Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Assessing the influence of industry 4.0 technologies on occupational health and safety

Germán Arana-Landín [a], Iker Laskurain-Iturbe [a,*], Mikel Iturrate [a], Beñat Landeta-Manzano [b]

[a] University of the Basque Country UPV/EHU, Faculty of Engineering (Gipuzkoa), Plaza Europa 1, 20018, San Sebastian, Spain
[b] University of the Basque Country UPV/EHU, Faculty of Engineering (Bilbao), Ingeniero Torres Quevedo Plaza, 1, 48013 Bilbao, Spain

ARTICLE INFO

Keywords:
Industry 4.0 technologies
Occupational health and safety
Occupational risks
ISO 45001

ABSTRACT

The aim of this article is to know the impact that the different Industry 4.0 technologies have on occupational health and safety risks, with special attention to the new emerging risks generated. To achieve this objective, an analysis of the literature was carried out. It allowed us to design a survey that was answered by 130 managers and/or technicians of pioneering companies in the development of Industry 4.0 technologies. Next, 32 of these projects were selected and a multiple case study was conducted through 37 in-depth interviews. Moreover, other source of information were analysed (project reports, technical reports, websites..).

The findings highlight that the analysed technologies (Additive Manufacturing, Artificial Intelligence, Artificial Vision, Big Data and/or Advanced Analytics, Cybersecurity, Internet of Things, Robotics and Virtual and Augmented Reality) help to reduce occupational health and safety risks (physical and mechanical). However, its impact depends on the type of technology and the method of application. Influences in new emerging risks (mainly psychosocial and mechanical) have been detected in all technologies except in Internet of Things. In addition, additive manufacturing, artificial intelligence, machine vision, the internet of things, robotics and virtual and augmented reality help to reduce ergonomic risks and artificial intelligence, big data and cybersecurity psychosocial risks. The results obtained have implications for policy makers, managers, consultants and those in charge of managing occupational health and safety risks in industrial companies.

1. Introduction

1.1. Scenario

Industry 4.0 (I40) was defined as a new paradigm to improve process/business performance through digitization and integration (vertical, horizontal and end-to-end) [1,2]. The main change in this new industrial era is a profound shift in the connectivity of manufacturing systems due to the integration of information and communication technologies, Internet of Things (IoT) and machines in cyber-physical systems (CPS) [3]. The I40 technologies (I40Ts) integration of digital applications and tools offers significant

* Corresponding author.
E-mail addresses: g.arana@ehu.eus (G. Arana-Landín), iker.laskurain@ehu.eus (I. Laskurain-Iturbe), mikel.iturrate@ehu.eus (M. Iturrate), benat.landeta@ehu.eus (B. Landeta-Manzano).

https://doi.org/10.1016/j.heliyon.2023.e13720
Received 11 August 2022; Received in revised form 7 February 2023; Accepted 8 February 2023
Available online 18 February 2023
2405-8440/

opportunities for progress and productivity growth in the workplace [5]. Referred to as the fourth industrial revolution, it is bringing considerable changes due to the implementation of new technologies such as additive manufacturing, artificial intelligence, artificial vision, Big Data, Internet of Things, robotics, cybersecurity or virtual and augmented reality. Developed countries have more opportunities to implement these technologies compared to developing countries [6]. Within developing countries, SMEs also have much more difficulty in accessing these technologies mainly because of the cost involved. So the different Industry 4.0 technologies have been implemented mainly in developed countries and in large companies [7,8].

In the literature, there are many examples about the advantages offered by these technologies. They are very large and varied. Among other benefits, they reduce the number of processes required, improve the work environment, reduce processing times, resources and tools required, improve operations management, facilitate decision making, facilitate mass customization, reduce lead times, increase productivity, help control information, enable real-time sensing, improve rapid information transmission, facilitate stakeholder collaboration, virtually support customer service and employee training [7–14]. However, modifications to working conditions must be implemented and the impact on occupational health and safety (OHS) risks must be analysed. Specifically, traditional risks and new emerging risks (NER) must be taken into account [15]. In this regard, Marchand et al. [16] and Botti et al. [17] state that these NERs are linked to the arrival of new hazards and exposures linked to the integration of I40Ts.

