results of the FA have been further extended in a multi-dimensional perspective through a Multi-Dimensional Scaling (MDS) algorithm. MDS is used to depict the proximity between documents, which is still based on co-citation values, whose ultimate purpose is to understand intra- and inter-factor relationships.

In addition to these techniques for document analyses, other approaches have been used to further explore the research field. In particular, bibliometric maps have been developed to identify main terms and respective relationships.

Note that this research adopts a strong interpretive dimension: we set a level of philosophical assumption that is intrinsic to the complexity of uncovering a research field's intellectual structure. Nevertheless, following a hermeneutic perspective, we use data analytics to provide an interpretation for reducing our subjective bias in the definition of the publications structure [12].

In practice, regarding the methodology developed for the analysis, the research also follows a complementary normative dimension. It is noteworthy that the complementary nature of the multi-method

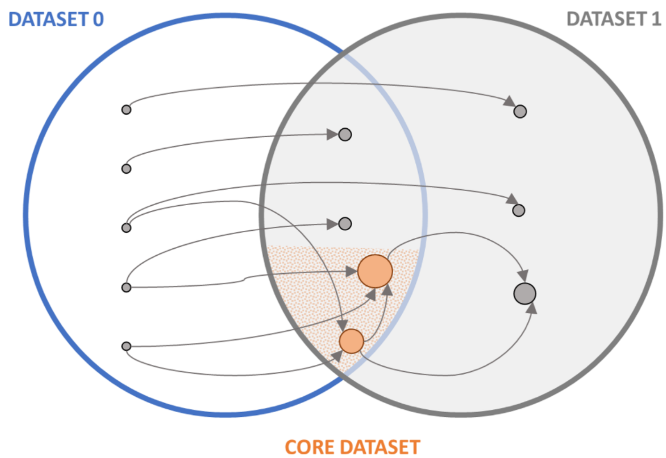


Fig. 2. Relationships among Dataset 0 (outcome of the search query), Dataset 1 (dataset of cited papers) and the Core Dataset (papers with co-citations over a certain threshold). The size of the bubbles is a function of the co-citations count of a paper.

approach proposed in this work is described in detail in order to support other researchers in performing other scientometrics research.

2. Methodology

The research methodology can be summarized in 9 steps that were based on the Scopus APIs and managed by means of Python scripts and other software for data analysis and visualization (Microsoft PowerBi, VOSviewer). Fig. 1 summarizes the research process, which is described in detail in the following 9 steps.

Step 1. The search key was finalized in Scopus by using the Scopus search query system.

Step 2. The Scopus API "Scopus_Search()" was implemented in order to extract the list of papers associated with the Scopus key defined in Step 1. The outcome of this extraction generated a set of papers that constitutes the so-called Dataset 0.

Step 3. Starting from the list of papers defined in Step 2, the Scopus API "Abstract_Retrieval()" was implemented in order to obtain the respective papers' metadata. The latter was structured in multi-dimensional tensors and required further manipulation to be completely exploited. In addition, the same Scopus API allowed the extraction of the list of papers cited by the papers included in Dataset 0 (whose size is n, number of papers in Dataset 0). These cited papers constitute Dataset 1, and they were used for subsequent analyses (Step 6).

Step 4. Based on the Dataset 0 metadata, an ad hoc Python script was developed in order to create citations pairs, i.e., a vector of citing-cited papers that exploits all the citations of papers included in Dataset 0.

Step 5. Based on the citations pairs in Step 4, a co-citation matrix was developed. The matrix has a n x n dimension (where n is the number of papers in Dataset 0). Note that for pragmatic reasons, a co-citation threshold was iteratively defined to isolate the papers to be included in the matrix itself. These papers constituted the Core Dataset (whose size is $m < n$) for the application of data reduction techniques.

Step 6. Starting from the list of papers obtained in Step 3, the Scopus API "Abstract_Retrieval()" was applied to gather all the papers' metadata. In this case, the metadata were obtained from the papers in Dataset 1. This step was necessary to combine the results of Step 5 so that all the metadata for papers in the Core Dataset (which is a subset of Dataset 1) were available for subsequent analyses. The connection between the co-citation matrix and the metadata tensors was performed through an ad hoc Python code.

Step 7. Combining all the information available from the co-citation matrix and the metadata tensors, an ad hoc Python code was developed as a basis for factor analysis. First, the co-citation matrix was translated into a Pearson correlation matrix (m x m) in order to make the co-citations comparable and standardized, providing a more robust basis for the following statistical analyses [13].

Second, starting from the m x m Pearson correlation matrix, a Principal Components Analysis (PCA) with varimax rotation was applied in order to extract the key factors of the Core Dataset. In this context, a factor is a linear combination of optimally weighted observed variables that accounts for a maximal amount of the variance in the observed variables (relying on the correlation values obtained from the co-citation matrix) that is not accounted for by the preceding components and is uncorrelated with all of the preceding components [14]. Varimax represents a valuable rotation criterion for this analysis since it allows rotating elements to create an economic set of factors with high individual loadings.

Third, the Pearson matrix was used as the basis for a MDS algorithm that was developed as a support to interpret the research factors individually and jointly and to explore the relationships among them.

Step 8. In addition to the specific information on the Core Dataset, the analysis was extended to the original search dataset, i.e., Dataset 0. A meta-analytic overview of such papers was developed by means of multiple statistical analyses performed in Microsoft PowerBI.

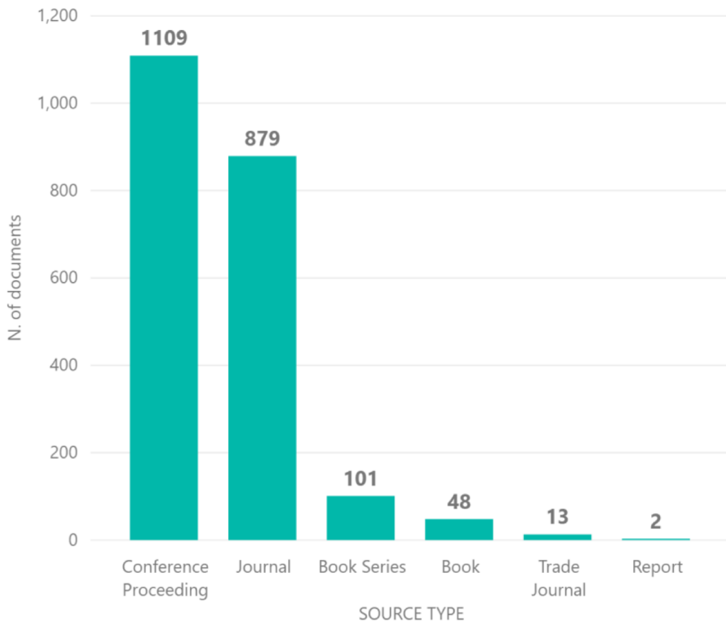
Step 9. An additional analysis was performed through the exploration of keywords and their co-occurrences. Co-occurrences refer to all combinations of keyword pairs in each document being revised. This analysis relied on the assumption by Law and Whittaker, i.e., that authors of scientific papers choose technical terms carefully, recognizing some type of association between them [15]. Therefore, if multiple authors use the same terms and associate them, the relation can be assumed to be significant. A threshold of significance was assigned, i.e., a number of documents that had to include the keyword in order to consider this relation relevant for the analysis.

Extending the concepts presented in Fig. 1, Fig. 2 sketches the relationships among different datasets for the scientometrics analysis.

3. Findings

From an operations point of view, for documents published until April, 1 2019, the 9-step methodology described in Section 2 started from the adoption of the following Scopus search key: TITLE-ABS-KEY ("human reliability" OR "human unreliability"). This broad key aims to include all documents where the phrases "human reliability" or "human unreliability" have been mentioned in the title, abstract or keywords. For the purpose of this meta-analysis, the search key was purposively not been narrowed in order to include all the contributions that play a role in the intellectual structure of the field. In formal terms, such choice implies that no explicit exclusion criteria were assigned; i.e., the articles were included in the analysis regardless of their subject area, year of publication, source type, etc. Exclusion and inclusion criteria were instead data-driven, following the analysis of citations and co-citations, differently from PRISMA-based reviews (e.g. [16]).

The following statistical information about the approach can be added. Dataset 0 (the outcome of the search query) includes 2140 documents. Therefore, with respect to Step 3 and Step 5, $n = 2140$. The length of the citation pair vector (cf. Step 4) is 42910, implying that Dataset 0 presents 42910 citations, which refer to all the papers in Dataset 1. The intersection between Dataset 0 and Dataset 1 accounts for 5272 citations, which constitute the starting point for defining the Core Dataset. Regarding Step 5, the dimension n of the co-citation matrix was reduced to the number m of papers that have at least 20 total co-citations in (Dataset 0 ∩ Dataset 1) in order to retain a significant while manageable number of papers. This choice ($m = 440$, cf. Step 5, Step 7) remains significant since it allowed the retention of those 440 papers, which include 39060 co-citations out of the 44930 co-citations (from the 5272 citations) from the total number of documents in Dataset 0 ∩ Dataset 1. This choice qualitatively confirms



SOURCE TYPE	PAPER TYPE	N. of docs
Conference Proceeding	Conference Paper	1057
Journal	Article	780
Book Series	Conference Paper	69
Conference Proceeding	Conference Review	41
Journal	Conference Paper	36
Book	Chapter	35
Journal	Review	32
Journal	Article in Press	22
Book Series	Chapter	13
Book	Book	11
Conference Proceeding	Article	11
Trade Journal	Article	11
Book Series	Article	8
Book Series	Conference Review	7
Book Series	Review	4
Journal	Abstract Report	2
Journal	Editorial	2
Journal	Erratum	2
Journal	Letter	2
Journal	Note	2
Report	Report	2
Book	Article	1
Book	Conference Paper	1
Journal	Short Survey	1
Trade Journal	Editorial	1
Trade Journal	Review	1
Total		**2140**

Fig. 3. Source type and paper type analysis.

Pareto theory: approximately 20% of the documents explains more than 85% of the co-citations.

Based on these preliminary analyses, it was been possible to proceed with the papers' findings, were divided into 3 classes:

- Statistical overview (Section 3.1)
- Research factors (Section 3.2)
- Key Term analysis (Section 3.3)

3.1. Statistical overview

Dataset 0 (the outcome of the search key in Scopus) was first analysed in terms of source type. In particular, most contributions (approximately 93%) in the dataset are listed as belonging to either conference proceedings (approximately 51%) or journals (approximately 42%). A more detailed overview of source types is presented in Fig. 3, where paper types are further explored. For a detail description of paper types and source types, please refer to [17].

The data summarized in Fig. 3 were analysed through a cumulative trend graph over years. It is possible to highlight a general increasing trend starting from early 2000s and an even larger increasing trend for journal articles (yellow area). The graph is a cumulative representation, and the border of the yellow area represents the total number of documents over the years. (Fig. 4)

Another bibliometric perspective can be gathered from the analysis of open access contributions. In particular, only 106 contributions were published as open access over the years (less than 5%). Even considering the last 15 years of literature, which is considered the beginning of the open access movement [18], the statistics are similar (approximately 5%); thus, the field underperforms with respect to the average number of open access articles currently in the literature (set at approximately 27% according to [18]). Nevertheless, a positive trend can be identified in the last four years: in the interval comprising 2016, 2017, 2018 and 2019, the percentage of open access articles reached 5.05%, 5.7%, 7.93%, and 17.5%, respectively. Fig. 5 summarizes the results, which are displayed in a graph showing the relative percentages of open and subscription access papers.

A further analysis of the publications allows the identification of the most relevant sources of literature. Two Elsevier journals are particularly relevant: Reliability Engineering and System Safety (8.6%) and Safety Science (2.2%). Reflecting the high interest in HRA in the nuclear domain, the third journal is Annals of Nuclear Energy (1.4%). As expected, the PSAM conference, which was organized by the International Association for Probabilistic Safety Assessment and Management, concentrates the largest number of publications (182 documents); the second largest concentration is in the European Safety and Reliability Conference (ESREL) (166 documents). Other large conferences are the Probabilistic Safety Assessment and Analysis (PSA)

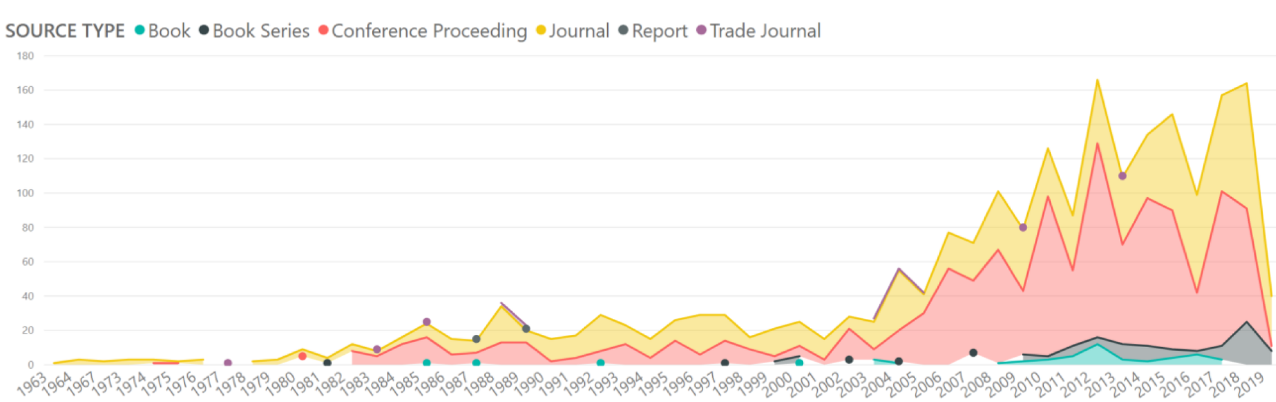


Fig. 4. Source type over years.

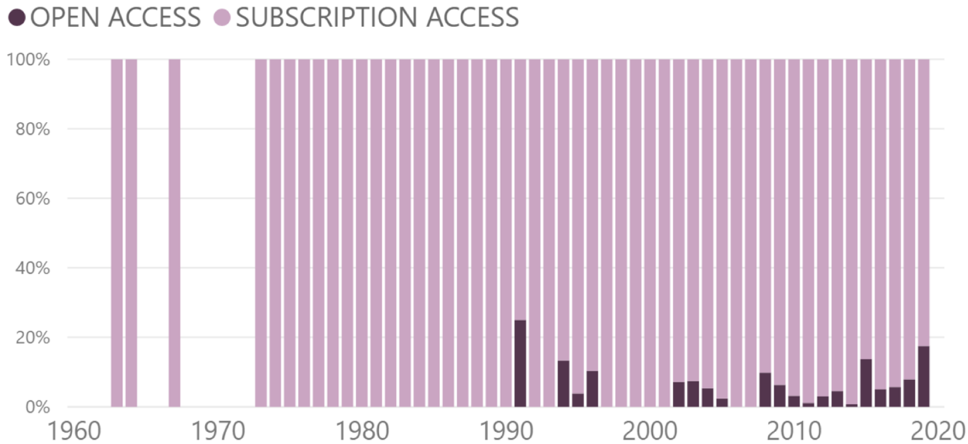


Fig. 5. Open and subscription access.

Table 1
Top 20 sources.

