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Human factors, ergonomics and Industry 4.0 in the Oil&Gas industry: a bibliometric analysis

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Abstract

Over the last few years, the Human Factors and Ergonomics (HF/E) discipline has significantly benefited from new human-centric engineered digital solutions of the 4.0 industrial age. Technologies are creating new socio-technical interactions between human and machine that minimize the risk of design-induced human errors and have largely contributed to remarkable improvements in terms of process safety, productivity, quality, and workers' well-being. However, despite the Oil&Gas (O&G) sector is one of the most hazardous environments where human error can have severe consequences, Industry 4.0 aspects are still scarcely integrated with HF/E. This paper calls for a holistic understanding of the changing role and responsibilities of workers in the O&G industry and aims at investigating to what extent, what type of, and how academic publications in the O&G field integrate HF/E and Industry 4.0 in their research. Bibliometric analysis has been conducted to provide useful insights to researchers and practitioners and to assess the status quo. Our findings show that academic publications have mainly focused on simulation-based training to increase process safety whereas revealed the lack of specific studies on the application of cognitive solutions, such as Augmented Reality-enabled tools or Intelligent Fault Detection and Alarm Management solutions.

Keywords: Human factor engineering; Oil and gas industry; Bibliometric analysis; Industry 4.0; Ergonomics

1. Introduction

Human Factors and Ergonomics (HF/E) has largely contributed to remarkable improvements in safety, productivity, quality, and well-being of workers in hazardous industrial systems, especially in the Oil&Gas (O&G) industry. In these high-risk environments, small errors can proliferate into process inefficiency, poor working conditions, and, ultimately, major consequences [1], [2]. Accident causation analysis revealed that human error (e.g.

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unsafe acts, cognitive deficiencies, lack of communication, poor decision making) may be of different nature [3]. The objective of HF/E is to optimize the overall system performance with real, fallible human beings at the controls and to minimize the risk of design-induced human performance issues, which may lead to major incidents, other adverse events, and inefficient production [4], [5]. The rising attention of the scientific community on HF/E in the O&G industry is corroborated by two very recent reviews [6], [7]. While previous research works are highly valuable and necessary for engineering novel technological solutions, they fall short in identifying which are the next research trends and challenges for the HF/E in the O&G industry.

Over the last few years, the HF/E discipline has significantly benefited from new human-centric engineered digital solutions of the 4.0 industrial age in different sectors [8], [9]. The introduction of new digital technologies in industrial companies is creating new socio-technical interactions between human and machine, enabling the transition to the Operator 4.0 and a human-automation symbiosis [10], [11]. However, because the topic of Industry 4.0 is relatively new, research on human work in this context is still limited [12]. Reviews and surveys with HF classification purposes have been largely conducted in the field of HF in the O&G field, but most of the existing research only considers a specific and narrow aspect (e.g. only offshore drilling), and the results of a comprehensive bibliometric analysis have not yet appeared. While there is a whole discipline of human factors – strictly oriented to safety – devoted to analyzing the causes of failure in upstream O&G production and to increasing the overall system reliability [6], the application of HF/E is loosely associated with the full stream industrial production performance and quality [13]. Furthermore, understanding if Industry 4.0 has already hit in the discussion of HF/E in the O&G industry is still a gap.

In light of this background, this paper aims to answer two research questions then:

- RQ1: Which are the main research themes addressed in the scientific literature of HF/E in the O&G industry?
- RQ2: What are the current gaps in HF/E applied to the O&G industry?
- RQ3: What is the relationship between the Industry 4.0 literature and the HF/E in the O&G sector?