In this evolution, the classic risk assessment methodology should be used to analyse the traditional risks but it could not be suitable for assessing some of the NERs [18]. For this reason, the new international OHS management standard ISO 45001:2018 [19] include in the annexes some requirements to manage the risks related with the integration of the new technologies. Specifically, the standard highlights the need to understand the new threats and opportunities that affect or may affect the organization's OHS performance, such as those arising from the integration of new technologies. In particular, the standard stresses that OHS hazards and risks should be minimized and opportunities for improvement maximized. Considering the rapid integration of I40Ts into business processes, the transformation of working conditions that directly influence OHS risks and the need to introduce new assessment methodologies.

1.2. Contribution

Badri et al. [20] highlight the need for manufacturers, researchers and experts to work together in order not to jeopardize the results achieved in preventive OHS management. Furthermore, in their literature review, they underline that the rapid integration of I4OTs and their continuous evolution generates a gap in relation to how they affect OHS risks that needs to be studied in depth.

Nowadays, the relationship of I40 with issues related to OHS is booming. For example, Smallwood and Allen [21] conducted one of the few I40 studies conducted in the construction sector in South Africa. The results indicate the level of awareness of I40 and the likelihood of such technologies being implemented is high and with big impact. Kumar et al. [22] conducted a study in the Indian automotive sector to analyse the social acceptance of I40Ts. This study can help organizations to take into account various social aspects that are vital for the best possible acceptance of these new technologies. Javaid et al. [23] has recently related the impact of I40 on sustainability, including labor sustainability. In the paper they show how I40 favors workers along with the environment (increased resource and energy productivity, deployment of sustainable infrastructure, worker health and safety, and improved quality of life). Adem et al. [24] analysed the impact of I40Ts on occupational health and safety but taking into account very specific risks: Eye-related disorders, Mental fatigue, Disorders resulting from static working position, Exposure to unknown hazardous particles as a result of cooperation with robots and Psychological pressure. They identified mental fatigue and psychological pressure the most critical risks associated with I40Ts. Recently, Zorzenon et al. [25] conducted a literature review based on 59 previous papers. It shows the great potential that I40 has on safety and health and the consequent risks. Despite this, there are few studies in the literature that, taking into account the same parameters, provide quantitative comparisons of the impact of different I40Ts on occupational health and safety risks in the industrial sector. Therefore, this work tries to analyse how each I40T impacts on traditional OHS risks in industrial companies and identifying the NERs that arise when integrating each I40T into industrial processes following the same research protocol.

2.1. Paper organization

In order to develop the proposed research work, the paper is structured as follows: after this introduction, a literature review about the influence of I40Ts on traditional OHS risks and NERs is presented. Section 3 provides the research method. Section 4 presents the results obtained from the study. Section 5 shows the discussion. Finally, before the list of references, Section 6 describes the conclusions, limitations and future lines of research.

2. Literature review

2.1. I40Ts

Bortolini et al. [26] points out that the different Industry 4.0 technologies are emerging at a considerable speed, creating a greater variety of I40Ts and making their classification more difficult. Despite this, they proposes a classification, shared by other authors such as Laskurain-Iturbe et al. [27], which have been used to draw up Table 1 describing 8 technology groups (see Table 2).

2.2. I40Ts and OHS risks

A review of the literature confirms that not many studies have been carried out linking I40Ts and traditional OHS risks [20,40]. In

Table 1
Description of industry 4.0 technologies.

I40 Technology	Description	Reference (source)
Additive Manufacturing (AM)	…. is primarily focused on 3D printing. It is based on depositing the material, layer by layer, in a controlled manner to enable companies to prototype or produce small batches, customized products, complex geometries or lightweight designs.	[12,28,29]
Artificial Intelligence (AI)	… is a cognitive science with the objective of making the best decisions about different research activities: robotics, automatic learning and image processing, natural language processing.	[30]
Artificial Vision (AV	… is the field that through the appropriate techniques, allows the obtention, the processing and the analysis of any information system coming from digital images intelligence in order to gather information and make decisions.	[31,32]
Big Data and Advanced Analytics (BDAA)	… gathers information from different sources and then evaluates it, to make the best decisions in real time and at a more advanced level than with traditional tools.	[33]
Cybersecurity (CS)	… aims to provide protection against cyberattacks on intelligent manufacturing lines connected to the Internet and industrial systems. It enables secure and reliable communications to prevent information theft or systems from being blocked.	[34,35]
IoT	… seeks to connect machines and information technologies through the use of intelligent devices, such as sensors, to optimise decision-making and respond in real time to the complexity of manufacturing processes.	[36]
Robotics (RB)	… aims to ensure the interaction between robots and humans. It should take place safely and the robots should learn from humans	[47]
Virtual and Augmented Reality (VAR)	… seeks to reflect the physical world (workers, machines, etc.) in a virtual model using data. This technology develops real situations in order to train operators, avoiding dangerous situations and improving the decision-making process. VAR even allows introducing objects into virtual models that do not exist in reality.	[38,39]