Source	Source type	# documents
Reliability Engineering and System Safety	Journal	185
Probabilistic Safety Assessment and Management (PSAM) - 2006, 2008, 2010, 2014, 2018	Conference Proceeding	182
European Safety and Reliability Conference (ESREL) - 2005, 2006, 2007, 2011, 2013, 2014, 2015, 2016, 2017, 2018	Conference Proceeding	166
Probabilistic Safety Assessment and Analysis (PSA) - 2005, 2008, 2011, 2013, 2015, 2017	Conference Proceeding	101
American Institute of Chemical Engineers (AIChE) - 2005, 2010, 2011, 2012, 2014, 2015, 2016, 2017, 2018	Conference Proceeding	64
Safety Science	Journal	48
IEEE Conference on Human Factors and Power Plants	Conference Proceeding	40
Proceedings of the Human Factors and Ergonomics Society	Conference Proceeding	37
Advances in Intelligent Systems and Computing	Book series	33
Annals of Nuclear Energy	Journal	30
Institution of Chemical Engineers Symposium Series	Conference Proceeding	27
Proceedings of the Annual Reliability and Maintainability Symposium	Conference Proceeding	27
Lecture Notes in Computer Science	Book Series	21
IFAC-Papers On Line	Conference Proceeding	20
International Conference on Nuclear Engineering, Proceedings, ICONE	Conference Proceeding	19
Applied Ergonomics	Journal	18
Journal of Loss Prevention in the Process Industries	Journal	16
Nuclear Engineering and Design	Journal	16
Risk Analysis	Journal	16
Hedongli Gongcheng/Nuclear Power Engineering	Journal	15
Ergonomics	Journal	15

organized by the American Nuclear Society (101 documents) and the American Institute of Chemical Engineers Meetings (AIChE) for Global Congress on Process Safety (64 documents). Note that in the case of multiple contemporary conferences (e.g., the 11th PSAM held jointly with ESREL in 2012), documents have been assigned to the one with the higher frequency (in the example, ESREL). Further details for the top 20 sources are listed in Table 1, where for multiple conferences, it is possible to find all relevant years listed.

An additional statistical analysis can be performed with respect to the geographical distribution of documents. This distribution represents the number of documents produced per affiliation country (note that one document may imply multiple affiliation countries, and there may be even more than one affiliation country for each author). As a first step for the analysis, only the affiliation(s) of the first author is considered here. This analysis aims to give an overall geographical representation rather than a detailed author-based analysis. From Fig. 6, it is possible to note the leading role of institutions in the United States, followed by those in China, the United Kingdom and South Korea. The top-ten affiliation countries include 3 EU countries (France, Germany, Italy), Norway, Brazil and Japan (see Fig. 6 for details).

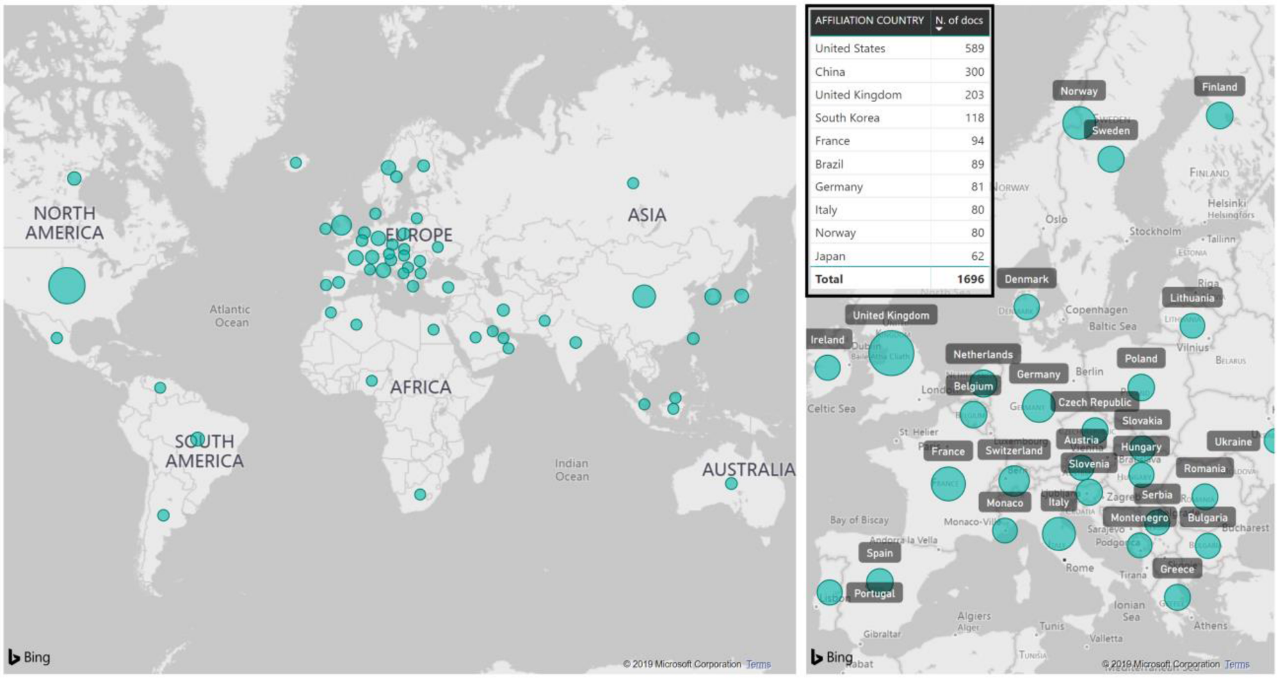
3.2. Research factors

3.2.1. Overall definition

Research factors (RFs) were determined by the adoption of a PCA with varimax rotation (cf. Step 7). The outcome of the approach consists of defining factor loadings for each document [9]. A factor loading represents the degree to which a specific document belongs to a factor. A significance threshold was defined as ±0.30, implying that a document was assigned to a factor if its factor loading was greater than the threshold value [11,19]. In the case of multiple loadings, the document-factor association refers to the factor with the highest score.

Starting from the Pearson co-citation matrix (Cronbach's alpha = 0.976), the PCA led to the definition of 10 factors, which in turn are able to explain approximately 78.5% of the variability. These factors include all the 440 documents previously identified (cf. Section 3 regarding the number of co-citations filtered). Regarding source type, the 440 documents constituting this Core Dataset can be compared with the number of documents in Dataset 0 (see Fig. 7). Although Dataset 0 includes a larger number of publications from conference proceedings rather than journals, the Core Dataset is mainly composed of journal articles. This is an expected outcome for bibliometric-based analyses: journal articles are usually the most cited document types.

For the FA, the interpretive analysis of the documents was performed by 3 researchers with an average of 10 years of academic and



AFFILIATION COUNTRY	N. of docs
United States	589
China	300
United Kingdom	203
South Korea	118
France	94
Brazil	89
Germany	81
Italy	80
Norway	80
Japan	62
Total	**1696**

Fig. 6. Worldwide geographical distribution of affiliations. Focus on Europe on the right, and table depicting top ten affiliation countries.

industrial experience in HRA. In particular, the researchers investigated the contributions listed for a factor in order to make inferences from the title and abstract for their classification. Such inferences were the basis for providing an interpretation of the PCA factor as a representative research factor. To check the validity of the inferences and provide coherent intra-factor and inter-factor associations, the individual classification was then confirmed and validated through two focus groups involving another researcher with experience in data analytics.

An inherent bias in the co-citations metric may lead to the assignment of a document to a PCA factor not completely aligned with it. This has been managed through reading all the abstracts and, if needed, the full text of the ambiguous documents. The publications identified as not pertaining to an RF (usually documents with scores distributed in multiple factors) were re-assigned to other factors with relatively lower scores but with greater topic alignment. Following this interpretative perspective, one of the smallest (in terms of number of documents) PCA factors was excluded since its isolation was mainly due to self-citations (and consequently self-co-citations) by some authors who monopolized the factor. Documents in this PCA factor were re-assigned to other factors where relevant: a total of 23 documents out of 440 were left unassigned. In general, self-citations were not excluded since given the cumulative nature of the production of new knowledge, they were recognized as a natural part of the communication process. For the co-citation threshold assumed in this case, it was determined that self-citations did not to play an important role in the citation rates attained by the highest-cited documents [20].

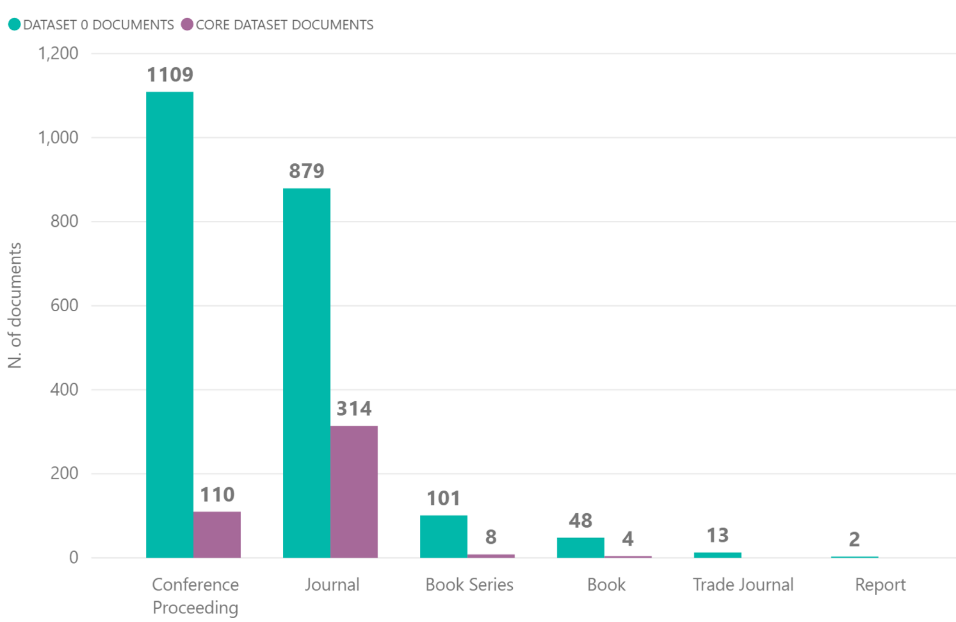


Fig. 7. Comparison between documents included in Dataset 0 and in the Core Dataset.

Table 2
Distribution of documents per RF.

FACTOR	# documents
RF1	68
RF5	65
RF3	64
RF8	59
RF2	51
RF4	38
RF6	28
RF9	24
RF7	20
unassigned	23
TOTAL	440

Nine RFs (out of the 10 PCA factors) were identified through the approach described above. An RF comprises a set of documents grouped by common research topics: for instance, these latter may be the main contributions of the publication, the method used, or the application field. For example, publications that use BBNs for analysis are mainly grouped in one RF (RF1). However, not all these publications aim to study the application of BBNs in HRA; some of them just make use of BBNs as a method for analysis, which may consider another product to be the main contribution. Nevertheless, publications that make use of BBNs for analysis will naturally cite (and be cited together with) publications that discuss and validate the use of BBNs, resulting in those being grouped in the same RF. For pragmatic reasons, a full list of all papers included in each of the 9 RFs is provided in the Appendix, while the following sections are intended to summarize main contributions and reference either the most cited papers per RF or those ones with higher FA rotated loadings, i.e., the ones that were usually easier to summarize semantically. A summary of the final association between RFs and documents is presented Table 2, and this summary is complemented by the information in the Appendix.

3.2.2. RF1 – Advances in quantification in HRA: Data collection and analysis methods

This publication group focuses on advances in quantification in HRA, including data collection and methods for analysis.

A large group of publications related to quantification in HRA focus on the use of BBNs. Indeed, the use of BBNs in the field of HRA is steadily increasing, as noted by [21] and [22]. In their reviews, they identify five main groups of BBN applications. The first group comprises publications on the modelling of organizational factors. This application is illustrated by [23], which proposes a fuzzy Bayesian network (BN) approach to improve the quantification of organizational influences in HRA. Another possibility is pointed out by [24]: BBN can be combined with system dynamics, ESD and FTs for a hybrid approach in how to incorporate organizational factors into PRA.

Other groups of applications identified in [21] are BBN-based extensions of existing HRA methods (e.g., [25]) and the assessment of situation awareness, as in [26], which provides a computational model for situational assessment.

The other two groups identified by [21] are the analysis of the relationships among failure influencing factors and the dependency assessment among human failure events. Indeed, BBN is a useful tool for dealing with dependencies. For instance, [27] presents a BBN model and uses the time slice concept of dynamic BN for explicit treatment of dependencies among HFEs.

The analysis of the relationship between PSFs is also closely related to dependency. In most of the HRA methods, dependency between PSFs is not considered. [28] propose a solution for this problem by using BBNs and artificial data sates. They model factors and estimate failure probabilities when dependency between PSFs is considered. Moreover, they use artificial data for the development and testing of the BBN. Artificial data refers to the generation of data with known properties in order to test a modelling approach and evaluate its performance. In a further work, they investigate an approach to incorporate information about uncertainty in the BBN parameter estimates and the effect of unreliable data [29,30]

An additional potential domain for the application of BBNs is in dealing with limited data. BBN allows for the use of expert judgement in combination with empirical data, and solutions have been provided in this direction. [31] propose a Bayesian approach to aggregate expert estimates on human error probabilities to determine the relationships in an HRA model. Another document [32] remarks that a challenge during the elicitation of expert judgement is the possible high number of questions that are necessary. These authors propose a quality indicator that would allow for adequate quantification of qualitative knowledge with a reduced number of questions. BBNs can be further used to consider the uncertainty related to expert judgement. Approaches for treating uncertainty with fuzzy systems have also been proposed, and [33] compare BBNs and fuzzy expert systems for the treatment of uncertainty. They conclude that BBN is preferred in cases characterized by quantifiable uncertainty in the input, while fuzzy expert systems are preferred in cases where there is very limited knowledge and the analyst feels constrained by a probabilistic framework.

The incorporation of expert judgement is not the only solution for scarcity of data that can be modelled through BBN. Simulation can be a valuable tool to generate data, as in [34], which presents a data collection methodology using a virtual environment for a simplified BN model of offshore emergency evacuation.

The application of BBNs in the field of HRA is also explored in connection with other techniques. A hybrid approach has been used in model-based HRA methodologies, which propose to overcome issues in general HRA methodologies. These issues, among others, have contributed to the variability in results seen in the application of different HRA methods and in cases where the same method is applied by different analysts. In an attempt to address these issues, a framework for a "model-based HRA" methodology has been proposed. This framework uses a hybrid model with event sequence diagrams, fault trees and BBNs. The BBN models the influence of performance shaping factors in the failure modes [35–38]

Other advances in quantification approaches for HRA include the use of simulators [39–42] for data collection and modelling. Regarding data collection, [43] remarks that data for HRA has been persistently viewed as lacking. Indeed, many sources of HRA-relevant data exist, and many efforts to collect the data have been and are being pursued. For instance, to inform human reliability analysis, the Human Event Repository Analysis (HERA) database was developed for the U.S. (NRC) as a repository of retrospective qualitative analyses of actual incidents [44]. In addition, the U.S. NRC has an active human reliability analysis (HRA) data program that, through the collection and analysis of human performance information, aims to improve HRA quality in the NRC's risk-informed programs [45,46]. The aims to collect and analyse licensed operator simulator training data for the primary objective of generating human error probabilities (HEPs) in HRA. The use of simulator data with the HURAM (Human-related event Root cause Analysis Method plus) methodology has also been adopted in Korean nuclear power plants [47].