To address the research questions, a bibliometric analysis of the extant literature on HF/E in the O&G industry has been conducted. This study aims to investigate to what extent, what type of, and how academic publications in the O&G field integrate HF/E in their research and, in the second stage, Industry 4.0. Hereafter, the paper explores the research trend and growth, the most influential and productive authors and document sources, and the most important topics and research streams, thus being a valuable guide for researchers and practitioners. A thorough review of the literature revealed the lack of specific studies on the application of Industry 4.0 technologies (such as Augmented Reality-enabled Operations, Virtual Reality-based training, Intelligent Fault Detection, Predictive Maintenance and Alarm Management, Human-Machine Interfaces for Process Control). This study ultimately pushes for prioritizing HF/E as part of an Industry 4.0 implementation roadmap in the O&G industry.

The remaining of the paper is organized as follows. Section 2 describes the methodology used in this work based on a bibliometric review approach to identify relevant papers for this study. In Section 3 the results of the analysis are presented. Section 4 is finally dedicated to discussing the emerging research fields and challenges for HF/E in the O&G industry. Finally, Section 5 summarizes the findings of this work and gives a brief outlook.

2. Methodology

Bibliometrics refers to the process of identification and evaluation of the corpus of literature within a given subject area, and the prediction of trends using mathematical, statistical, and other measurement methods [14], [15]. The present study used a well-defined protocol, which begins by defining the topic of intellectual interest.

2.1. Scanning

The current study utilized Elsevier's Scopus database for the collection and screening of the peer-reviewed literature. Researchers use the Scopus database extensively for bibliometric analysis as it offers various benefits for undertaking such studies and generally includes many more documents than other scientific databases, such as ISI Web of Science. The search keywords were identified based on the cross-analysis of a random sample of peer-

reviewed articles related to the topic under study. The search has been conducted in the title, abstract and author/indexed keywords of the papers. The query consisted of a combination (AND) of three sets of keywords:

- "human error" OR "human reliability" OR "human factor" OR "human engineering" OR "ergonomic*";
- "industr*" OR "factory" OR "production" OR "plant";
- "oil" OR "gas" OR "petroleum".

The search, updated at 6th November 2020, resulted in 1902 documents.

2.2. Selection

The study utilized 1786 English documents that we further manually scanned. After detailed scrutiny, we excluded the documents with missing details – 119 documents with undefined authors and 15 documents with undefined source titles. Duplication of articles was manually checked and removed, resulting in 63 duplicated papers. From Scopus, we retrieved then several tags such as authors, title, year, source title, citation record, author affiliations, country, abstract, etc., and created a Microsoft Excel database with the bibliometric details of these papers. The research team read title and abstract of the remaining articles to eliminate irrelevant articles. The final dataset consisted of 756 documents. Conference Papers are classified as 469, which is 62.04% of the total documents. The other major category was Articles, which is 33.86% (256). The remaining minor categories were Books (3), Book Chapters (12), Reviews (10), Notes (2), Short Surveys (3) and Abstract Report (1). An overview of the distribution of documents types in Scopus over the whole timespan under analysis is given in Fig. 1 (excluded 2 conference papers attributed to 2021). To be noted is the number of papers published in 2020 that is expected to increase significantly after the preparation of this article.

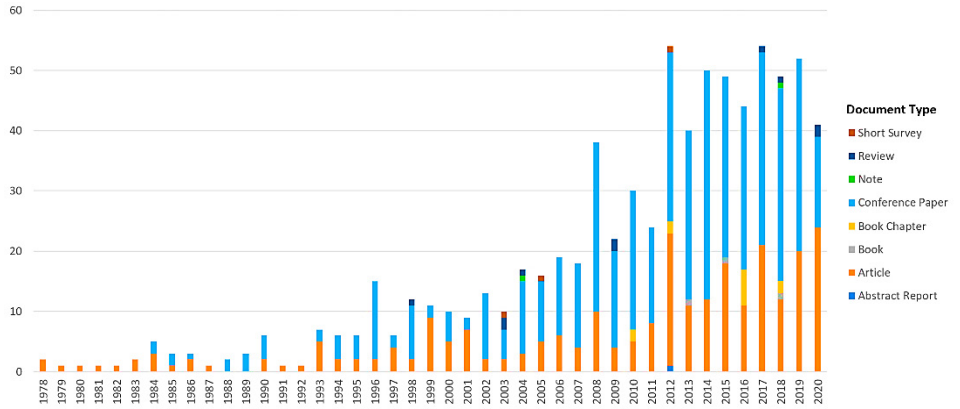

Fig. 1. Distribution of document types in Scopus from 1978-2020.