general, Podgórski et al. [40] assert that digital control platforms can reduce occupational risks. Guo et al. [41] analysed risk maps and wearable technologies, and recommend the use of technologies, such as VAR for safety training (smart glasses and helmets). However, Moore [42] highlights that VAR and BDAA, despite reducing mechanical risks, increase psychosocial risks. He added that RB creates new mechanical risks, but other mechanical, chemical, biological and ergonomic risks tend to be lower.

However, Guo et al. [41] and Fallaha et al. [43] highlight the need to study each traditional risk linked with each I40Ts. Considering this need, this subsection has been classified according to each traditional risks:

Taking into account the state of the art, the following research question (RQ) is posed in order to shed light on the impacts offered by the different I40Ts in the prevention of occupational health risks in industry.

RQ1. What are the influences of each I40T on each type of OHS risk?

2.3. I40Ts and NERs

Some authors affirms that in general digital management of operations and wireless communication provides to the employees better working conditions and a safer manufacturing environment [60,61]. However, workers need to adapt their skills to the new processes [43]. The need for continuous training to keep skills updated is considered a top impact across all activity sectors and increasing with business size in the European Union [62]. The "operator 4.0" generation represents the "operator of the future", an intelligent, skilled operator who performs "machine-assisted work" [37]. The I40Ts require operators to be able to communicate with machines (cognitive skills) rather than physical strength. Cognitive ergonomics integrates human brain processes such as observation, processing and delivery of information. These processes require the human ability to retain, rehearse, recall and convert information depending on the type of task or job to maintain the work environment [43,63]. They also require an engineering philosophy for adaptive production systems focused on treating automation as a further enhancement of human physical, sensory, and cognitive capabilities through the integration of human cyber-physical systems [64].

Moore [42] highlights that VAR and BDAA increase stress, discrimination, precariousness, musculoskeletal disorders and job loss. On the other hand, several authors suggest that severe restrictions in the form of so-called "functional stupidity" are an equally important and under-recognized part of organizations. “Functional stupidity" refers to the absence of reflexivity, a planned state of ignorance by tolerating unanswered questions and avoiding challenges to the status quo [65–68]. Moreover, in the context of the complexity and functional opacity of the systems, the interactions between simple and interdependent components (systems, human, computer, etc.) bring unexpected reactions and NERs. As consequence, some authors confirm that the systems are more vulnerable to accidents with less safety margins because the capacity for immediate analysis and reaction of the operators is reduced due to the dependency of indirect information [69,70].

Meanwhile, the European Agency for Safety and Health at Work identified specific NERs covering physical, biological, psychosocial and chemical hazards [62,71,72]. These NERs were found in 5% of the 45,420 respondents. One multifactorial emerging risk that most respondents agreed with was the complexity of technologies and work processes with complex human-machine interfaces (HMI). The ESENER [62] report stated, among others, the need to reduce repetitive movements to minimise risks in processes with human-robot

Table 2
Summary of the review of the literature on influences of I40Ts on OHS risks.