3.2.3. RF2 – Human cognitive process across application domains

The RF 2 focuses on the human cognitive process across various application domains, ranging from maritime transport [48,49] to power systems [50]. Vanderhaegen et al. [51] address diagnosis and cognitive ergonomics, while Kontogiannis and Malakis [52] propose a framework of cognitive strategies in error detection to make human performance resilient to changes in work demands within aviation and work traffic control. The need for addressing human reliability from this perspective is also shared by Kim and Bishu [53], who state that human errors have been generally modelled on the basis of probabilistic concepts, leaving the consideration of cognitive aspects of human behaviours as merely optional.

On the other hand, He et al. [54] affirm that the Cognitive Reliability and Error Analysis Method (CREAM) relies on a sound cognitive model and framework and emphasizes the whole characteristics of the context. CREAM is a representative method of the so-called second-generation human reliability analysis (HRA) methods. For this reason, for application in the construction industry, Liao et al. [55] use CREAM as a basis to develop a model of the relationship between performance shaping factors and human error.

Bedford et al. analyse CREAM sensitivity with respect to the choices made for common performance conditions (CPCs – contextual conditions under which a given action is performed) and the intrinsic uncertainty when interpreting the method categories [56]. Such limitations are increased in the case of scarcity of empirical data, as shown by Wang et al. [57]. New CREAM performance conditions specifically related to space missions, i.e., an International Space Station ingress procedure, were also defined [58,59].

Expert judgement is essential for the study of cognitive processes, and several authors make use of systematic methods to obtain it. El-Ladan and Turan [60] and Maniram Kumar et al. [61] apply structured and guided expert elicitation methods to interview experts and increase the fidelity of second-generation HRA techniques.

To overcome CREAM limitations, as a complement to the methods employed, novel quantitative techniques are used to enhance its inherent perspective human error probability (HEP) analysis. Yang et al. [62], Kim et al. [63] and Ashrafi et al. [64], given updated information about a dynamic context, introduce concepts from Bayesian theory to improve HEP evaluation. To account for CPC ambiguity and unevenness, fuzzy versions of the CREAM paradigm are suggested by Marseguerra et al. [65], Geng et al. [66] and Konstantinidou et al. [67].

3.2.4. RF3 – Human performance and human factors dynamically modelled

This RF focuses on human performance and human factors described dynamically and through a comparison of diverse HRA methods.

Joe et al. [68] affirm that there is a general lack of focus on simulations of human operators and on how the reliability of human performance can affect risk-margins and the performance of nuclear plants. To explore this, human performance data were collected during simulator trials and compared with the HRA lessons from Massaiu et al. [69]. Another aspect considered was the transition of technology in nuclear power plants, an issue that has raised many important human performance issues. For this reason, a survey was conducted by Liao and Chang [70] to examine the causal factors of human-system interface-related human errors in control rooms. Human performance is assessed not only for safety-critical industries (aerospace engineering, and nuclear engineering) but also for the automotive industry [71]. Operators' performance may be reflected in overall team performance. The relevant literature shows how appropriate methods, such as the Performance Evaluation of Teamwork (PET) [72] and Phoenix (model-based human reliability analysis methodology) [73], can account for this performance interconnectedness.

The THERP (technique for human error rate prediction) is one of the most established and detailed HRA methods, and it considers specific performance shaping factors (PSFs) to assess human error probability. Bubb [74] applies the method to a case study within manufacturing. Other HRA methods, such as the standardized plant analysis risk-human reliability analysis (SPAR-H) technique, were inspired by the use of the THERP in the treatment of PSFs. The SPAR-H method was developed to aid in characterizing and quantifying human performance at nuclear power plants [75] and has subsequently been used for other domains [76].

Van de Merwe et al. [77] apply SPAR-H to managed-pressure drilling operations and find it a useful support for project managers. Boring [78] aimed to bridge the SPAR-H HRA method with NASA's man-machine integration design and analysis system (MIDAS) for use in simulating and modelling the human contribution to risk in nuclear power plant control room operations. Defining the PSF role across the HRA stages, Boring [79] also wonders how many PSFs are necessary for techniques such as SPAR-H.

Human performance has an intrinsic dynamic nature, and HRA experts are focusing on including this aspect in novel analysis methods [80]. For instance, the Simulator for Human Error Probability Analysis (SHERPA) [81] aims to merge the advantages of simulation tools and the principles of traditional HRA methods. The "dynamic risk modelling project" [82] developed a simulation approach for the quantitative analysis of critical air traffic control activities by operators. Droguett et al. [83] adopts a Bayesian approach to provide dynamism to HRA.

Human performance analysis and the related inclusion of its dynamic features are also the objects of benchmarking studies. Boring et al. [84] discuss a study comparing and evaluating HRA methods in assessing operator performance in simulator experiments. Moreover, Boring et al. [85] address the drivers of crew performance in a method-to-method comparison.

3.2.5. RF4 – Quantitative definition of human actions and their dependency

This RF focuses on the quantitative definition and assessment of human actions, tasks, and commissions and their interdependency, interaction, hierarchy, or dependency on external factors.

The study of potential errors within human actions and how these contribute to accidents is paramount in HRA, but it is not free from challenges. An important output of human action assessment is the isolation of actions with the greatest potential to reduce accident risk [86]. To provide solid foundations to the analysis, the quantification may be based on operational experience, as Preischl and Hellmich [87] show by covering a wide variety of tasks and human error probabilities in the operations of German nuclear power plants. Prosek and Cepin [88] instead illustrate how parametric safety analysis studies provide relevant parameters for the HRA of human actions, whose complexity cannot be disregarded while assessing error probability [89]. To this regard, Park and Jung [90] identify an objective tool to evaluate the level of complexity of a task in HRA terms.

Human actions may depend on several factors. For this reason, dependency from contextual factors such as cultural variability is investigated by Park [91]. Intra-dependency among human actions also plays an important role in human reliability analysis, as dependent tasks may have an important influence on each other's probability. The modelling of dependencies may be based on the lessons learned from available HRA methods [92]. Julius and Grobbelaar [93] developed a tool and guidelines to obtain comparable HRA results when evaluating the human interactions of similar tasks. Other authors [94,95] opt for advanced computational models to assess the dependency between tasks. Fuzzy logic-based approaches are also considered for a number of case-studies [96–98], ranging from dependencies between operators in digital control systems [99] to the use of medical devices [100]. A solution to handle dependency in HRA is also demonstrated by using the analytic hierarchy process (AHP) method [101–103]: first, dependency influencing factors among human tasks are identified, and following the AHP weighting process, the weights of the factors are then determined by experts [104].

3.2.6. RF5 – Recent methodological developments and digital human-system interface

Factor 5 focuses on methodological developments that aim to fill the gaps and advance the field of HRA.

The majority of the papers are recent and concern HRA and digital HSIs. As HRA was originally developed in the analogue control room age, many authors assert that the available guidance on assessing the interaction between humans and digital human-system interfaces is insufficient and identify areas that need attention [105–108] Referring to tasks performed in analogue control rooms, the HEPs contained in the methods might no longer apply. For instance, after evaluating various sources of data, [109] conclude that "existing human reliability assessment methods are likely to be optimistic in their estimates of HEPs where diagnosis is involved". New data on human performance and human error are thus collected to not only assess the reliability of human-interface interaction with digital artefacts [110–115] but also help in the development of the methods [116–118] An equally large set of contributions addresses issues related to performance shaping factors (PSF) not only due to the digitalization of the HSI, as in [119]. PSFs are discussed and defined for optimal selection in HRA [112], for improving the way they are treated (in SPAR-H) [120], or are studied individually, e.g., in relation to fatigue [121] or complexity [122]. Even more papers focus on estimating the effects of PSFs on human performance. This is accomplished through a literature review [121,123], computer simulation [124], or Bayesian belief network applications [125,126] or by analysing operational data [127], microworld data [118] and data from human-in-the-loop simulators [128,129]. The issue of objectively measuring PSFs is approached from several angles by a research group in South Korea [130–132].

3.2.7. RF6 – Advancements of HRA in healthcare

This factor emphasizes contributions related to the advancements of HRA in the field of healthcare.

This research stream can be considered a relatively recent area of study, as pointed out by [133]. They remark that HRA is still not broadly applied in healthcare, and the reason may be the lack of awareness of the usefulness of the techniques and their applicability to the problem of human error in the clinical context. The authors review popular HRA techniques and discuss their feasibility for use in healthcare. While some areas of healthcare have used certain HRA techniques, there is considerable scope to use other techniques and to apply techniques to other aspects of healthcare that have not yet explored. Lyson [134] provides a framework to select techniques for error prediction in the healthcare sector.

A large group of papers under this factor relates to doctors' performance during surgeries. Concerning developments in HRA, Onofrio, Trucco and Torchio [135] propose a taxonomy for PSFs in surgery applications. They remark that in spite of the growing interest in HRA application in healthcare, only a limited number of studies use PSFs to describe the working context. Cox Dolan and MacEwen [136] focus on HRA development in a specific type of surgery: cataract surgery. They remark that HRA is a prospective method of assessment of surgical performance and can be further used in the training and assessment of cataract surgery.

In particular, laparoscopic surgeries are a field of interest for HRA application. For instance, Ghazanfar et al. [137] analyse how divided attention affects novices and experts during this type of surgery. The observational clinical-HRA (OCHRA) [138] was developed for use in laparoscopic surgery. It is used by Talebpour et al. to analyse competency level for laparoscopic surgery, by [139] to analyse a proficiency-gain curve, and by Miskovic et al. [140] to measure competence level during laparoscopic colorectal surgery. Other areas of application of OCHRA include laparoscopic rectal cancer surgery [141], laparoscopic cholecystectomy [142], and laparoscopic pyloromyotomy [143]. In the context of operative and cognitive skills, Tang et al. [144] further propose a new approach that combines OCHRA with Objective Structured Clinical Examination (OSCE) for competence assessment during laparoscopic surgery.

HRA in healthcare also leverages the HEART methodology. Castiglia, Giardina and Tomarchio [145] use HEART to evaluate the potential exposure of medical operators working in a high dose rate brachytherapy irradiation plant. Ward et al. [146] apply HEART as part of the investigations into a surgical incident involving the accidental retention inside a patient's venous system of a guide wire for central venous catheterization (CVC). Chadwick and Fallon [147] apply a modified version of HEART to the radiotherapy treatment process.

Other approaches are also proposed, including one by Pandya et al. [148], who provide a generic task-type-performance-influencing factors structure.

3.2.8. RF7 – HRA and human factors in design

RF 7 focuses on the application of human reliability concepts and tools to system design, bridging the gap between HRA and human factors.

The papers included in this factor are not concerned with a complete HRA examinations for system design purposes but rather provide examples of how to use HRA-related techniques for the identification, measurement and reduction of human-caused risks at the design stage. HRA techniques allow identifying bottlenecks in operating processes and improving the system design in socio-technical activities, such as the command and control room operations of a military vessel [149]. Further results refer to the identification of safety functional requirements (SFRs) in the nuclear industry, combining human perspectives with technical information [150]. Similarly, to combine traditional hardware and software requirements with the ones coming from the system users, corrective design actions based on the application of HRA techniques have been taken for a missile system design [151]. Following the increasing interest in car driving automation, to propose a way forward for regulation, training, car design, and intersection layout, an HRA perspective has been adopted for modelling driver-car interaction [152]. More focused on regulatory aspects, in a comparison with the ISO Guide (ISO/IEC Guide 73, ISO Guide 51, etc.), human-oriented, risk-preventing strategies have been developed in the design stage, emphasizing the need for collaborative participation [153].

The interest in the early design phase is further extended with research focusing on the system lifecycle. The early results focused on human-computer interaction to ensure usability during the entire lifecycle [154] and were later extended to the joint-cognitive dimension [155]. Human-computer interactions remain particularly relevant for both individual and team performance, as confirmed by an experimental research study in the nuclear domain [156], especially for the socio-technical design of 4th generation nuclear reactors [157]. An experimental project showed how a 12-month program supported the integration of human-oriented analysis with traditional engineering approaches for both early concept design and later product qualification and certification [158]. In this context, the System Development Safety Triptych represents a checklist of considerations developed for the interplay of human factors and human reliability in the design, testing, and modelling stages of product development and planned for use during the conception, design and implementation of a system [159].

3.2.9. RF8 – Benchmarking exercises in HRA

RF 8 reflects an overall empirical connotation but is focused on benchmarking among different techniques and assessment methodologies. In HRA literature, this perspective considers the significant differences in the scope, approach and underlying models of the available literature and the subsequent need for comparing respective results with available empirical data [160]. Benchmarking can be intended for use between a method and empirical data, as well as between different methods and data. For the former, see the Qinshan nuclear power plant exercise involving different human interactions that are skill-based, rule-based and knowledge-based [161]. Regarding the latter comparison, see the 1992 benchmarking exercise conducted to compare the THERP, SLIM, and a rank-ordering procedure. The results suggested the need for the use of a more structured perspective when applying the methods [162], a problem partly solved in more recent applications [163]. Benchmarking has been referred to also in methods' results and proceduralized risks, such as the risks in the fuzzy fault tree analysis compared with the modern gamma rays irradiators' risks suggested by the International Commission on Radiological Protection [164]. Benchmarking also extends to very technical aspects, such as the probability distribution for the definition of hazard rate parameters (i.e., log-normal, gamma, inverse Gauss) [165]. When assessing a method, critiques have been recognized regarding the reliability of available data as well as the advantages afforded by an investigator's and a reporter's background in a marine transportation case study [166]. The need for a structured approach has also been examined through the introduction of a combined methodology based on HRA and a failure modes, effects, and criticality analysis [167].

A recent study identifies some specific analysis criteria designed to compare and map HRA methods (e.g., required data evidence, theoretical basis, and PSF coverage) and finally suggests the benefits arising from the use of a cross-fertilization approach for socio-technical systems [168]. This trend is also confirmed by another research study comparing results obtained from traditional analysis; some documents in this RF argue for the potential benefits arising from a resilience engineering point of view [169]. Similarly, an exploratory benchmarking exercise between traditional techniques and one of the most used resilience engineering methods, i.e. the functional resonance analysis method (FRAM), promotes the complementary perspective these methods can offer [170].

3.2.10. RF9 – The use of fuzzy logic in HRA

This RF is strongly related to other factors, in particular RF1, and concerns HRA advances obtained by using fuzzy logic. The importance of applying fuzzy concepts to reliability analysis was explored by Onisawa [171]. Szwarcman et al. [172] further present a methodology for the characterization of human reliability based on fuzzy sets concepts. They propose a human reliability index for the identification of problems that may lead to human errors, as well as possible strategies for the control of potentially adverse impacts of interactions that add uncertainty and complexity to processes. One particular area of HRA that can benefit from the use of fuzzy logic is the treatment of uncertainty. For instance, demonstrating an application for HRA, [173] presents two techniques for sensitivity and uncertainty analysis of fuzzy expert systems. Baziuk, Rivera and Nuñez Mc Leod [174] propose an approach to facilitate the identification of uncertainties and future treatment with fuzzy sets. They attempt to unify human behavioural science and engineering in a unified human reliability model. Fuzzy logic can also be applied by using an existing HRA method as a basis. For example, Kirytopoulos [175] proposes a fuzzy logic system based on CREAM to provide more sophisticated estimations of the tunnel operators' performance in safety-critical situations.

3.2.11. Multi-dimensional scaling

The significance of the RFs has also been tested through a MDS algorithm. Based on the Pearson co-citation matrix as a similarity measure, MDS is intended to depict the conceptual proximity among contributions and RFs in the Core Dataset. Two-dimensional and three-dimensional MDS maps have been developed to find an interpretable configuration (two, or three dimensions at maximum) that is still statistically representative. Among the tested results, a three-dimensional, non-metric random starting configuration has been selected since it allowed an acceptable value of its goodness-of-fit (stress < 0.2) [176]. In this MDS map, each document's position reflects its relative correlation with other documents: the higher the correlation is, the closer the documents.