2.3. Analysis

In this paper, various performance indicators have been extracted for the bibliometric analysis. In particular, Total Papers (TP) is the total number of publications, Total Citations (TC) is the total number of citations received, and the Citations per Paper (CPP) is the total number of received citations count divided by total publications. In other cases, the occurrences count (C) is considered. Such indicators were considered for the analysis of the research growth rate, most productive and influential authors, top source journals and conferences, most productive countries and institutions, most influential papers, and most popular keywords.

3. Bibliometric analysis

3.1. Research growth

HF/E in O&G has been gaining rapid attention. Fig. 1 shows the distribution of the total number of publications over the years grouped by document type. The first publications on the impact of human factors in the O&G industry came out in the latest 70s but the field remained largely unexplored until the beginning of the 90s. Later, the total number of publications started to increase rapidly, till it reached a maximum of 54 in 2012 and, again, in 2017. Furthermore, the total number of citation count is shown in Fig. 2. It was maximum in 2006 because of two of the most cited articles in the field [16], [17] that alone represent 10.09% of the total number of citations (308 and 214, respectively, out of 5175). Besides this exceptional value, in the subsequent years, the citation count continued to increase up to 333 in 2012. In more recent years, citation count decreased to 25; this is because these publications are comparatively more recent, the citation counts of which will certainly increase in the coming years.

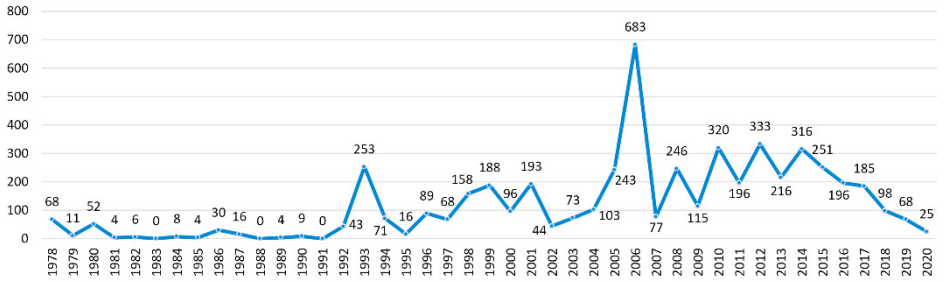

Fig. 2. Total number of citations in Scopus from 1978-2020.

3.2. Most productive and highly cited authors

The most productive authors were extracted and sorted out based on the number of publications. The ranking of the authors with the same number of publications count is then given based on the TC. The top 10 list of most productive authors are shown in Tab. 1. Flin, R. is the highest contributor with 18 publications, followed by Laumann K., Mearns K., Salehi S., with 15, 11, 11 publications, respectively. Authors out of this top 10 list have published 7 or fewer documents in the field. To create the list of the most influential authors, the authors were sorted based on TC and, secondly, based on the CPP. Flin R., who was the most productive author, is also the most influential author with 354 citations. Hudson P., Chang J.I. and Lin C.-C. have also more than 300 citations (311, 308, and 308, respectively). Chang J.I. and Lin C.-C. have published only one article though. After them, we have Lawrie and Parker with TP of 2 and TC of 255. Mearns K. closely follows with a TC of 251 but resulted to be more productive (TP = 8). Interestingly, four authors in the top 10 list of the most productive authors also appear in the top 10 list of the most influential authors, thus proving the role of these authors in the field under study. Instead, some authors published only one paper (Chang, Lin, Paté-Cornell), but received remarkable attention from the community for their study.