Study	Methodology	I40T	Main results
[41]	Survey (215 answers)	VAR	Highly recommend the use of VARs for safety training (smart glasses and helmets) in the construction industry.
[40]	Theoretical work	IoT and AI	A framework for real-time risk assessment and the ability to monitor the risk level of each individual worker was proposed.
[20]	Literature Review (11 papers)	Various	Failure to link technologies to workplace risks will multiply during the transition period.
[42]	Theoretical work	Various	VAR and BDAA, despite reducing mechanical risks, increase psychosocial risks. RB creates new mechanical risks, but other mechanical, chemical, biological and ergonomic risks tend to be lower.
[23]	Literature review (218 papers)	IoT, BDAA, AI	Industry 4.0 benefits workers along with the environment (including worker health and safety and improved quality of life).
[25]	Lirature review (59 papers)	Various	Great potential of the different I40Ts on safety and health and the consequent risks.
PHYSICAL RISKS			
[44]	Case study	IoT	Wireless communications and information technologies are capable of continuously and effectively detecting hazards in the workplace.
[45]	Theoretical work	IoT and BDAA	Organizations should better adapt their management practices, including those related to health and safety, and avoid physical hazards.
[46]	Case study	BDAA	Improve intelligent predictive maintenance for the diagnosis and prognosis of failures in machine centers.
[47]	Case study	VAR	Augmented Reality contributes to compliance with safety standards and principles by enabling the pre-training of operators in tasks with high physical risk.
[48]	4 Case studies	AM	AM makes it possible to integrate the manufacturing process in places where the required concentration is optimal because the noise level of the new processes is negligible and heavy transports are reduced.
CHEMICAL RISKS			
[49]	Case study	RB	Some hazards can be avoided through the use of RBs controlled by manual or automated processes.
BIOLOGICAL RISKS			
[50]	Theoretical work	RB	The use of robots helps reduce biological risks since they are controlled from a safe distance
[51]	Theoretical work	General	The need to work from different locations (forced by COVID in some companies) to avoid biological and/or chemical risks requires improving not only the company's cybersecurity but also the security of communication and information systems.
ERGONOMIC RISKS			
[52]	Theoretical work	IoT (CPS)	In the context of I40, there should be OSH with special emphasis on ergonomics and human factors. They add that the role of ergonomists and industrial designers is critical to derive benefits from cyber-physical systems.
[53]	Literature review (36 papers)	AI and RB	Avoiding physical and repetitive tasks by training employees in robot programming, control and maintenance
PSYCHOSOCIAL RISKS			
[54]	Survey (746 answers)	Various	The implementation of I40Ts offers environmental and social opportunities, as well as the improvement of psychosocial risks.
[55]	Survey (3162 answers)	Various	Psychosocial risks are becoming increasingly important despite the evolution of labor relations linked to I40T and the acceleration of changes in the market.
[24]	Survey	Various	Mental fatigue and psychological pressure are the most critical risks associated with I40Ts.
MECHANICAL RISKS			
[56]	Theoretical work	RB	Robots must recognize actions that may cause injury or threaten worker safety.
[57]	Theoretical work	IoT and BDAA	These two technologies pose enormous challenges to improve performance and prevent accidents.
[58]	Theoretical work	RB	They proposed that the robots have a safety eye and stop working if a person or equipment enters the safety zone.
[59]	Theoretical work	Various	Exploiting real-time data in the manufacturing process has a positive impact on the performance, reliability, sustainability and safety of industrial systems.

interaction. In addition, the increasing complexity and the growing use of information and communication of information and communication technologies in automated manufacturing have led to HMI problems [73]. Stacey et al. [74] pointed out that information and communication technologies, including information and communication technologies - enabled technologies, such as RBs and AI, are likely to have significant impacts on the nature of processes and associated risks. Likewise, the emergence of the virtual work environment, following the development of information and communication technologies, has also led to the NERs [75]. However, the techniques that exist to identify and to assess an occupational risk such as NER are very limited [76].

Considering all these aspects, the second objective of this research seeks to answer the following research question.

RQ2. What are the main NERs caused by each type of I40T?

3. Research methodology

The initial process of the research process consisted of conducting the literature review between October 2019 and December 2019, using Web of Science, Scopus and Google Scholar databases. The following keywords were entered to search for published literature: "occupational risks" OR "emerging risks" OR "safety management" OR "accident prevention" OR "ISO 45001" OR "occupational health and safety" AND "Industry 4.0". In addition, some rules were also established for the advanced search: "English" was the language, "Article" was the document type, and "Journals" was the source type. Of course, there are other sources, such as conference papers, but we focused on journal articles, as they are more reliable sources of knowledge [77]. After careful filtering, 36 article references were incorporated.

The result of the review of the literature on the subject allowed us to obtain a first approximation to the research problem that would make it possible to adequately approach both the design of the research and the propositions to be confirmed. Likewise, the initial literature review work included the exploration of the methodologies to be used in the research. It was concluded that the empirical study would be carried out in three main phases.