Relying on the graphical representation, it has been possible to define a meta-dimension for the map that gives a holistic interpretation of the nature of multiple RFs, as shown in Fig. 8. An overall dimension, which goes from "theoretical", extends through "simulation-based", and finally reaches "applied", indicates the nature of the considered works.

As mentioned in Section 1, HRA theoretical foundations may not be directly reflected in scientific indexed databases, as these theoretical foundations may be the results of proprietary research or may be publicly available but not recorded in citation databases such as Scopus. For this reason, the dimension identified in Fig. 8 originates from an area that is not covered by the analysis. This area lies on a lower level where no documents are graphically represented, as they are not found in the considered databases. While this lower level represents the very HRA theoretical origins, both foundational components and simulations are observed in RF2 and RF4 and address processing and response. Human cognitive processes, such as diagnosis, are the focus of publications grouped under RF2 and are treated across various domains. Actions, their interdependency and their quantification are the subjects of RF4. The distinction outlined by RF2 and RF4 is characteristic of traditional HRA methods, such as the technique for human error rate prediction (THERP) [177], the accident sequence precursor (ASP) HRA methodology [178], the SPAR-H HRA method [179,180], and the Petro-HRA method [76,181]. Quantitative aspects are found also within the works of RF1 and discuss the advances in the pivotal step of HRA quantification (e.g., in terms of simulations), which represents a pillar of HRA theory and reflects an overlapping area with RF4.

RF1 dedicates more attention to the use of data and simulations. Data collection for HRA is an important sub-topic of RF1. RF9, which focuses on HRA and fuzzy logic, shows some overlap with RF2, demonstrating that the complexity and uncertainty encountered during the assessment of cognitive process may be dealt with by classes of simulated alternatives whose boundaries are not sharply defined. RF3 lays the foundations for simulations (both in virtual and real environments), as the work labelled with this RF study human performance and human factors from a dynamic perspective in an effort to continuously refine HRA models and reproduce a realistic evolution of events.

RF5 spans along the whole theoretical/simulation-based/applicative dimension. For this reason, it well represents the tension involved in the improvement of HRA theories through new data, which may come from either simulations or verifiable observations from the applications in specific sectors. RF6 and RF7 are relatively isolated on the map (Fig. 8) with respect to the other RFs and present a strong applicative connotation. The two RFs show how empirical studies support the advancement of HRA in healthcare, while the application of human reliability concepts and tools allows considering human factors in the design of systems.

3.3. Key term analysis

This analysis has been performed to further explore the content of documents and their evolution over time. Note that the key terms are the key words as originally proposed by the authors of the articles. Ideally, the key words should reflect the main content and contributions of the paper. For the analysis, we assume this to be accurate. Moreover, we present the key words as written by the authors, including acronyms. As a result, for instance, some maps may have "probabilistic safety assessment" and "PSA", although the meaning of both key terms is the same.

Following a time interval of approximately 5 years for each cluster, the article database (Dataset 0) has been divided into clusters according to the articles' publication year. Therefore, 4 clusters have been identified: 1999-2003, 2004-2008, 2009-2013, and 2014-2019. The final period is four months longer than the previous ones. The size of the sample cluster before 1999 was too small for any representative analyses. It is interesting to observe how the increase in the number of papers generated, as expected, an increase in the variety of topic areas. The analysis allows us to explore the relative frequency of key terms (size of the bubble) and the interconnectedness (links between bubbles) of methods, models, and research aspects. The thickness of the lines depicts the strength of the relationship between the key terms: a thicker line connecting two key terms indicates that those have often been used together. The analyses were performed in VOSviewer [182]. To have a manageable and significant number of terms, the threshold for the number of documents that should include the keywords was set to 5.

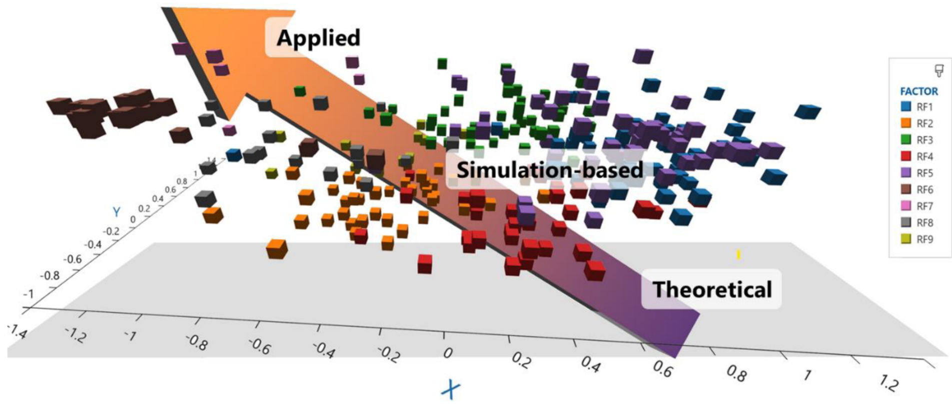


Fig. 8. Multi-Dimensional Scaling map with the associated RFs.

3.3.1. Cluster: 1999–2003

There are only 4 key terms significantly used in the references between the years 1999 and 2003. These are "human reliability", "human error", "human factors" and "risk analysis". "Human factors" is a central connection to the key words. Note that as a discipline, human factors was established earlier than HRA. Indeed, the oldest professional body for human factors' specialists and ergonomists is The Chartered Institute of Ergonomics and Human Factors, formed in 1946 in the UK. The 5-year period of Dataset 1 is characterized by few sources dealing with generic issues in the field rather than more specific topical contributions (see Fig. 9).

3.3.2. Cluster: 2004–2008

In the period 2004-2008, the significant key terms increased to 14 (see Fig. 10). Note that compared to the previous years, in this period, the term "HRA" is substantially used, which indicates a popularization of the discipline so that its acronym is well known in this period. During this period, the publications initially concerned human factors, human error, PRA, and human reliability assessment and progressed to significantly include human error probability and performance shaping factors. The latter is connected to human factors, as the factors analysed in the human factors discipline affect operators' performance and, as such, can serve as a foundation for performance shaping factors in HRA. CREAM, developed in 1998, is used as key word in this period and is associated with PSA. Note that this does not necessarily mean that CREAM was not used in HRA in the previous years. However, it may be assumed that during this period, it became a more popular method since the key words were chosen by the articles' authors to make their paper identifiable and easily found.

3.3.3. Cluster: 2009–2013

The degree of specialization of the sources explodes to 45 items in the 2009-2013 period (see Fig. 11). In addition to CREAM, the key terms include the methods SPAR-H, published in 2005, and THERP. Moreover, in addition to risk analysis, PRA and PSA, HRA appears connected also to LOPA, process safety, risk management, and resilience engineering, indicating a broader use of HRA in risk-related disciplines. Concerning fields of application, this period reveals the use of the key word "patient safety" in addition to the expected "nuclear power plants", indicating a significant number of papers concerning the use of HRA in healthcare. Compared with previous years, in this period, the key words, namely, performance shaping factors and performance influencing factors, were increasingly used. They are connected to Bayesian networks, indicating the increasing use of BBNs for modelling PSFs and organizational factors. This increased usage suggests a popularization of the recognition of the impact of organizational factors in human performance and the need to model them as PSFs.

3.3.4. Cluster: 2014–2019

The key terms increase to 53 between 2014 and 2019, exhibiting a rather complex network of interrelated clusters (e.g., key terms such as "Bayesian networks", "PSF", "expert opinion/judgment" appear in several clusters) (see Fig. 12). In addition to "patient safety", which was used during the previous cluster, this period of time also includes "surgery", which focuses on the use of HRA in healthcare, and "maritime safety", indicating the use of HRA in fields other than nuclear. An additional key term that gained importance in this period is "cognitive". Given the increasing awareness that cognitive errors should be assessed in human reliability, this was expected. "Digital main control room" is also an expected added key term for this period. Unlike the more popular terms such as "human factors", this term was not used as a key word by a large number of papers during the 5 years analysed and therefore cannot be clearly viewed in Fig. 12. Digital main control rooms are an important and recent modification in NPPs' operation, and the HRA community has been discussing and proposing how to analyse this new form of interaction with HRA. A similar phenomenon occurs with the key term "HRA data": compared to other terms, this term is not very popular; therefore, it cannot be seen in Fig. 12. However, the topic is of increasing interest in the HRA community, in particular due to the SACADA and HuREX projects.

Fig. 9. Bibliometric map of key terms, and respective relationships [1999–2003].

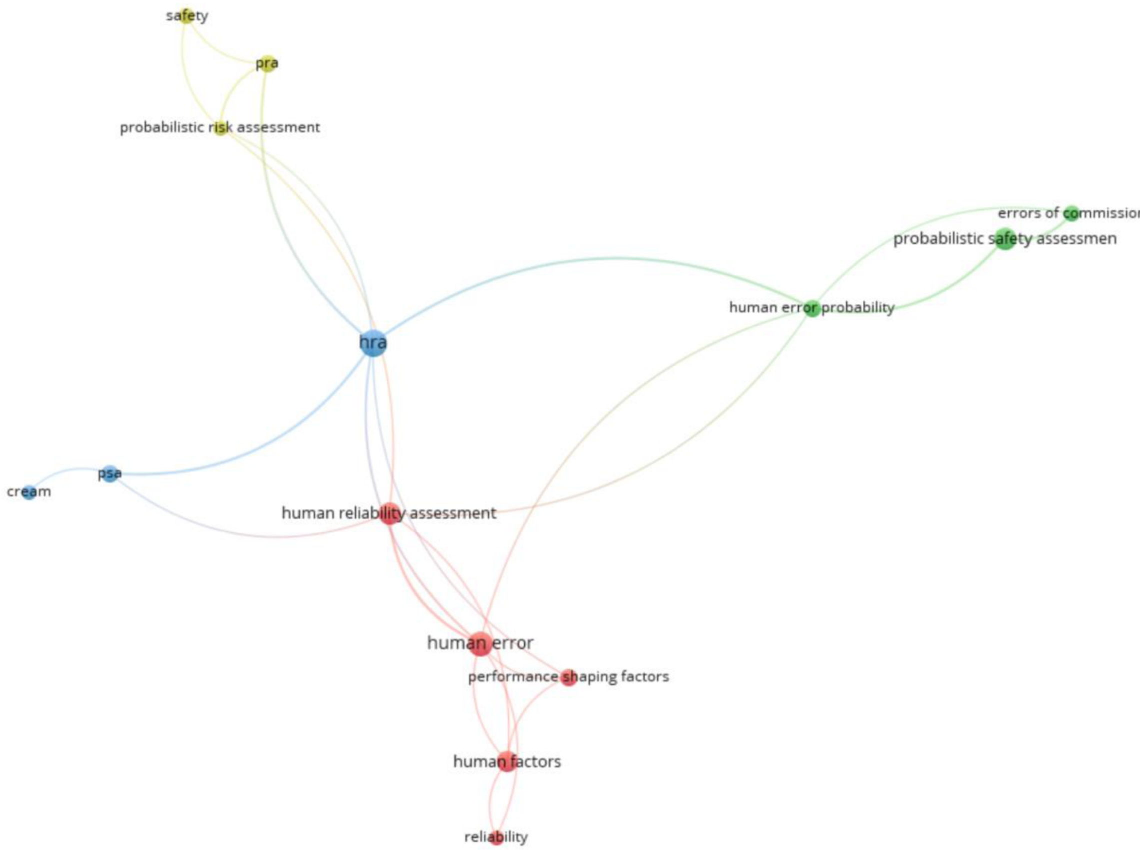


Fig. 10. Bibliometric map of key terms and respective relationships [2004–2008].

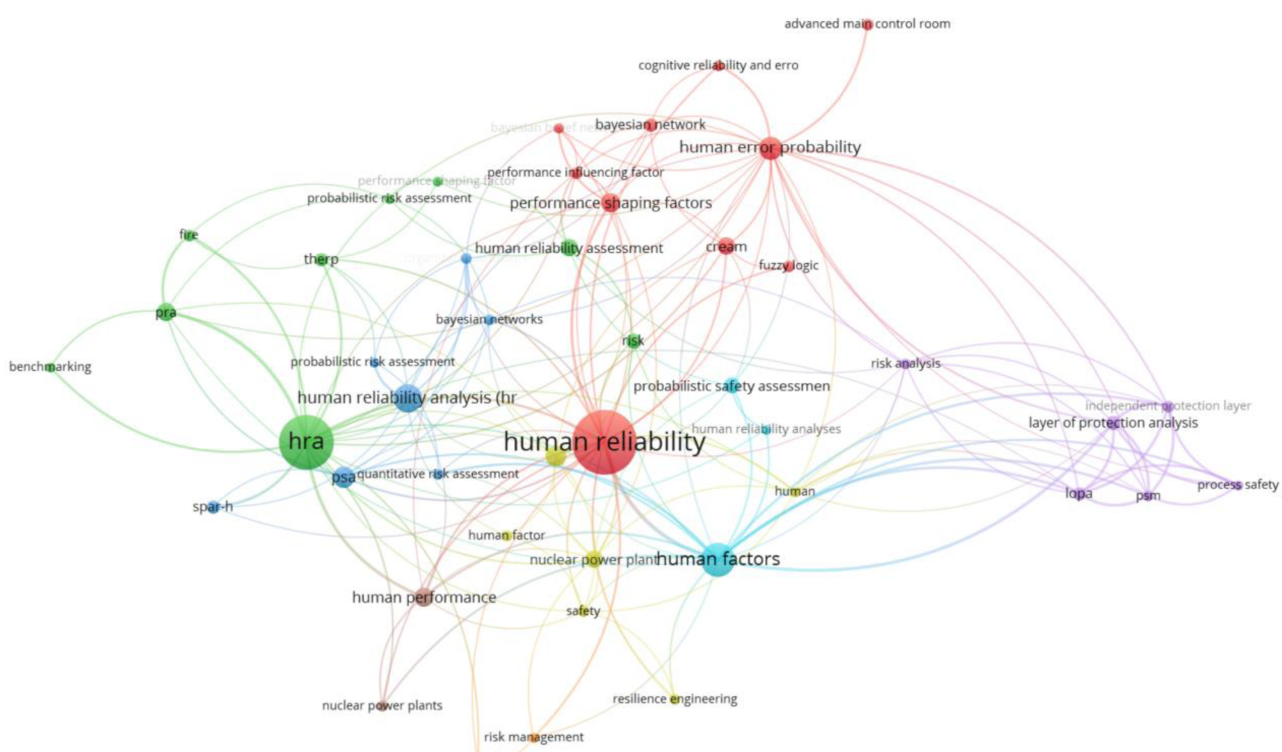


Fig. 11. Bibliometric map of key terms and respective relationships [2009–2013].