3.3. Top source journal

In this section, we have extracted in Tab. 2 the TP and TC of the top 10 most productive and most influential journals in the area of HF/E in the O&G industry. Similarly to the case of the authors, we have sorted the journals out based on TP first and TC then, for the top productive journals, and based on TC first and TP then, for the top influential authors. It emerged that Safety Science and Journal of Loss Prevention in the Process Industries are the most important journals in the field, with the highest amount of publications (25 and 17 respectively) and the highest amount of citations (760 and 737 respectively). Alone, they contribute to more than a third (34.72%) of TC count with only 15.44% of the articles published in the field. Interestingly, Risk Analysis has attained a very high citation count (351) with just 4 papers in the field. As opposed to Risk Analysis, Work has instead the lowest CPP, with 14

publications but only 29 citations. However, in general, we conclude that the two rankings include the same journals, meaning that they are well-known and generally accepted sources for research papers on HF/E in the O&G industry. This journal-specific analysis also shows the range of coverage HF/E has gained in the last years mostly focuses on safety and risk management in hazardous processes.

Tab. 1. Top 10 most productive authors and top 10 most influential authors.

#	Top productive authors				#	Top influential authors			
	Authors	TP	TC	CPP		Authors	TP	TC	CPP
1	Flin R.	18	354	19.67	1	Flin R.	18	354	19.67
2	Laumann K.	15	139	9.27	2	Hudson P.	8	311	38.88
3	Mearns K.	11	251	22.82	3	Chang J.I.	1	308	308.00
4	Salehi S.	11	26	2.36	4	Lin C.-C.	1	308	308.00
5	Rasmussen M.	10	95	9.50	5	Lawrie M.	2	255	127.50
6	Teodoriu C.	10	10	1.00	6	Parker D.	2	255	127.50
7	Khan F.	9	171	19.00	7	Mearns K.	11	251	22.82
8	Hudson P.	8	311	38.88	8	Gordon R.	8	240	30.00
9	Gordon R.	8	240	30.00	9	Paté-Cornell M.E.	1	213	213.00
10	Johnsen S.O.	8	29	3.63	10	Vinnem J.E.	3	209	69.67

Tab. 2. Top source journals.

#	Top productive journals				#	Top influential journals			
	Journal name	TP	TC	CPP		Journal name	TP	TC	CPP
1	Safety Science	25	760	30.40	1	Safety Science	25	760	30.40
2	J. of Loss Prevention in the Process Industries	17	737	43.35	2	J. of Loss Prevention in the Process Industries	17	737	43.35
3	Applied Ergonomics	14	196	14.00	3	Risk Analysis	4	351	87.75
4	Work	14	29	2.07	4	Reliability Engineering and System Safety	11	256	23.27
5	Process Safety and Environmental Protection	12	185	15.42	5	Ergonomics	9	209	23.22
6	Process Safety Progress	12	93	7.75	6	Applied Ergonomics	14	196	14.00
7	Reliability Engineering and System Safety	11	256	23.27	7	Process Safety and Environmental Protection	12	185	15.42
8	Ergonomics	9	209	23.22	8	Journal of Hazardous Materials	3	146	48.67
9	Int.l Journal of Industrial Ergonomics	8	141	17.63	9	Int.l Journal of Industrial Ergonomics	8	141	17.63
10	Risk Analysis	4	351	87.75	10	Work and Stress	2	139	69.50

3.4. Top source conference

In Tab. 3 we have extracted the top 10 most productive and most influential conferences. The conferences supported by the Society of Petroleum Engineers (SPE) represent a significant share of the most productive conferences. The SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production has the highest number with a total of 67 publications, followed by the European Safety and Reliability Conference with 24 publications. Regarding the most influential conferences, the first one is for the IEEE/RSJ Int.l Conf. on Intelligent Robots and Systems, IROS. However, this conference has published only 1 paper in the field under study [18] that received 107 citations. Therefore, we can conclude that this position in the ranking is not due to the conference's influence but to the specific paper. Instead, the SPE International Conference on Health, Safety and Environment in Oil and Gas Exploration and Production, which is also the most productive conference in the field, attained the highest citation count of 93 (besides the IROS conference at the 1st place). The Annual Meeting of the Human Factors and Ergonomics Society is at the third place, with a TC of 60 and a very high CPP (6.00). Only two conferences have a better CPP: the International Offshore and Polar Engineering Conference and the SPE Intelligent Energy Conference and Exhibition. However, these conferences are characterized by a low number of