1st phase of the research

In December 2019, fieldwork started with a survey addressed to the 168 represents (managers and technicians) of innovative companies from Europe, America, Asia and Africa. The companies were chosen for the development of Industry 4.0 technology projects proposed by potential venture clients of a start-up acceleration programme (first four editions) called BIND 4.0 [78], winner of the 'Improving the Business Environment' award of the European Enterprise Promotion Awards 2020 (EEPA) [79]. All of these companies are providers of advanced manufacturing technologies, smart energy, health technology, and food technology.

The aim of this phase was to collect information on the impact of each I40T (AM, AI, AV, BDAA, CS, IoT, RB and VAR) on the safety and health of workers in the industry, using hazards (physical, chemical, biological, ergonomic, psychosocial and mechanical) as variables. The questionnaire included questions that followed the same structure so as not to influence participants' answers. They were asked: "Please assess the influence (direct, indirect or potential) that the project may have on … ". Based on Schumacher et al. [80], a Likert scale was used (-4, has a very strong negative influence; 0, no influence; +4, has a very strong positive influence). In addition, the survey included the possibility to add more information and to include information on new risks in the open-ended questions. Once the questionnaire was developed, it was pre-tested in five companies to validate it [81]. In this test, the questionnaire was sent by e-mail. Five interviews were then conducted to check the correct understanding of the questionnaire and the need to leave open questions to complete the research.

Project managers and technicians who did not complete the questionnaire within 15 days were asked to participate again. In total, 130 projects responded. The response rate was therefore 71.4% and the responses received were divided as follows per I40T: 8 from AM, 28 from IA, 18 from AV, 24 from BDAA, 5 from CS, 26 from IoT, 5 from RB and 16 from VAR.

The data obtained in this phase limited to some extent the scope of the quantitative analysis. Nevertheless, it did offer us the possibility of carrying out an exploratory approach to the research phenomenon and obtaining very useful information to design the next phase, such as establishing the unit of analysis (one per technology), designing the case protocol or the evidence collection plan. Likewise, the first phase facilitated the selection of the case studies for the subsequent phase.

2nd phase of the research

In the second phase of the research, the qualitative case study methodology was used, following a protocol designed for this purpose. The case study methodology makes it possible to observe a phenomenon in its context, considering different sources of data and using the necessary tools (in-depth interviews with the main key players, on-site visits, various documentation, etc.) to obtain quantitative and/or qualitative evidence [82]. In fact, the case study enables to start an investigation without knowing the precise limits of the case, and some of the conditions initially considered as contextual may even end up being part of the case [83].

We selected those cases that had carried out projects that have shared manufacturer and their risk clients in which the staff involved by both (managers and technicians involved) were really accessible and willing to collaborate in our purpose. We also tried, as far as possible, to reach a minimum of two cases of each technology.

Subsequently, once the list of cases and people who had agreed to participate in the study had been formalised, we decided to establish the following set of fundamental techniques (sources of evidence) as viable means of carrying out the qualitative study.

- In-depth interviews with project managers and technicians, according to an interview script, a shortened version of which was previously sent to the interviewee.
- Analysis of multiple sources of evidence (reports, technical documentation, internal communications, etc.) (data triangulation [83]).
- On-site visit to the companies, where the effects of I40 technologies on the company are analysed through passive and active observation (methodological triangulation [83]).

A total of 37 managers and technicians from 32 projects were interviewed between January 2020 and February 2021. From these case studies, the research shows the analysis of 27 projects, grouped by technology [technology (number of cases)]: AM (4), AI (4), AV (2), BDAA (3), CS (2), IoT (6), RB (2), VAR (4)]. The main objective was to gain first-hand knowledge of the key aspects identified in the interviews and to collect numerous documents, such as project reports or technical reports for analysis (methodological triangulation). The search and collection of new data continued until the evidence did not allow us to obtain additional information. Although information channels were kept open at later stages, including during the search for common patterns of behaviour. In some cases it was necessary to collect further evidence to confirm the preliminary results of the analysis [84].