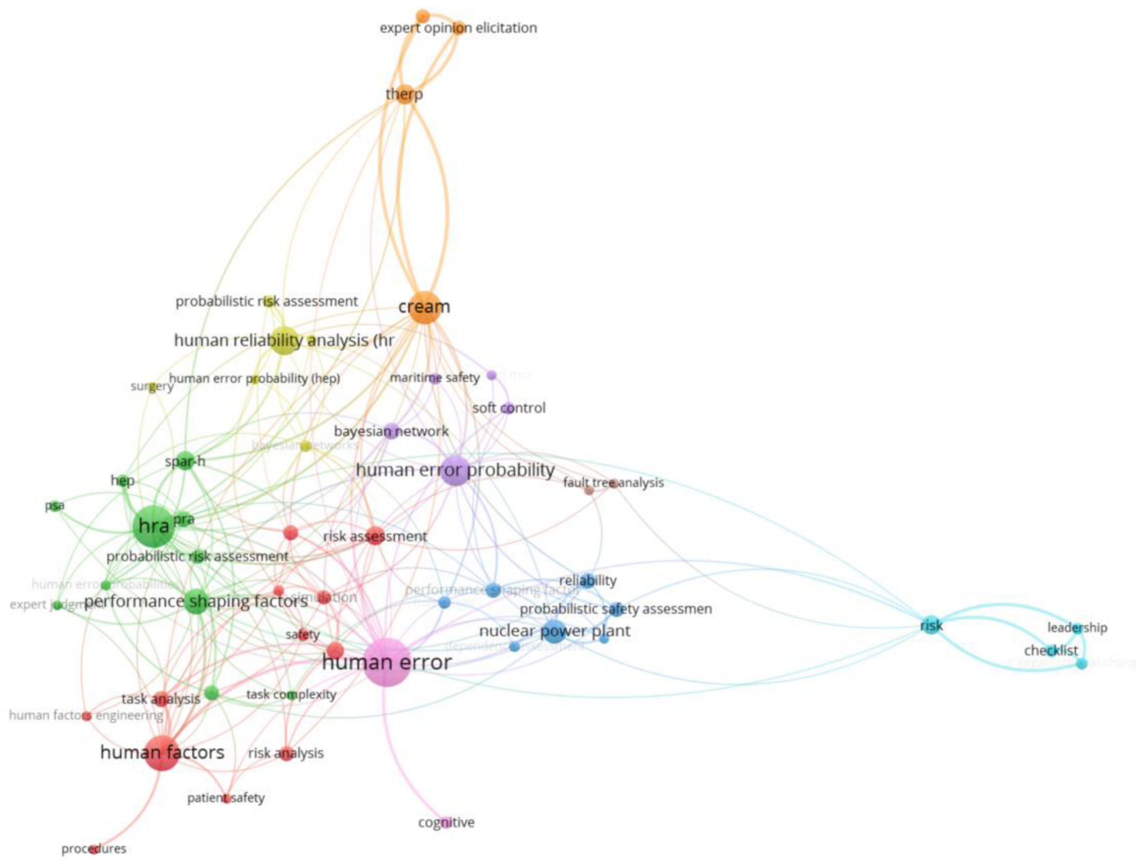


Fig. 12. Bibliometric map of key terms, and respective relationships [2014–2019].

4. Discussion and conclusions

Regarding the methodological contribution proposed in this research, the multi-method approach allows the use of complementary perspectives to explore the intellectual structure of research on HRA. Through analytic expressions grounded on relevance theory, the approach could be further extended through Pennant diagrams to capture main documents (or authors) in terms of text (or citations) entropy [183]. Other analyses based on naturalistic text analyses may automatically support content extraction. In the long run, the process described may be linked to (near) real-time data extraction and analysis so that scholars may access such outcomes autonomously. Through modern technologies and database informative structure, the notion itself of literature reviews including systematic data analytics may evolve through support vector machines or artificial neural networks [184].

The statistical overview (results from the methodology step 8) highlights an increasing trend in terms of the number of publications (especially journal articles) from the early 2000s. Currently, HRA research is not concentrated within few world regions but is mainly spread across the American, European and Asian continents. The journals and conferences reporting a larger number of publications are not surprising, as they clearly show the following aspects of HRA:

- It addresses the topic of reliability and safety, as the main journals for HRA publications are Reliability Engineering and System Safety and Safety Science, and the main conferences are PSAM and ESREL;
- Its origins are within the nuclear sector, and it has been adopted by other safety-critical sectors such as the process industry, as several publications are from the Annals of Nuclear Energy and the PSA conference by the American Nuclear Society, together with the Global Congress of Process Safety.

Despite the increasing trend in publications, there is still a need to improve access to HRA publications by promoting open access. However, this trend may be slowly reversing in Europe. Two main factors motivate this: several initiatives seeking nationwide licenses combine reading paywalled articles and publishing in an open access format into one fee [185], and the projects that received or are receiving Horizon 2020 funding are required to make sure that any peer-reviewed journal article they publish is openly accessible and free of charge [186]. Such trend inversion is confirmed by the increase of HRA open access publications within the 2016-2019 interval.

The research factors (results from the methodology step 7) reveal that cognition processes are recognized and studied independently from actions. Methods such as CREAM rely on a sound cognitive model and framework that emphasizes the whole characteristics of the context. Expert judgement is essential for the study of cognitive processes, but the discussion on how to use it in a structured and guided fashion to increase HRA fidelity is still open. At the same time, human action assessment allows for isolation of actions, which has intrinsic potential to reduce accident risk. However, it should not be forgotten that human actions may depend on several factors, such as contextual factors, or be intra-dependent on each other.

In the field of HRA, the use of BBNs both as a stand-alone approach and combined with other techniques to create hybrid approaches is steadily increasing within the relevant literature. BBNs are effectively used to model organizational factors and deal with the mentioned dependencies but continuously require data for development and testing. A solution may reside in the fact that new data on human performance and human error are collected to assess the reliability of the human-interface interaction with digital systems. Indeed, data collection for use in HRA is the focus of two substantially large projects: SACADA [187] and HuREX [188]. SACADA is a database developed by the U.S. NRC and collects operator performance data in cooperation with nuclear companies. The data are collected during training programmes with the aim of supporting NPP's operator training programmes and improving HRA quality. SACADA is an ongoing project, and the NRC made a portion of the database available to the public. Updates on SACADA, NPPs partners, and the database structure can be found at the NRC website. Similarly, HuREX provides a framework for HRA data collection. HuREX is an ongoing project by the Korea Atomic Energy Research Institute that aims to generate HEP data and correlations between PSFs and HEPs. Computer simulation, data from human-in-the-loop simulators, and operational data from surveys are other approaches to accumulating human reliability data. Despite the existence of several strategies, uncertainties related to the collected data (e.g., unreliable or sparse data) may be present. For this reason, the importance of applying fuzzy concepts to new generation HRA is being recognized by the experts.

Notably, a number of works identify and underline that human performance has a dynamic nature that is not fully captured by HRA. Experts are focusing on including this aspect in novel analysis methods through benchmarking studies or new sessions of simulations. These areas of study and application focus on developments in human performance in the context of highly critical tasks for humans. These areas include healthcare (surgeries, radiotherapy treatment processes, etc.), nuclear, chemical, manufacturing, and railway domains, which in addition to experiencing relatively well-known issues, cyclically remains subject to transitions towards new technologies and emerging risks.

The results from the multi-dimensional scaling provide a spatial positioning of the single factors represented on a map. There are two main takeaways from these results. First, an overall dimension from "theoretical", through "simulation-based", and finally extending to "applied" indicates the nature of the considered works and resembles the evolution process of a generic methodology, starting from the definition of its basic theory and the study of its feasibility, through the demonstration of its maturity on simulations, and extending to its testing in real cases to show its readiness. The very origin of the HRA dimension is located among a number of foundational documents that are not analysed by this work and represent most of the theoretical elements at the basis of the topic. However, as HRA is addressed by a number of methods (even grouped within generations), this evolution has been iterated repetitively within the scientific literature, showing a clear pattern in Fig. 8. Second, the factors are not only organized based on this dimension but also highly interlaced due to transversal topics that outline general trends, as can be appreciated both graphically (Fig. 8) and thematically. The dependency of human actions is one of these transversal topics (addressed by RF1, RF3 and RF4, which are graphically adjacent in Fig. 8). However, the related uncertainty (RF2 and RF9, graphically adjacent in Fig. 8) and complexity (RF4 and RF9, graphically adjacent in Fig. 8) require integration with novel approaches based on fuzzy concepts (RF2, RF4 and RF9, graphically adjacent in Fig. 8). On the other hand, limited data (RF1 and RF2, graphically adjacent in Fig. 8) for HRA may require the use of appropriate expert judgement (RF1 and RF2) and ad hoc simulations (RF1, RF2, RF3 and RF5, graphically adjacent in Fig. 8). Another novel approach that is proving suitable for HRA is the adoption of BBNs (RF1, RF2, RF3 and RF5, graphically adjacent in Fig. 8), which represent one of the most recent developments together with an extended digitalization incentive (RF4 and RF5, graphically adjacent in Fig. 8). Moreover, the study of HRA applications in domains that fall outside the traditional safety-critical sectors, such as the nuclear and process industries, is common across the factors (RF3, RF4 and RF8, graphically adjacent in Fig. 8) and represents the main feature of the most delineated factor in the map (RF6).

The key term analysis (results from methodology step 9) outlines clear research streams within the HRA literature. While the publications from the period 1999-2003 show rather predictable key words ("human reliability", "human error", "human factors" and "risk analysis"), the second period (2004-2008) shifts its focus to the fundamental HRA elements and addresses human factors, human error and their probabilistic modelling through performance shaping factors. The emerging HRA methodology denominated CREAM also becomes one of most considered key words, demonstrating the rise of a method that is rather popular today. "CREAM" is also a key word of the period 2009-2013, which sees a focus on both a consolidated first-generation technique (THERP) and its emerging derivation (SPAR-H). The key words "process safety", "resilience engineering" and, especially, "patient safety" demonstrate that HRA is increasingly employed beyond its traditional application fields, such as in "nuclear power plants", and gradually becoming a pillar of the overall industrial risk analysis. Moreover, the analysis of this period registers the appearance of "BBNs" as a key word, later confirmed in the period 2014-2019, when the adoption of this quantitative technique for HRA further strengthens. The trend concerning the application of HRA within relatively new fields is also confirmed in this last analysed period, as the key words "surgery" and "maritime safety" are registered. Finally, the digitalization wave is registered within the HRA community, as "digital main control room" and "HRA data" become key words. It is expected that data-based and BBN-related topics may eventually lead HRA towards future research involving the adoption of relatively more sophisticated machine learning techniques, mimicking recent risk analysis trends [189].

In conclusion, this study allows the promotion of awareness and an understanding of publications in the field of HRA. In a nutshell, the scope of this analysis focused mainly on exploring and discussing publications within HR rather than on the challenges of the field itself. Nonetheless, further research can start from the results of the present study to provide additional observations and critical reflections on the discipline, also considering the social structure of the field.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

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APPENDIX - Data of the 423 (out of 440) papers in the core dataset assigned to RFs

Factor	Title	Year	Source
RF1	A Bayesian approach to treat expert-elicited probabilities in human reliability analysis model construction	2013	Reliability Engineering and System Safety
RF1	A computational method for probabilistic safety assessment of I&C systems and human operators in nuclear power plants	2006	Reliability Engineering and System Safety
RF1	A computational model for evaluating the effects of attention, memory, and mental models on situation assessment of nuclear power plant operators	2009	Reliability Engineering and System Safety
RF1	A data-informed PIF hierarchy for model-based human reliability analysis	2012	Reliability Engineering and System Safety
RF1	A dynamic Bayesian networks modelling of human factors on offshore blowouts	2013	Journal of Loss Prevention in the Process Industries

RF1	A fuzzy Bayesian network approach to improve the quantification of organizational influences in HRA frameworks	2012	Safety Science
RF1	A human reliability analysis approach to clinical risk management: First steps towards a new methodology	2007	Proceedings of the European Safety and Reliability Conference 2007, ESREL 2007 - Risk, Reliability and Societal Safety
RF1	A model-based approach to HRA: Example application and quantitative analysis	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	A model-based approach to HRA: Qualitative analysis methodology	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	A model-based human reliability analysis framework	2010	10th International Conference on Probabilistic Safety Assessment and Management 2010, PSAM 2010
RF1	A model-based human reliability analysis methodology	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	A new method for human reliability assessment in railway transport	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	A pilot experiment for Science-based Human Reliability Analysis validation	2013	International Topical Meeting on Probabilistic Safety Assessment and Analysis 2013, PSA 2013
RF1	A pilot study for errors of commission for a boiling water reactor using the CESA method	2013	Reliability Engineering and System Safety
RF1	A review of the current status of HRA data	2014	Safety, Reliability and Risk Analysis: Beyond the Horizon - Proceedings of the European Safety and Reliability Conference, ESREL 2013
RF1	A survey of Bayesian Belief Network Applications in Human Reliability Analysis	2015	Safety and Reliability: Methodology and Applications - Proceedings of the European Safety and Reliability Conference, ESREL 2014
RF1	A taxonomy and database for capturing human reliability and human performance data	2006	Proceedings of the Human Factors and Ergonomics Society
RF1	A virtual experimental technique for data collection for a Bayesian network approach to human reliability analysis	2014	Reliability Engineering and System Safety
RF1	An analytic model for situation assessment of nuclear power plant operators based on Bayesian inference	2006	Reliability Engineering and System Safety
RF1	An HRA-based simulation model for the optimization of the rest breaks configurations in human-intensive working activities	2015	IFAC-PapersOnLine
RF1	Application of ATHEANA in human failure events analysis	2005	Hedongli Gongcheng/Nuclear Power Engineering
RF1	Application of Bayesian Belief networks to the human reliability analysis of an oil tanker operation focusing on collision accidents	2013	Reliability Engineering and System Safety
RF1	Assessing offshore emergency evacuation behavior in a virtual environment using a Bayesian Network approach	2016	Reliability Engineering and System Safety
RF1	Bayesian belief networks for human reliability analysis: A review of applications and gaps	2015	Reliability Engineering and System Safety
RF1	Bridging the gap between HRA research and HRA practice: A Bayesian network version of SPAR-H	2013	Reliability Engineering and System Safety
RF1	Bridging the simulator gap: Measuring motivational bias in digital nuclear power plant environments	2018	Reliability Engineering and System Safety
RF1	Challenges in leveraging existing human performance data for quantifying the IDHEAS HRA method	2015	Reliability Engineering and System Safety
RF1	Comparing the treatment of uncertainty in Bayesian networks and fuzzy expert systems used for a human reliability analysis application	2015	Reliability Engineering and System Safety
RF1	Considerations on the elements of quantifying human reliability	2004	Reliability Engineering and System Safety
RF1	Dependency assessment in human reliability analysis using an evidential network approach extended by belief rules and uncertainty measures	2018	Annals of Nuclear Energy
RF1	Deriving causal Bayesian networks from human reliability analysis data: A methodology and example model	2012	Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability
RF1	Developing and evaluating the Bayesian Belief Network as a Human Reliability model using artificial data	2012	Advances in Safety, Reliability and Risk Management - Proceedings of the European Safety and Reliability Conference, ESREL 2011
RF1	Development of a risk analysis model to evaluate human error in industrial plants and in critical infrastructures	2017	International Journal of Disaster Risk Reduction
RF1	Eliciting engineering judgments in human reliability assessment	2006	Proceedings - Annual Reliability and Maintainability Symposium
RF1	Error Categorization and Analysis in Man-Computer Communication Systems	1973	IEEE Transactions on Reliability
RF1	Evaluating the bayesian belief network as a human reliability model - The effect of unreliable data	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	Guidance on dependency assessment in SPAR-H	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	HRA in China: Model and data	2011	Safety Science
RF1	HRA method analysis criteria	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	Human factors, human reliability and risk assessment in license renewal of a nuclear power plant	2009	Reliability Engineering and System Safety
RF1	Human failure event dependency modeling and quantification: A Bayesian network approach	2014	Safety, Reliability and Risk Analysis: Beyond the Horizon - Proceedings of the European Safety and Reliability Conference, ESREL 2013
RF1	Human performance/error data collection for incident analysis via timeline generation method and tool: A case study	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	Human Reliability Analysis Based on Human Abilities Theory Model	2018	IEEE Transactions on Fuzzy Systems
RF1	Human reliability assessment theory and practice	2009	Human Reliability Assessment Theory and Practice
RF1	Human Reliability Assessment under Uncertainty – Towards a Formal Method	2015	Procedia Manufacturing