papers dealing with the field under study (4 and 3, respectively). To conclude, we also cite the International Conference on Probabilistic Safety Assessment and Management, PSAM, that appears in both rankings with a TP of 11 and a TC of 38, thus obtaining a good CPP of 3.45. Based on the themes of these conferences, we can conclude that the topics reflect the ones of the journals, namely: (1) health, safety and environment; (2) process safety.

3.5. Country- and institution-wise analysis

Tab. 4 shows the countries and institutions sorted by TP. Unlike the previous sections, countries and institutions are directly associated to the authors, therefore the affiliation (institution + country) of all the authors of the papers was considered for the calculation of TP. As an example, if a paper was written by two authors coming from the same country, that country is counted twice in this calculation. The United States tops the list with a count of 190, followed by United Kingdom, Norway, and Brazil with a count of 115, 102, and 65, respectively. The remaining countries – after position 10 – are characterized by a percentage lower than 2%. As far as the institutions are concerned, the first rank is acquired by the Norwegian University of Science and Technology with a count of 41 (representing 6.39% of authors). The second position is attained by the University of Aberdeen, Scotland, with a count of 20, which is the same as that of Equinor ASA (former Statoil). After this, the Federal University of Rio de Janeiro, the University of Stavanger and DNV GL AS have a count of 14. This analysis shows the strong position of Norwegian institutions (universities and organizations) in the field of HF/E applied to the O&G industry.

3.6. Top 10 highly influential papers

Tab. 5 gives the list of the 10 most influential papers ranked by citations (TC) in Scopus. The most influential article (representing alone almost 6% of the total count of citations) is [16]. In the second position, Parker et al. [17] is cited 214 times in Scopus, followed by Paté-Cornell M.E. [19] with a citation count of 213. These are the three papers whose citation count is more than 200. There are five papers then [18], [20]–[23] with a citation count of more than 100. These papers substantiate the role of human/organizational factors to reduce hazards and enhance safety in the O&G industry. Such can be organized into three groups:

- surveys of the causes of past accidents in the O&G industry. It is generally accepted that human errors represent the cause of about 30% of accidents and the review of past events' reports can be useful for prediction;
- analysis of human errors and their connection to the underlying causes, the human factors, such as stress, training, experience, event factors, etc., but also organizational culture, employees' safety behavior and attitudes;
- identification and definition of risk management measures through quantitative methods.

3.7. Most popular keywords

Tab. 6 gives the list of the most popular keywords used in Scopus. Besides the keywords used for our document search, most papers relate to "*risk assessment*", "*risk management*" and "*process safety*", followed by papers focusing on "*training*" and development of a "*safety culture*". Other keywords also indicate the human factor modeling and analysis techniques, such as "*HAZOP*", "*SPAR-H*", "*Fault Tree Analysis*", "*Fuzzy Logic*" or "*HFACS*", and the application areas, that are "*maintenance*", "*control room*" and "*alarm management*". What emerges from the analysis of keyword occurrence is that "*Simulation*" appeared among the most popular keywords, thus showing how Industry 4.0 key enabling technologies [26] are starting to take the first steps into this field.

In this section, we have also used the VOSviewer tool to visualize the author's keywords co-occurrence network and identify research streams. In Fig. 3 the size of the keywords is determined by the keyword's occurrence, while the color is determined by the cluster to which the item belongs. Despite the clusters are not mutually exclusive because the keywords are often used interchangeably, the following clusters (i.e. research streams) can be identified: (1) Training & Safety (purple); (2) Ergonomics & Physical Health (brown); (3) Performance Shaping Factors (light blue); (4) Alarm management and control rooms (pink); (5) Organization & Safety culture (red); (6) Accident causation analysis (blue); (7) Human reliability analysis (yellow); (8) Risk assessment/management (green).