After examining, categorising and tabulating each piece of evidence collected, an individual analysis of each case was conducted, attempting to determine the connection between the data and identify common patterns of behaviour between the cases. Subsequently, a cross-analysis of the cases grouped by technology was performed [85].

3rd phase of the research

Finally, a third phase was carried out, as it was agreed that it was necessary to obtain reliable group opinion from a group of experts to reduce the degree of subjectivity in the assessment of the results obtained in the case study and to provide different points of view. In fact, it is worthwhile to compare even those findings with sufficient confirmatory evidence with new informants, even experts, and other external stakeholders from the same area of knowledge, but from different fields, as is the case here [86,87]. This is not why it is redundant, but rather confirmatory and, therefore, reinforces the constructive validity of the research [88]. In this regard, Thurmond [89] spoke in similar terms, focusing his discourse on methodological triangulation, as a strategy to deepen the understanding of the reality of the phenomenon and reinforce the validity of the results of qualitative studies. Thus, in our research, the group was made up of 7 members, participants from the previous phases of the research (2), risk clients (2), academics (1), technology centre (1), consultant (1) and organization public (1), who were shown the results of the previous phase. We wanted to get feedback from participants from previous phases and new participants, in order to have different perspectives.

The ethics committee of the CEISH-UPV/EHU approved the research methodology and consent was obtained from all research participants.

4. Results

This section presents the main results of the cross-case analysis, the most significant qualitative evidence and the main NERs detected. The results are summarised in Tables 3–10 (sections 4.1 to 4.8). The tables summarise the main results of the analysis of the common patterns of the cases. The search method by which the evidence was obtained is also indicated (interviews (I), available documentation, communications … (D), and visits (V) and the case (or cases) of origin. In addition, they show the assessment of the quality of the sources from which the evidence was obtained (Q) and the level of theoretical saturation (TS) achieved from the triangulation [92].

The next column in the tables shows the assessment of the transferability of the phenomenon (TP). This explains the property of being transferable to other specific contexts by providing a coarse description of the sender and receiver contexts (case-by-case transfer) [93]. The issue of generalising the results of qualitative studies (including, therefore, the case study) is not free of suspicions. For this reason, the case study's capacity for analytical generalisation of the phenomenon has to be exploited, for which it is necessary to rely mainly on the internal validity tests of the different cases (literal replication) [83] (see Appendix 2 for more details).