RF1	Human reliability modeling for the Next Generation System Code	2013	Annals of Nuclear Energy
RF1	Human unimodel for nuclear technology to enhance reliability (HUNTER): A framework for computational-based human reliability analysis	2017	PSAM 2016 - 13th International Conference on Probabilistic Safety Assessment and Management
RF1	Incorporating organizational factors into Probabilistic Risk Assessment (PRA) of complex socio-technical systems: A hybrid technique formalization	2009	Reliability Engineering and System Safety
RF1	Incorporating organizational factors into probabilistic risk assessment of complex socio-technical systems: Principles and theoretical foundations	2009	Safety Science
RF1	Looking for errors of omission and commission or The Hunting of the Snark revisited	2000	Reliability Engineering and System Safety
RF1	Methodology for collection and analysis of simulator data for HRA applications	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	Model-based HRA methodology: Procedures for qualitative analysis	2013	International Topical Meeting on Probabilistic Safety Assessment and Analysis 2013, PSA 2013
RF1	Nuclear Action Reliability Assessment (NARA), further development of a data-based HRA tool	2008	Contemporary Ergonomics 2008
RF1	On the study of human reliability in transportation systems of systems	2015	2015 10th System of Systems Engineering Conference, SoSE 2015
RF1	Overview and preliminary results of the US empirical HRA study	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	Overview of the NRC's HRA data program and current activities	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	Performance factors for the analysis of crew responses to Nuclear Power Plant simulated emergencies	2014	Safety, Reliability and Risk Analysis: Beyond the Horizon - Proceedings of the European Safety and Reliability Conference, ESREL 2013
RF1	Probabilistic—Risk—Assessment Applications In the Nuclear-Power Industry	1998	IEEE Transactions on Reliability
RF1	Qualitative human event analysis with simulator data by using HuRAM+ and HERA	2014	Safety, Reliability and Risk Analysis: Beyond the Horizon - Proceedings of the European Safety and Reliability Conference, ESREL 2013
RF1	Railway action reliability assessment, a railway-specific approach to human error quantification	2013	Rail Human Factors: Supporting Reliability, Safety and Cost Reduction
RF1	Representation of parameter uncertainty in Bayesian Belief Networks for Human Reliability Analysis	2014	Safety, Reliability and Risk Analysis: Beyond the Horizon - Proceedings of the European Safety and Reliability Conference, ESREL 2013
RF1	Results and insights derived from the intra-method comparisons of the US HRA empirical study	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	Simulator-based human factors studies across 25 years: The history of the Halden man-machine laboratory	2011	Simulator-based Human Factors Studies Across 25 Years: The History of the Halden Man-Machine Laboratory
RF1	SLIM-MAUD: A Computer-Based Technique for Human Reliability Assessment	1986	International Journal of Quality & Reliability Management
RF1	SPAR-H step-by-step guidance	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF1	The measure of human error: Direct and indirect performance shaping factors	2007	IEEE Conference on Human Factors and Power Plants
RF1	Validating THERP: Assessing the scope of a full-scale validation of the Technique for Human Error Rate Prediction	2015	Annals of Nuclear Energy
RF1	Validation of human reliability assessment of techniques: Part 1 - Validation issues	1997	Safety Science
RF2	A Bayesian Network to Ease Knowledge Acquisition of Causal Dependency in CREAM: Application of Recursive Noisy-OR Gates	2017	Quality and Reliability Engineering International
RF2	A critical review of methods and models for evaluating organizational factors in Human Reliability Analysis	2014	Progress in Nuclear Energy
RF2	A critique of recent models for human error rate assessment	1988	Reliability Engineering and System Safety
RF2	A fuzzy and Bayesian network CREAM model for human reliability analysis – The case of tanker shipping	2018	Safety Science
RF2	A fuzzy modeling application of CREAM methodology for human reliability analysis	2006	Reliability Engineering and System Safety
RF2	A human reliability analysis method based on CREAM and uncertain reasoning	2012	Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/Journal of Tianjin University Science and Technology
RF2	A method for marine human error probability estimate: APJE-SLIM	2011	Applied Mechanics and Materials
RF2	A methodological extension to human reliability analysis for cargo tank cleaning operation on board chemical tanker ships	2015	Safety Science
RF2	A modified CREAM to human reliability quantification in marine engineering	2013	Ocean Engineering
RF2	A modified human reliability analysis for cargo operation in single point mooring (SPM) off-shore units	2016	Applied Ocean Research
RF2	A new hybrid approach to human error probability quantification–applications in maritime operations	2017	Ocean Engineering
RF2	A phase of comprehensive research to determine marine-specific EPC values in human error assessment and reduction technique	2016	Safety Science
RF2	A proactive approach to human error detection and identification in aviation and air traffic control	2009	Safety Science
RF2	A probabilistic approach for determining the control mode in CREAM	2006	Reliability Engineering and System Safety
RF2	A simplified CREAM prospective quantification process and its application	2008	Reliability Engineering and System Safety
RF2	A weighted CREAM model for maritime human reliability analysis	2015	Safety Science
RF2	An application of CREAM for human reliability analysis in power system switching operation	2014	Applied Mechanics and Materials
RF2	Application of CREAM human reliability model to cargo loading process of LPG tankers	2015	Journal of Loss Prevention in the Process Industries
RF2	Application of Fuzzy HEART and expert elicitation for quantifying human error probabilities in LPG refuelling station	2017	Journal of Loss Prevention in the Process Industries
RF2	Approach for assessing human decision reliability	2000	Reliability Engineering and System Safety

RF2	Bayesian modelling for human error probability analysis in CREAM	2011	ICQR2MSE 2011 - Proceedings of 2011 International Conference on Quality, Reliability, Risk, Maintenance, and Safety Engineering
RF2	Comparison of human reliability analysis methods	2005	Hedongli Gongcheng/Nuclear Power Engineering
RF2	Development of a human reliability assessment technique for the maintenance procedures of marine and offshore operations	2017	Journal of Loss Prevention in the Process Industries
RF2	Estimating Human Error Probability using a modified CREAM	2012	Reliability Engineering and System Safety
RF2	Evaluation of a software implementation of the cognitive reliability and error analysis method (CREAM)	2007	Proceedings of the Human Factors and Ergonomics Society
RF2	Evaluation of significant transitions in the influencing factors of human reliability	2008	Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability
RF2	Failures without errors: Quantification of context in HRA	2004	Reliability Engineering and System Safety
RF2	Fuzzy Human Reliability Analysis: Applications and Contributions Review	2016	Advances in Fuzzy Systems
RF2	Fuzzy modelling of HEART methodology: Application in safety analyses of accidental exposure in irradiation plants	2009	Radiation Effects and Defects in Solids
RF2	Human Error and Human Reliability Analysis	2012	Handbook of Human Factors and Ergonomics: Fourth Edition
RF2	Human error assessment during maintenance operations of marine systems – What are the effective environmental factors?	2018	Safety Science
RF2	Human error probability estimation in ATEX-HMI area classification: From THERP to FUZZY CREAM	2015	Chemical Engineering Transactions
RF2	Human error risk analysis in offshore emergencies	2010	Safety Science
RF2	Human reliability analysis - Taxonomy and praxes of human entropy boundary conditions for marine and offshore applications	2012	Reliability Engineering and System Safety
RF2	Human reliability analysis by fuzzy "CREAM"	2007	Risk Analysis
RF2	Human reliability analysis in spaceflight applications	2013	Quality and Reliability Engineering International
RF2	Human reliability analysis in spaceflight applications, part 2: Modified CREAM for spaceflight	2014	Quality and Reliability Engineering International
RF2	Human reliability analysis of the Tokai-Mura accident through a THERP-CREAM and expert opinion auditing approach	2016	Safety Science
RF2	Human reliability assessment during offshore emergency conditions	2013	Safety Science
RF2	Human Reliability Engineering	1978	IEEE Transactions on Reliability
RF2	Human-reliability analysis of cooperative redundancy to support diagnosis	2004	IEEE Transactions on Reliability
RF2	Overview of typical methods for human reliability analysis	2007	Guofang Keji Daxue Xuebao/Journal of National University of Defense Technology
RF2	Quantitative developments in the cognitive reliability and error analysis method (CREAM) for the assessment of human performance	2006	Annals of Nuclear Energy
RF2	Quantitative evaluation of human-reliability based on fuzzy-clonal selection	2011	IEEE Transactions on Reliability
RF2	Quantitative human reliability analysis methods and application of offshore engineering	2011	Tianjin Daxue Xuebao (Ziran Kexue yu Gongcheng Jishu Ban)/Journal of Tianjin University Science and Technology
RF2	Screening, sensitivity, and uncertainty for the CREAM method of Human Reliability Analysis	2013	Reliability Engineering and System Safety
RF2	Structured information analysis for human reliability analysis of emergency tasks in nuclear power plants	2001	Reliability Engineering and System Safety
RF2	Subjective analysis of system reliability and its analyzer	1996	Fuzzy Sets and Systems
RF2	The Mechanism of how Design Failures cause Unsafe Behavior: The Cognitive Reliability and Error Analysis Method (CREAM)	2016	Procedia Engineering
RF2	Uncertainty of human error and fuzzy approach to human reliability analysis	2006	International Journal of Uncertainty, Fuzziness and Knowlege-Based Systems
RF2	User strategies in recovering from errors in man-machine systems	1999	Safety Science
RF3	A mid-layer model for human reliability analysis: Understanding the cognitive causes of human failure events	2010	10th International Conference on Probabilistic Safety Assessment and Management 2010, PSAM 2010
RF3	A performance shaping factors causal model for nuclear power plant human reliability analysis	2010	10th International Conference on Probabilistic Safety Assessment and Management 2010, PSAM 2010
RF3	A probabilistic cognitive simulator for HRA studies (PROCOS)	2007	Reliability Engineering and System Safety
RF3	A quantitative method for human reliability in power system based on CREAM	2013	Dianli Xitong Baohu yu Kongzhi/Power System Protection and Control
RF3	A Review of Cognitive Models in Human Reliability Analysis	2017	Quality and Reliability Engineering International
RF3	A role for human reliability analysis (HRA) in preventing drinking water incidents and securing safe drinking water	2009	Water Research
RF3	A Simulator for Human Error Probability Analysis (SHERPA)	2015	Reliability Engineering and System Safety
RF3	An analytical approach to quantitative effect estimation of operation advisory system based on human cognitive process using the Bayesian belief network	2008	Reliability Engineering and System Safety
RF3	An integrated framework to the predictive error analysis in emergency situation	2002	Journal of Loss Prevention in the Process Industries
RF3	Application of the human cognitive reliability model and confusion matrix approach in a probabilistic risk assesmeent	1988	Reliability Engineering and System Safety
RF3	Bridging human factors and human reliability analysis	2008	Proceedings of the Human Factors and Ergonomics Society
RF3	Bridging human reliability analysis and psychology, Part 2: A cognitive framework to support HRA	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF3	Cognitive environment simulation: a tool for modeling intention formation for human reliability analysis	1992	Nuclear Engineering and Design
RF3	Cognitive modeling and dynamic probabilistic simulation of operating crew response to complex system accidents. Part 1: Overview of the IDAC Model	2007	Reliability Engineering and System Safety
RF3	Cognitive modeling and dynamic probabilistic simulation of operating crew response to complex system accidents. Part 2: IDAC performance influencing factors model	2007	Reliability Engineering and System Safety
RF3	Cognitive modeling and dynamic probabilistic simulation of operating crew response to complex system accidents. Part 3: IDAC operator response model	2007	Reliability Engineering and System Safety
RF3	Cognitive modeling and dynamic probabilistic simulation of operating crew response to complex system accidents. Part 4: IDAC causal model of operator problem-solving response	2007	Reliability Engineering and System Safety