Tab. 3. Top source conferences.

#	Top productive conferences				#	Top influential conferences			
	Conference name	TP	TC	CPP		Conference name	TP	TC	CPP
1	SPE Int.l Conf. on Health, Safety and Environment in Oil and Gas Exploration and Production	67	93	1.39	1	IEEE/RSJ Int.l Conf. on Intelligent Robots and Systems, IROS	1	107	107.00
2	European Safety and Reliability Conference	24	23	0.96	2	SPE Int.l Conf. on Health, Safety and Environment in Oil and Gas Exploration and Production	67	93	1.39
3	Institution of Chemical Engineers Symposium Series	20	9	0.45	3	Annual Meeting of the Human Factors and Ergonomics Society	10	60	6.00
4	Annual Offshore Technology Conf.	17	29	1.71	4	Int.l Conf. on Probabilistic Safety Assessment and Management	11	38	3.45
5	SPE Abu Dhabi Int.l Petroleum Exhibition and Conf.	17	10	0.59	5	Int.l Offshore and Polar Engineering Conf.	4	36	9.00
6	SPE Annual Technical Conf. and Exhibition	13	28	2.15	6	Annual Offshore Technology Conf.	17	29	1.71
7	SPE Int.l Conf. and Exhibition on Health, Safety, Environment, and Sustainability	12	5	0.42	7	SPE Annual Technical Conf. and Exhibition	13	28	2.15
8	Int.l Conf. on Probabilistic Safety Assessment and Management	11	38	3.45	8	European Safety and Reliability Conf.	24	23	0.96
9	Annual Meeting of the Human Factors and Ergonomics Society	10	60	6.00	9	SPE/IADC Drilling Conf.	9	21	2.33
10	Advances in Intelligent Systems and Computing	10	4	0.40	10	SPE Intelligent Energy Conf. and Exhibition	3	20	6.67

Tab. 4. Top 10 most productive countries and institutions.

#	Countries	C	%	#	Institution name	C	%
1	United States	190	23.26%	1	Norwegian University of Science and Technology	41	6.39%
2	United Kingdom	115	14.08%	2	University of Aberdeen	20	3.12%
3	Norway	102	12.48%	3	Equinor ASA	20	3.12%
4	Brazil	65	7.96%	4	Federal University of Rio de Janeiro	14	2.18%
5	Canada	36	4.41%	5	University of Stavanger	14	2.18%
6	Netherlands	30	3.67%	6	DNV GL AS	14	2.18%
7	China	29	3.55%	7	Schlumberger Limited	14	2.18%
8	Iran	22	2.69%	8	Society of Petroleum Engineers International	13	2.02%
9	Australia	21	2.57%	9	University of Oklahoma	13	2.02%
10	Italy	18	2.20%	10	Memorial University of Newfoundland	12	1.87%

Tab. 5. Top 10 most influential papers.

#	Ref.	Authors	Year	Source	TC	%
1	[16]	Chang J.I., Lin C.-C.	2006	Journal of Loss Prevention in the Process Industries	308	5.95%
2	[17]	Parker D., Lawrie M., Hudson P.	2006	Safety Science	214	4.14%
3	[19]	Paté-Cornell M.E.	1993	Risk Analysis	213	4.12%
4	[20]	Vinnem J.E., Bye R.,…, Vatn J.	2012	Journal of Loss Prevention in the Process Industries	125	2.42%
5	[21]	Mearns K., Flin R., Gordon R., Fleming M.	2001	Work and Stress	116	2.24%
6	[22]	Flin R., O'Connor P., Mearns K.	2002	Team Performance Management: An Int.l Journal	107	2.07%
7	[18]	Heyer C.	2010	IEEE/RSJ Int.l Conf. on Intelligent Robots and Systems	107	2.01%
8	[23]	Gordon R.P.E.	1998	Reliability Engineering and System Safety	104	1.82%
9	[24]	Azadeh A., Fam I.M.,…, Nikafrouz M.	2008	Information Sciences	94	1.58%
10	[25]	Skogdalen J.E., Vinnem J.E.	2011	Reliability Engineering and System Safety	82	1.45%

Tab. 6. Most popular keywords.