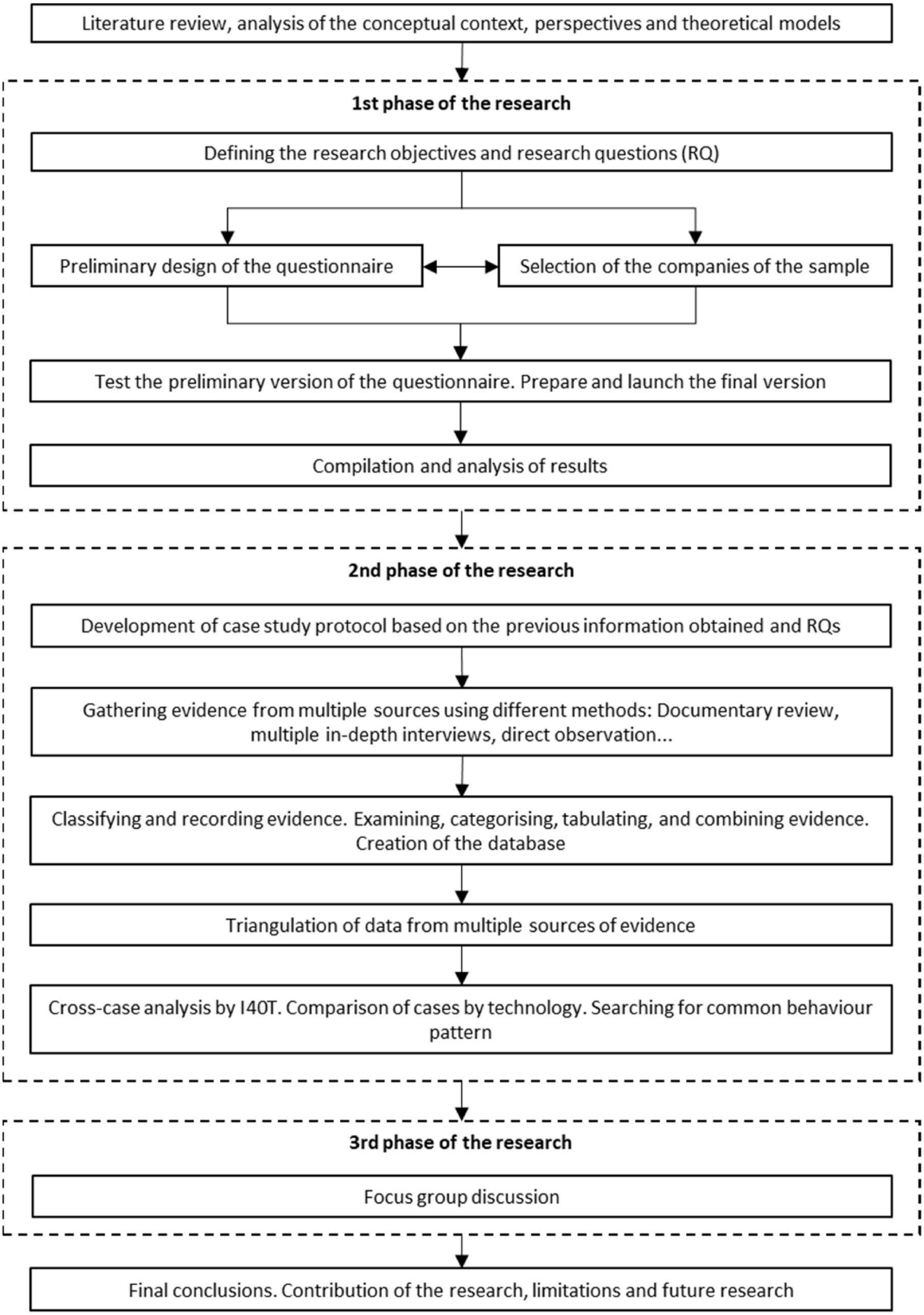
The last column in the tables shows the assessment of the level of influence of each I40T on each type of Risk (IoR), taking into account: the interviews carried out, the analysis of the documentation provided by the companies, and the visits made to the companies.

These last two columns, TP and IoR, were elaborated with the collaboration of the aforementioned focus group, in order to reinforce the validity of the construction and as a reliability test, in accordance with the methodological indications of Blome and Schoenherr [94], Gibbert et al. [88], Riege [95], and Yin [83] (see Appendix 2).

4.1. Additive manufacturing technology and occupational health and safety risks

AM1 uses 3D robots with AM technology by layers rather than by wear for the manufacture of aircraft parts. Using this technology, they were able to reduce the weight of parts by 50% and consequently the physical effort required in handling these objects has been reduced. However, there are new few chemical risks caused by additives in certain raw materials that can cause minor allergic reactions (see Table 3).

The manager of AM2, which produces parts for machine tools, states that the workers display substantial physical and ergonomic improvements because they do not need to carry heavy raw materials. Depending on the AM technology, the risks differ. There may be



(caption on next page)

Fig. 1. Diagram of the methodological process followed. Source: Compiled by the authors, based on Creswell and Clark [90] and Ivankova et al. [91].

Table 3
Influence of additive manufacturing on occupational health and safety risks.

Brief description of the projects	Data source
AM1 - Printing of metal and plastic material for suppliers to aircraft manufacturers	I (M, T), D, V
AM2 - Minimization of biowaste in the food industry through atomic level applications	I (T), D, V
AM3 - Special coating with nanotechnology in the manufacture of brake discs	I (M), D, V
AM4 - Consultancy to implement AM in industrial processes	I (M), D

Risks	Main evidence	*Quality source*	Saturation Theoretical	Transferability	Influence on risk
Physicist	Less weight to carry	●●[2]	●●	●	▲▲[3]
	Less distance to be covered with weights	●●	●●	●●●	
	Noise reduction	●●●●	●●●	●●●●	
	Burns with hot surfaces	●●●	●●●	●●●	
Chemistry	Inhalation of metal dusts	●●●	●●	●●●	▽▽
	Allergic reactions due to some additives in a few cases	●●	●	●	
	Harmful vapours	●●●	●●●	●●●	
Biological	*No clear and relevant evidence*				
Ergonomic	Reduction of awkward positions	●●●	●●	●●	▲▲▲
	Reduction of raw material handling	●●●	●	●●●	
Psychosocial	*No clear and relevant evidence*				
Mechanics	Reduced contact with machines	●●●	●●●	●●	▲▲