RF3	Cognitive modeling and dynamic probabilistic simulation of operating crew response to complex system accidents. Part 5: Dynamic probabilistic simulation of the IDAC model	2007	Reliability Engineering and System Safety
RF3	Cognitive modelling: A fundamental issue for human reliability assessment methodology?	1992	Reliability Engineering and System Safety
RF3	Contributing factor map: A taxonomy of influences on human performance and health in space	2014	IEEE Transactions on Human-Machine Systems
RF3	Cross-disciplinary method for predicting and reducing human error probabilities in manual assembly operations	2013	Total Quality Management and Business Excellence
RF3	Data-theoretic methodology and computational platform for the quantification of organizational mechanisms in probabilistic risk assessment	2017	International Topical Meeting on Probabilistic Safety Assessment and Analysis, PSA 2017
RF3	Data-theoretic methodology and computational platform to quantify organizational factors in socio-technical risk analysis	2019	Reliability Engineering and System Safety
RF3	Dynamic accident sequence analysis in PRA: A comment on 'Human reliability analysis-Where shoudst thou turn?'	1990	Reliability Engineering and System Safety
RF3	Dynamic human reliability analysis: Benefits and challenges of simulating human performance	2007	Proceedings of the European Safety and Reliability Conference 2007, ESREL 2007 - Risk, Reliability and Societal Safety
RF3	Fuzzy uncertainties in human reliability analysis	2011	Proceedings of the World Congress on Engineering 2011, WCE 2011
RF3	How many performance shaping factors are necessary for human reliability analysis?	2010	10th International Conference on Probabilistic Safety Assessment and Management 2010, PSAM 2010
RF3	Human error mechanisms in complex work environments	1988	Reliability Engineering and System Safety
RF3	Human error quantification using performance shaping factors in the SPAR-H method	2008	Proceedings of the Human Factors and Ergonomics Society
RF3	Human error risk management for engineering systems: A methodology for design, safety assessment, accident investigation and training	2004	Reliability Engineering and System Safety
RF3	Human performance in control rooms of nuclear power plants: A survey study	2011	Human Factors and Ergonomics In Manufacturing
RF3	Human performance modeling for dynamic human reliability analysis	2015	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)
RF3	Human reliability	2018	Springer Series in Reliability Engineering
RF3	Human reliability analysis through Bayesian networks: An application in maintenance of transmission lines	2007	Producao
RF3	Human reliability data requirements	1997	Disaster Prevention and Management: An International Journal
RF3	Human reliability: A key to improved quality in manufacturing	2005	Human Factors and Ergonomics In Manufacturing
RF3	Integrating team factor into current human reliability analysis of nuclear power plant	2011	Yuanzineng Kexue Jishu/Atomic Energy Science and Technology
RF3	International HRA empirical study, overall methodology and HAMMLAB results	2011	Simulator-based Human Factors Studies Across 25 Years: The History of the Halden Man-Machine Laboratory
RF3	Is human failure a stochastic process?	1997	Reliability Engineering and System Safety
RF3	Issues in benchmarking human reliability analysis methods: A literature review	2010	Reliability Engineering and System Safety
RF3	Lessons learned on benchmarking from the international human reliability analysis empirical study	2010	10th International Conference on Probabilistic Safety Assessment and Management 2010, PSAM 2010
RF3	Methodology for improving HRA by simulator studies	2006	Proceedings of the 8th International Conference on Probabilistic Safety Assessment and Management, PSAM 2006
RF3	Model-based human reliability analysis: Prospects and requirements	2004	Reliability Engineering and System Safety
RF3	Modeling human intention formation for human reliability assessment	1988	Reliability Engineering and System Safety
RF3	Modeling human reliability analysis using MIDAS	2006	5th International Topical Meeting on Nuclear Plant Instrumentation Controls, and Human Machine Interface Technology (NPIC and HMIT 2006)
RF3	Organizational factor inclusion in Human Reliability Analysis (HRA) tools	2015	Safety and Reliability: Methodology and Applications - Proceedings of the European Safety and Reliability Conference, ESREL 2014
RF3	Phoenix - A model-based Human Reliability Analysis methodology: Quantitative analysis procedure and data base	2014	PSAM 2014 - Probabilistic Safety Assessment and Management
RF3	Quantifying organizational factors in human reliability analysis using the big data-theoretic algorithm	2015	International Topical Meeting on Probabilistic Safety Assessment and Analysis, PSA 2015
RF3	Quantitative analysis of ATM safety issues using retrospective accident data: The dynamic risk modelling project	2009	Safety Science
RF3	Recovery from equipment failures in ATC: Determination of contextual factors	2007	Reliability Engineering and System Safety
RF3	Reliability analysis and operator modelling	1996	Reliability Engineering and System Safety
RF3	Representing cognitive activities and errors in HRA trees	1993	Reliability Engineering and System Safety
RF3	Safety investigation of team performance in accidents	2004	Journal of Hazardous Materials
RF3	Simulative analysis of performance shaping factors impact on human reliability in manufacturing activities	2015	27th European Modeling and Simulation Symposium, EMSS 2015
RF3	Some developments in human reliability analysis approaches and tools	1988	Reliability Engineering and System Safety
RF3	Stochastic models for predicting human reliability	1982	Microelectronics Reliability
RF3	Team performance modeling for HRA in dynamic situations	2002	Reliability Engineering and System Safety
RF3	The application of the SPAR-H method in managed-pressure drilling operations	2012	Proceedings of the Human Factors and Ergonomics Society
RF3	The Development of Dynamic Human Reliability Analysis Simulations for Inclusion in Risk Informed Safety Margin Characterization Frameworks	2015	Procedia Manufacturing
RF3	The IDA cognitive model for the analysis of nuclear power plant operator response under accident conditions. Part I: Problem solving and decision making model	1997	Reliability Engineering and System Safety
RF3	The phenotype of erroneous actions	1993	International Journal of Man-Machine Studies
RF3	The role of error in organizing behaviour	1990	Ergonomics
RF3	Using operator workload data to inform human reliability analyses	2007	IEEE Conference on Human Factors and Power Plants
RF3	Phoenix - A model-based Human Reliability Analysis methodology: Quantitative analysis procedure and data base	2014	PSAM 2014 - Probabilistic Safety Assessment and Management
RF4	A fuzzy set-based approach for modeling dependency among human errors	2009	Fuzzy Sets and Systems
RF4	A graphical model based on performance shaping factors for assessing human reliability	2017	IEEE Transactions on Reliability
RF4	Another view of the state of human reliability analysis (HRA)	1990	Reliability Engineering and System Safety

RF4	Comparison of methods for dependency determination between human failure events within human reliability analysis	2008	Science and Technology of Nuclear Installations
RF4	Decision and commission errors - From identification to quantification issues	2002	IEEE Conference on Human Factors and Power Plants
RF4	Dependency assessment in human reliability analysis based on D numbers and AHP	2017	Nuclear Engineering and Design
RF4	Dependency assessment in human reliability analysis based on evidence credibility decay model and IOWA operator	2018	Annals of Nuclear Energy
RF4	Dependency Assessment in Human Reliability Analysis Using Evidence Theory and AHP	2015	Risk Analysis
RF4	DEPEND-HRA-A method for consideration of dependency in human reliability analysis	2008	Reliability Engineering and System Safety
RF4	Developing an agent-based hierarchical modeling approach to assess human performance of infrastructure systems	2016	International Journal of Industrial Ergonomics
RF4	Development of a method for consideration of dependency between human failure events	2006	Proceedings of the European Safety and Reliability Conference 2006, ESREL 2006 - Safety and Reliability for Managing Risk
RF4	Evidential Analytic Hierarchy Process Dependency Assessment Methodology in Human Reliability Analysis	2017	Nuclear Engineering and Technology
RF4	HEPI: A new tool for human error probability calculation for offshore operation	2006	Safety Science
RF4	Human error and the associated recovery probabilities for soft control being used in the advanced MCRs of NPPs	2016	Annals of Nuclear Energy
RF4	Human error contribution in collision and grounding of oil tankers	2010	Risk Analysis
RF4	Human error data collection as a precursor to the development of a human reliability assessment capability in air traffic management	2008	Reliability Engineering and System Safety
RF4	Human error probabilities from operational experience of German nuclear power plants, Part II	2016	Reliability Engineering and System Safety
RF4	Human reliability analysis data obtainment through fuzzy logic in nuclear plants	2012	Nuclear Engineering and Design
RF4	Human reliability analysis: A critique and review for managers	2011	Safety Science
RF4	Human reliability assessment for medical devices based on failure mode and effects analysis and fuzzy linguistic theory	2014	Safety Science
RF4	Human reliability data, human error and accident models - Illustration through the Three Mile Island accident analysis	2004	Reliability Engineering and System Safety
RF4	Identification and assessment of factors influencing human reliability in maintenance using fuzzy cognitive maps	2015	Quality and Reliability Engineering International
RF4	Identifying objective criterion to determine a complicated task - A comparative study	2015	Annals of Nuclear Energy
RF4	Importance of human contribution within the human reliability analysis (IJS-HRA)	2008	Journal of Loss Prevention in the Process Industries
RF4	Inclusion of task dependency in human reliability analysis	2014	Reliability Engineering and System Safety
RF4	Integrating human reliability analysis approaches in the EPRI HRA calculator	2006	Proceedings of the 8th International Conference on Probabilistic Safety Assessment and Management, PSAM 2006
RF4	Investigating a homogeneous culture for operating personnel working in domestic nuclear power plants	2016	Reliability Engineering and System Safety
RF4	Little stories to explain human reliability assessment: A practical approach of the MERMOS method	2007	IEEE Conference on Human Factors and Power Plants
RF4	Measuring the influence of task complexity on human error probability: An empirical evaluation	2013	Nuclear Engineering and Technology
RF4	Methodology for analyzing the dependencies between human operators in digital control systems	2016	Fuzzy Sets and Systems
RF4	Review of advances in human reliability analysis of errors of commission, Part 1: EOC identification	2008	Reliability Engineering and System Safety
RF4	Review of advances in human reliability analysis of errors of commission-Part 2: EOC quantification	2008	Reliability Engineering and System Safety
RF4	Study on the identification of main drivers affecting the performance of human operators during low power and shutdown operation	2016	Annals of Nuclear Energy
RF4	Success criteria time windows of operator actions using RELAP5/MOD3.3 within human reliability analysis	2008	Journal of Loss Prevention in the Process Industries
RF4	The CESA method and its application in a plant-specific pilot study on errors of commission	2004	Reliability Engineering and System Safety
RF4	The MDTA-based method for assessing diagnosis failures and their risk impacts in nuclear power plants	2008	Reliability Engineering and System Safety
RF4	Using Evidence Credibility Decay Model for dependency assessment in human reliability analysis	2017	Annals of Nuclear Energy
RF4	Using expert models in human reliability analysis-a dependency assessment method based on fuzzy logic	2010	Risk Analysis
RF5	A Bayesian method for using simulator data to enhance human error probabilities assigned by existing HRA methods	2014	Reliability Engineering and System Safety
RF5	A classification scheme of erroneous behaviors for human error probability estimations based on simulator data	2017	Reliability Engineering and System Safety
RF5	A framework to estimate probability of diagnosis error in NPP advanced MCR	2018	Annals of Nuclear Energy
RF5	A framework to estimate task opportunities from the operational experience of domestic nuclear power plants	2016	Safety Science
RF5	A quantitative measure of fitness for duty and work processes for human reliability analysis	2017	Reliability Engineering and System Safety
RF5	A statistical approach to estimating effects of performance shaping factors on human error probabilities of soft controls	2015	Reliability Engineering and System Safety
RF5	A taxonomy of performance influencing factors for human reliability analysis of emergency tasks	2003	Journal of Loss Prevention in the Process Industries
RF5	An empirical study on the basic human error probabilities for NPP advanced main control room operation using soft control	2013	Nuclear Engineering and Design

RF5	An empirical study on the human error recovery failure probability when using soft controls in NPP advanced MCRs	2014	Annals of Nuclear Energy
RF5	An Evidential Reasoning-Based CREAM to Human Reliability Analysis in Maritime Accident Process	2017	Risk Analysis
RF5	An experimental investigation on relationship between PSFs and operator performances in the digital main control room	2017	Annals of Nuclear Energy
RF5	Analysis of an operators' performance time and its application to a human reliability analysis in nuclear power plants	2007	IEEE Transactions on Nuclear Science
RF5	Applicability of human reliability assessment methods to human-computer interfaces	2013	Cognition, Technology and Work
RF5	Application of performance shaping factor (PSF) for work improvement in industrial plant maintenance tasks	2001	International Journal of Industrial Ergonomics
RF5	Application of the CARA HRA tool to air traffic management safety cases	2008	9th International Conference on Probabilistic Safety Assessment and Management 2008, PSAM 2008
RF5	Applying Analytic Hierarchy Process (AHP) to choose a human factors technique: Choosing the suitable Human Reliability Analysis technique for the automotive industry	2017	Safety Science
RF5	Benchmarking HRA methods against simulator data - Design and organization of the international HRA empirical study	2008	9th International Conference on Probabilistic Safety Assessment and Management 2008, PSAM 2008
RF5	Calculating nominal human error probabilities from the operation experience of domestic nuclear power plants	2018	Reliability Engineering and System Safety
RF5	Can we quantify human reliability in Level 2 PSA?	2014	PSAM 2014 - Probabilistic Safety Assessment and Management
RF5	Capturing cognitive causal paths in human reliability analysis with Bayesian network models	2017	Reliability Engineering and System Safety
RF5	Collection of offshore human error probability data	1998	Reliability Engineering and System Safety
RF5	Comparison between conventional and digital nuclear power plant main control rooms: A task complexity perspective, Part II: Detailed results and analysis	2013	International Journal of Industrial Ergonomics
RF5	Considerations for the treatment of computerized procedures in human reliability analysis	2012	8th International Topical Meeting on Nuclear Plant Instrumentation, Control, and Human-Machine Interface Technologies 2012, NPIC and HMIT 2012: Enabling the Future of Nuclear Energy
RF5	Considering performance shaping factors in situation-specific human error probabilities	1996	International Journal of Industrial Ergonomics
RF5	CORE-DATA: A computerized human error database for human reliability support	1997	IEEE Conference on Human Factors and Power Plants
RF5	Development of a qualitative evaluation framework for performance shaping factors (PSFs) in advanced MCR HRA	2011	Annals of Nuclear Energy
RF5	Estimating the quantitative relation between PSFs and HEPs from full-scope simulator data	2018	Reliability Engineering and System Safety
RF5	Fifty years of THERP and human reliability analysis	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF5	Human Error Data Collection and Comparison with Predictions by SPAR-H	2014	Risk Analysis
RF5	Human error mode identification for NPP main control room operations using soft controls	2011	Journal of Nuclear Science and Technology
RF5	Human error probabilities from operational experience of German nuclear power plants	2013	Reliability Engineering and System Safety
RF5	Human reliability analysis for control room upgrades	2009	Proceedings of the Human Factors and Ergonomics Society
RF5	Human reliability analysis for digital human-machine interfaces: A wish list for future research	2014	PSAM 2014 - Probabilistic Safety Assessment and Management
RF5	Human reliability analysis for digitized nuclear power plants: Case study on LingAo II NPP	2017	PSAM 2016 - 13th International Conference on Probabilistic Safety Assessment and Management
RF5	Human Reliability Analysis for Digitized Nuclear Power Plants: Case Study on the LingAo II Nuclear Power Plant	2017	Nuclear Engineering and Technology
RF5	Human reliability under sleep deprivation: Derivation of performance shaping factor multipliers from empirical data	2015	Reliability Engineering and System Safety
RF5	Identification of human-induced initiating events in the low power and shutdown operation using the commission error search and assessment method	2015	Nuclear Engineering and Technology
RF5	Identifying key performance shaping factors in digital main control rooms of nuclear power plants: A risk-based approach	2017	Reliability Engineering and System Safety
RF5	Inclusion of fatigue effects in human reliability analysis	2011	Reliability Engineering and System Safety
RF5	Insights on human error probability from cognitive experiment literature	2015	International Topical Meeting on Probabilistic Safety Assessment and Analysis, PSA 2015
RF5	Leveraging existing human performance data for quantifying the IDHEAS HRA method	2014	Safety, Reliability and Risk Analysis: Beyond the Horizon - Proceedings of the European Safety and Reliability Conference, ESREL 2013
RF5	Measuring variability of procedure progression in proceduralized scenarios	2012	Annals of Nuclear Energy
RF5	Methods for building Conditional Probability Tables of Bayesian Belief Networks from limited judgment: An evaluation for Human Reliability Application	2016	Reliability Engineering and System Safety
RF5	Microworlds, simulators, and simulation: Framework for a benchmark of human reliability data sources	2012	11th International Probabilistic Safety Assessment and Management Conference and the Annual European Safety and Reliability Conference 2012, PSAM11 ESREL 2012
RF5	Modelling and assessment of dependent performance shaping factors through Analytic Network Process	2011	Reliability Engineering and System Safety
RF5	Next generation human reliability analysis - Addressing future needs today for digital control systems	2014	PSAM 2014 - Probabilistic Safety Assessment and Management
RF5	NUCLARR and human reliability: Data sources and data profile	1988	IEEE Conference on Human Factors and Power Plants
RF5	Phoenix - A model-based human reliability analysis methodology: Qualitative analysis overview	2014	PSAM 2014 - Probabilistic Safety Assessment and Management
RF5	Phoenix - A model-based Human Reliability Analysis methodology: Qualitative Analysis Procedure	2016	Reliability Engineering and System Safety
RF5	Quantification of performance shaping factors (PSFs)' weightings for human reliability analysis (HRA) of low power and shutdown (LPSD) operations	2017	Annals of Nuclear Energy