#	Keyword	C	#	Keyword	C	#	Keyword	C	#	Keyword	C
1	Human factors	76	14	HRA	9	27	Fault tree analysis	6	40	Fire	4
2	Human error	33	15	Oil and gas	9	28	Hazard analysis	6	41	Fuzzy logic	4
3	Ergonomics	18	16	Risk analysis	9	29	Communication	5	42	HFACS	4
4	Human reliability analysis	17	17	Petroleum	8	30	Health	5	43	Human factors engineering	4
5	Risk assessment	17	18	Safety culture	8	31	Human error probability	5	44	Human reliability assessment	4
6	Safety	17	19	Training	8	32	Human errors	5	45	Leadership	4
7	Process safety	14	20	HAZOP	7	33	Human performance	5	46	Management	4
8	Reliability	14	21	Maintenance	7	34	Shift work	5	47	Organizational factors	4
9	Oil and gas industry	12	22	Oil industry	7	35	Accident analysis	4	48	Performance shaping factors	4
10	Human factor	11	23	Risk	7	36	Accidents	4	49	Petroleum industry	4
11	Offshore	11	24	Situation awareness	7	37	Alarm management	4	50	Quantitative Risk Analysis	4
12	Human reliability	10	25	SPAR-H	7	38	Control room	4	51	Safety management	4
13	Risk management	10	26	Fatigue	6	39	Drilling	4	52	Simulation	4