RF5	Quantitative estimation of the human error probability during soft control operations	2013	Annals of Nuclear Energy
RF5	Some empirical insights on diagnostic performance of the operating crew in a computer-based advanced control room	2011	Human Factors and Ergonomics In Manufacturing
RF5	Study on a new framework of Human Reliability Analysis to evaluate soft control execution error in advanced MCRs of NPPs	2016	Annals of Nuclear Energy
RF5	Suggested improvements to the definitions of Standardized Plant Analysis of Risk-Human Reliability Analysis (SPAR-H) performance shaping factors, their levels and multipliers and the nominal tasks	2016	Reliability Engineering and System Safety
RF5	Task complexity as a performance shaping factor: A review and recommendations in Standardized Plant Analysis Risk-Human Reliability Analysis (SPAR-H) adaption	2015	Safety Science
RF5	The development of a nuclear chemical plant human reliability management approach: HRMS and JHEDI	1997	Reliability Engineering and System Safety
RF5	The evaluation of fatigue as a performance shaping factor in the Petro-HRA method	2018	Reliability Engineering and System Safety
RF5	The origins of the SPAR-H method's performance shaping factor multipliers	2007	IEEE Conference on Human Factors and Power Plants
RF5	The SACADA database for human reliability and human performance	2014	Reliability Engineering and System Safety
RF5	The use of a process mining technique to characterize the work process of main control room crews: A feasibility study	2016	Reliability Engineering and System Safety
RF5	The use of empirical data sources in HRA	2004	Reliability Engineering and System Safety
RF5	The virtual human reliability analyst	2018	Advances in Intelligent Systems and Computing
RF5	Use of a big data analysis technique for extracting HRA data from event investigation reports based on the Safety-II concept	2018	Reliability Engineering and System Safety
RF5	What HRA needs to support site-wide, multi-hazard Level 2 PRA	2013	International Topical Meeting on Probabilistic Safety Assessment and Analysis 2013, PSA 2013
RF5	Next generation human reliability analysis - Addressing future needs today for digital control systems	2014	PSAM 2014 - Probabilistic Safety Assessment and Management
RF6	A human factors and reliability approach to clinical risk management: Evidence from Italian cases	2010	Safety Science
RF6	A model for break scheduling assessment in manufacturing systems	2017	Computers and Industrial Engineering
RF6	A systemic methodology for risk management in healthcare sector	2011	Safety Science
RF6	Abdominal Wall Lift Versus Positive-Pressure Capnoperitoneum for Laparoscopic Cholecystectomy: Randomized Controlled Trial	2004	Annals of Surgery
RF6	Analysis of technical surgical errors during initial experience of laparoscopic pyloromyotomy by a group of Dutch pediatric surgeons	2004	Surgical Endoscopy and Other Interventional Techniques
RF6	Application of human reliability analysis to nursing errors in hospitals	2004	Risk Analysis
RF6	Application of objective clinical human reliability analysis (OCHRA) in assessment of technical performance in laparoscopic rectal cancer surgery	2016	Techniques in Coloproctology
RF6	Competence assessment of laparoscopic operative and cognitive skills: Objective Structured Clinical Examination (OSCE) or Observational Clinical Human Reliability Assessment (OCHRA)	2006	World Journal of Surgery
RF6	Developing the foundations of a cognition-based human reliability analysis model via mapping task types and performance-influencing factors: Application to radiotherapy	2018	Proceedings of the Institution of Mechanical Engineers, Part O: Journal of Risk and Reliability
RF6	Errors enacted during endoscopic surgery - A human reliability analysis	1998	Applied Ergonomics
RF6	Healthcare human reliability analysis - By heart	2013	Contemporary Ergonomics and Human Factors 2013
RF6	High definition video teaching module for learning neck dissection	2014	Journal of Otolaryngology - Head and Neck Surgery
RF6	Human reliability analysis (HRA) techniques and observational clinical HRA	2010	Minimally Invasive Therapy and Allied Technologies
RF6	Human reliability analysis in healthcare: A review of techniques	2004	International Journal of Risk and Safety in Medicine
RF6	Human reliability analysis of cataract surgery	2008	Archives of Ophthalmology
RF6	Human reliability analysis: A new method to quantify errors in cataract surgery	2008	Eye
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RF6	Human reliability assessment of a critical nursing task in a radiotherapy treatment process	2012	Applied Ergonomics
RF6	Identification and categorization of technical errors by Observational Clinical Human Reliability Assessment (OCHRA) during laparoscopic cholecystectomy	2004	Archives of Surgery
RF6	Is competency assessment at the specialist level achievable? A study for the national training programme in laparoscopic colorectal surgery in England	2013	Annals of Surgery
RF6	Methodology for the analysis and quantification of human error probability in manufacturing systems	2017	Proceedings - 14th IEEE Student Conference on Research and Development: Advancing Technology for Humanity, SCOReD 2016
RF6	Observational clinical human reliability analysis (OCHRA) for competency assessment in laparoscopic colorectal surgery at the specialist level	2012	Surgical Endoscopy
RF6	Proficiency-gain curve for an advanced laparoscopic procedure defined by observation clinical human reliability assessment (OCHRA)	2009	Surgical Endoscopy and Other Interventional Techniques
RF6	Risk analysis using fuzzy set theory of the accidental exposure of medical staff during brachytherapy procedures	2010	Journal of Radiological Protection
RF6	The effect of divided attention on novices and experts in laparoscopic task performance	2015	Surgical Endoscopy
RF6	Towards a framework to select techniques for error prediction: Supporting novice users in the healthcare sector	2009	Applied Ergonomics
RF6	Towards a Taxonomy of Influencing Factors for Human Reliability Analysis (HRA) Applications in Surgery	2015	Procedia Manufacturing
RF6	Using human reliability analysis to detect surgical error in endoscopic DCR surgery	2003	Clinical Otolaryngology and Allied Sciences
RF7	A probabilistic method for analyzing the reliability effect of time and organizational factors	1994	European Journal of Operational Research
RF7	Advanced Control Rooms and Crew Performance Issues: Implications for Human Reliability	1992	IEEE Transactions on Nuclear Science

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RF7	Balancing human and technical reliability in the design of advanced nuclear reactors	2011	Nuclear Engineering and Design
RF7	Defining and assessing safety functions performed by people	2013	Cognition, Technology and Work
RF7	Dynamic reliability and human factors for safety assessment of technological systems: A modern science rooted in the origin of mankind	2010	Cognition, Technology and Work
RF7	Human communication, mutual awareness and system dependability. Lessons learnt from air-traffic control field studies	2001	Reliability Engineering and System Safety
RF7	Human performance reliability in the design-for- usability life cycle for safety human-computer interfaces	1999	Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)
RF7	Human reliability	1985	Nuclear Engineering and Design
RF7	Human reliability analysis of an offshore emergency blowdown system	1987	Applied Ergonomics
RF7	Manual backup operations: Some behavioral aspects of human reliability	1979	Microelectronics Reliability
RF7	Meeting human reliability requirements through human factors design, testing, and modeling	2007	Proceedings of the European Safety and Reliability Conference 2007, ESREL 2007 - Risk, Reliability and Societal Safety
RF7	Modelling human error rates for human reliability analysis of a structural design task	1992	Reliability Engineering and System Safety
RF7	Proposal for a sustainable framework process for the generation, validation, and application of human reliability assessment within the engineering design lifecycle	2007	Reliability Engineering and System Safety
RF7	Reliability of drivers in urban intersections	2010	Accident Analysis and Prevention
RF7	System ergonomics as an approach to improve human reliability	1988	Nuclear Engineering and Design
RF7	Task analysis for industrial work process from aspects of human reliability and system safety	1999	Risk Analysis
RF7	The contribution of ergonomics to risk analysis in the design process: The case of a future control room	2012	Work
RF7	The role of frameworks, models, data, and judgment in human reliability analysis	1986	Nuclear Engineering and Design
RF7	Workload prediction for improved design and reliability of complex systems	2008	Reliability Engineering and System Safety
RF8	A case study of a human reliability assessment for an existing nuclear power plant	1996	Applied Ergonomics
RF8	A Literature Survey of the Human Reliability Component in a Man-Machine System	1988	IEEE Transactions on Reliability
RF8	A systematic approach to analysing errors of commission from diagnosis failure in accident progression	2005	Reliability Engineering and System Safety
RF8	Advanced investigation of HRA methods for probabilistic assessment of human barriers efficiency in complex systems for a given organisational and environmental context	2015	International Topical Meeting on Probabilistic Safety Assessment and Analysis, PSA 2015
RF8	Advances in human reliability analysis methodology. Part I: frameworks, models and data	1994	Reliability Engineering and System Safety
RF8	Application of ATHEANA: A technique for human error analysis	1997	IEEE Conference on Human Factors and Power Plants
RF8	Applications of integrated human error identification techniques on the chemical cylinder change task	2015	Applied Ergonomics
RF8	Assessment of human reliability based on evaluation of plant experience: Requirements and implementation	1999	Reliability Engineering and System Safety
RF8	Assessment of human reliability factors: A fuzzy cognitive maps approach	2007	International Journal of Industrial Ergonomics
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RF8	Context and human reliability analysis	1993	Reliability Engineering and System Safety
RF8	Data-based method for assessing and reducing human error to improve operational performance	1988	IEEE Conference on Human Factors and Power Plants
RF8	Development of a human reliability assessment system for the management of human error in complex systems	1989	Reliability '89 (Part 1)
RF8	Devolving ergonomics: The key to ergonomics management programmes	1994	Ergonomics
RF8	Dougherty's dilemma and the one-sidedness of human reliability analysis (HRA)	1990	Reliability Engineering and System Safety
RF8	Effects of cold environments on human reliability assessment in offshore oil and gas facilities	2014	Human Factors
RF8	Empirical evaluation of THERP, SLIM and ranking to estimate HEPs	1992	Reliability Engineering and System Safety
RF8	Engineering approach for human error probability quantification	2009	Journal of Systems Engineering and Electronics
RF8	Error mode prediction	1999	Ergonomics
RF8	Expert elicitation approach for performing ATHEANA quantification	2004	Reliability Engineering and System Safety
RF8	Foundations for a time reliability correlation system to quantify human reliability	1988	IEEE Conference on Human Factors and Power Plants
RF8	Fuzzy risk analysis of a modern γ-ray industrial irradiator	2011	Health Physics
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RF8	HEART - A PROPOSED METHOD FOR ASSESSING AND REDUCING HUMAN ERROR.	1986	Proceedings - Advances in Reliability Technology Symposium
RF8	Human and organizational error data challenges in complex, large-scale systems	2009	Safety Science
RF8	Human error identification in human reliability assessment. Part 1: Overview of approaches	1992	Applied Ergonomics
RF8	Human error identification in human reliability assessment. Part 2: Detailed comparison of techniques	1992	Applied Ergonomics
RF8	Human error in European air traffic management: The HERA project	2002	Reliability Engineering and System Safety
RF8	Human reliability analyses by random hazard rate approach	2004	COMPEL - The International Journal for Computation and Mathematics in Electrical and Electronic Engineering
RF8	Human reliability analysis (HRA) in the context of HRA testing with empirical data	2007	IEEE Conference on Human Factors and Power Plants
RF8	Human reliability analysis in the man-machine interface design review	2001	Annals of Nuclear Energy
RF8	Human reliability analysis: a human point of view	1992	Reliability Engineering and System Safety
RF8	Human reliability analysis: Need, status, trends and limitations	1990	Reliability Engineering and System Safety
RF8	Human reliability analysis-where shouldst thou turn?	1990	Reliability Engineering and System Safety

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RF8	Human reliability data requirements	1995	International Journal of Quality & Reliability Management
RF8	Human reliability methodology. A discussion of the state of the art	1992	Reliability Engineering and System Safety
RF8	Human-centered modeling in human reliability analysis: Some trends based on case studies	1997	Reliability Engineering and System Safety
RF8	Interdisciplinary safety analysis of complex socio-technological systems based on the functional resonance accident model: An application to railway trafficsuper-vision	2011	Reliability Engineering and System Safety
RF8	ISSUES IN HUMAN RELIABILITY.	1982	Human Factors
RF8	Lessons learned on Human Reliability Analysis (HRA) methods from the International HRA Empirical Study	2010	10th International Conference on Probabilistic Safety Assessment and Management 2010, PSAM 2010
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RF8	Methodological approach for performing human reliability and error analysis in railway transportation system	2011	International Journal of Engineering and Technology
RF8	Methods of Predicting Human Reliability in Man–Machine Systems	1964	Human Factors: The Journal of Human Factors and Ergonomics Society
RF8	Non-probabilistic prospective and retrospective human reliability analysis method - application to railway system	2001	Reliability Engineering and System Safety
RF8	On expert judgements in safety analyses in the process industries	1989	Reliability Engineering and System Safety
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RF8	The validation of three human reliability Quantification techniques - THERP, HEART and JHEDI: Part III - practical aspects of the usage of the techniques	1997	Applied Ergonomics
RF8	The validation of three human reliability quantification techniques THERP, HEART and JHEDI: Part 1 - Technique descriptions and validation issues	1996	Applied Ergonomics
RF8	The validation of three human reliability quantification techniques THERP, HEART and JHEDI: Part II - results of validation exercise	1997	Applied Ergonomics
RF8	Understanding safety and production risks in rail engineering planning and protection	2009	Ergonomics
RF8	Validation of human reliability assessment techniques	1985	Reliability Engineering
RF8	Validation of human reliability assessment techniques: Part 2 - Validation results	1997	Safety Science
RF8	Why human error modeling has failed to help systems development	1999	Interacting with Computers
RF9	A fuzzy system for the assessment of human reliability	2009	2009 International Fuzzy Systems Association World Congress and 2009 European Society for Fuzzy Logic and Technology Conference, IFSA-EUSFLAT 2009 - Proceedings
RF9	A representation of human reliability using fuzzy concepts	1988	Information Sciences
RF9	Advantages and disadvantages of physiological assessment for next generation control room design	2007	IEEE Conference on Human Factors and Power Plants
RF9	An application of fuzzy concepts to modelling of reliability analysis	1990	Fuzzy Sets and Systems
RF9	An approach to human reliability in man-machine systems using error possibility	1988	Fuzzy Sets and Systems
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RF9	Controller recovery from equipment failures in air traffic control: A framework for the quantitative assessment of the recovery context	2014	Reliability Engineering and System Safety
RF9	Critique of current human reliability analysis methods	2002	IEEE Conference on Human Factors and Power Plants
RF9	Embedding the human factor in road tunnel risk analysis	2014	Process Safety and Environmental Protection
RF9	Evaluating human reliability using fuzzy relation	1993	Microelectronics Reliability
RF9	Fuzzy human reliability analysis on the Chernobyl accident	1988	Fuzzy Sets and Systems
RF9	Human factors impact on risk analysis of complex systems	2000	Journal of Hazardous Materials
RF9	Human interaction with technology: The accidental user	1996	Acta Psychologica
RF9	Human reliability and safety evaluation of man-machine systems	1983	Automatica
RF9	Lessons learned from dependency usage in HERA: Implications for THERP-related HRA methods	2007	IEEE Conference on Human Factors and Power Plants
RF9	On assessing operator response time in human reliability analysis (HRA) using a possibilistic fuzzy regression model	1996	Reliability Engineering and System Safety
RF9	On the way to assess errors of commission	2004	Reliability Engineering and System Safety
RF9	Quantifying the unimaginable - The case for human performance limiting values	2008	9th International Conference on Probabilistic Safety Assessment and Management 2008, PSAM 2008
RF9	Suggestions for an improved HRA method for use in Probabilistic Safety Assessment	1995	Reliability Engineering and System Safety
RF9	The reliability of man-machine interaction	1992	Reliability Engineering and System Safety
RF9	The SPAR H human reliability analysis method	2004	American Nuclear Society 4th International Topical Meeting on Nuclear Plant Instrumentation, Control and Human Machine Interface Technology
RF9	Towards a unified human reliability model	2012	Advances in Safety, Reliability and Risk Management - Proceedings of the European Safety and Reliability Conference, ESREL 2011
RF9	Towards human factor taxonomy with cognitive generic terms	2014	Lecture Notes in Engineering and Computer Science
F9	Two techniques of sensitivity and uncertainty analysis of fuzzy expert systems	2009	Expert Systems with Applications

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