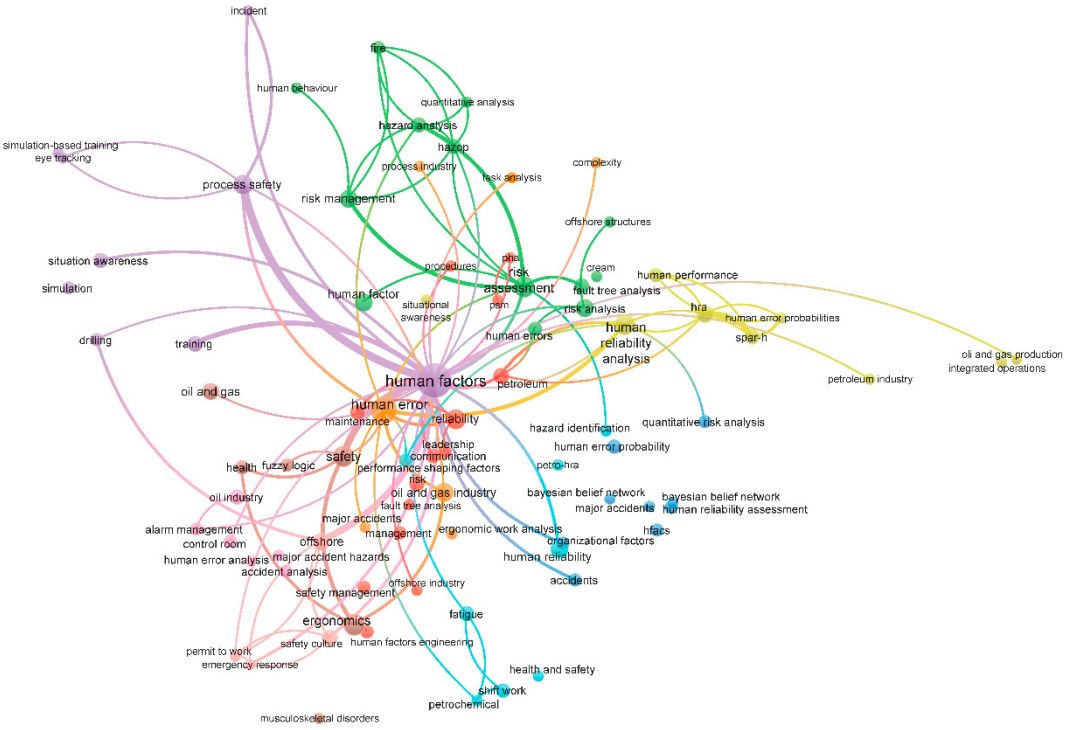

Fig. 3. Author keywords co-occurrence network.

4. Discussion

HFs have a crucial role in industrial engineering, especially when new levels of socio-technical interaction between humans, machines, materials and objects occur. While the literature has largely focused on identifying key human factor root causes [27], the current trend is to investigate how novel digital solutions are affecting the worker's cognitive workload. For example, the control room is one such area where a display of hundreds of parameters and alarms maintains a constant cognitive load on the worker and, in case of lack of attention, severe consequences can follow [28]. When dealing with perceptual errors involving rich information displays, intelligent

vocal assistants or early warning systems based on predictive capabilities have proved their benefits but no applications or prototypes have been found in the scientific literature related to the O&G field. Furthermore, studies like [28] reveal significant differences in information acquisition patterns of the novice and expert workers, thus confirming the importance of training to minimize the possibility of errors. One way to train workers for such challenging environments is through simulation-based training. As showed by the results reported in Section 3.7, simulation has become a relevant area of interest in the O&G sector, the only one explicitly mentioning HF/E aspects. Simulation-based training may help to improve operational efficiency and safety by minimizing the errors that can cause extensive delays in terms of non-productive time or to speed up the time needed to obtain certifications (very common in the O&G industry). However, in this research domain, simulations generally lack training on non-technical skills or human factors such as situational awareness, communication, decision making, etc. While research has already proved the effectiveness of serious games and immersive virtual reality-based simulation for improving learning during safety training in O&G plants [29], incorporation of HF/E aspects is still at a preliminary stage.

Given the broad spectrum of HFs and the complexity of O&G activities, mapping how I4.0 technologies may support the field is therefore still a gap. The only paper in the database of this study dealing explicitly with Industry 4.0 (the term Industry 4.0 was mentioned in the abstract) was aimed at testing wireless PPE that incorporates intelligent tools and fabrics capable of reacting in real time to risk situation by monitoring biometrics of the worker, environmental data and providing recommendations to the worker [30]. The 4th industrial revolution is also based on the concept of "cognitive automation" that can assist the operators in carrying out their activities, reducing the workload or simplifying cognitive activities (for example through the use of augmented reality) [31]. In particular, employee's maintenance work under strict time constraints can greatly benefit from such technologies and simplify the learning of procedures and protocols they must adhere to.

5. Conclusions

This paper calls for a holistic understanding of the changing role and responsibilities of workers in the 4.0 industrial age, especially for critical and hazardous environments, such as the O&G industry. Due to the novelty of the concepts of human-automation symbiosis and socio-technical systems, further research in this field is high demand. In this paper, we conducted a bibliometric review on HF/E literature in the O&G industry to investigate the manner and to which extend academic publications have explored such aspects. Secondly, our findings show that academic publications on HF/E have scarcely integrated Industry 4.0 aspects and focused mainly on simulation-based training to increase process safety. A thorough review of the literature revealed the lack of specific studies on the application of Industry 4.0 technologies (such as Augmented Reality-enabled Operations, Virtual Reality-based training, Intelligent Fault Detection, Predictive Maintenance and Alarm Management, Human-Machine Interfaces for Process Control). This study ultimately pushes for prioritizing HF/E as part of an Industry 4.0 implementation roadmap in the O&G industry. Further work will be devoted to a deeper content analysis of the HF/E literature in the O&G sector and mapping the new digital technologies and Industry 4.0 with HFs.

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