Notes: [1]Origin of data: interviews (I) with managers (M) and/or technicians (T), available documentation, communications … (D) and visits (V). [2] The aggregated values provided summarise each aspect's rating in terms of level as a five-point Likert-type item, from very low or none (○), to very high (●●●●). [3] It captures the level of impact on each risk as a nine-point Likert-type item, from a very negative potential influence (-4 or ▽▽▽▽), none **(-)**, to a very positive potential influence (+4 or ▲▲▲▲). Source: developed by the authors.

risks of burns, mainly due to contact with hot surfaces. Adopting the usual safety measures in the industry, the risks are properly managed and controlled. However, it is necessary to bear this in mind in order to avoid overconfidence.

Likewise, AM3 is dedicated to consulting services for adapting the manufacturing processes to the AM Technology. Parts can be printed as close to the work area as possible, so transport is minimized and employees have to cover a shorter distance while carrying less weight. The technician also highlights the noise reduction and the improvement in the design of the machines to make them safer, thus helping to reduce accidents at work. New risks derive from contact with some materials, such as resins or photopolymers, or in the emission of harmful vapours in the melting of materials, such as thermoplastics like acrylonitrile butadiene styrene or acrylonitrile styrene acrylate. Also, special care must also be taken in the handling of metal powders to avoid direct contact with them and their inhalation.

4.2. Artificial intelligence technology and occupational health and safety risks

AI1 is dedicated to developing a technology for voice recognition of operators. The project technician comments that this technology substantially reduces worker fatigue and stress as a result of not having to search for or write down information manually. In addition, the considerably reduction of the risk of failure due to distraction, minimising possible accidents with the machines. However, Table 4 shows the detection of infections transmitted through the headsets have been detected. Despite being considered a minor risk, it is necessary to establish specific protocols to clean headsets or ensure their individual use.

AI2 develops an intelligent heating, ventilation and air conditioning system that can be adapted to an existing building/facility or can be custom-made for a new building using IoT devices. The manager of this project affirms that the system automatically updates the ideal comfort standards of the building. This achieves the ideal level of indoor air quality and mixed air temperatures, increasing the comfort of workers.

AI3 implements a platform to maintain security and protection remotely and efficiently via cameras (using AV). This allows the client to better understand when and how often workers engage in risky behaviour that may jeopardize their safety. The data obtained help to implement improvement actions and to prevent injuries, accidents, potential employee fatigue or ergonomic problems. However, some workers felt anxious about being controlled and examined by the cameras. According to the project manager, it is very important to inform, train and teach the true usefulness of this type of technology.

4.3. Artificial vision technology and occupational health and safety risks

AV1 implemented machine vision systems to automatize the previous manual quality inspection of valves. As a result, the technician affirms that employees have fewer possible vision problems and less fatigue or muscle stress due to prolonged visual overexertion. However, in Table 5 is shown the detection of psychological stress and depression of some workers due to the lack of capacity to get new skills for new tasks.

Table 4
Influence of artificial intelligence on occupational health and safety risks.

Brief description of the projects	*Data source*
AI1 - Monitoring the construction of a wind farm using non-satellite imagery	I (T), D
AI2 - Voice recognition technology for operators to search or type in procedures	I (M), D
AI3 - Analysis of data (heating, air-conditioning) of buildings/factories	I (M), D
AI4 - Analysis of camera data to optimise procedures	I (T), D

Risks	***Main evidence***	***Quality source***	***Theoretical saturation***	***Transferability***	***Influence on risk***
Physicist	Reduced time and fatigue thanks to voice search and the use of cameras to exploit data	●●●[2]	●●	●●●●	▲▲[3]
	Improved comfort at work (e.g. air quality, temperature)	●●●	●	●	
Chemistry	*No clear and relevant evidence*				
Biological	Transmission of infections through headphones	●●	○	●	–
Ergonomic	Improved ergonomics thanks to data collected by cameras	●●	●	●●	▲▲
Psychosocial	Reducing stress by avoiding manual typing/searching for information	●	●	●	▲
	Some workers feel anxious about being controlled	●●	●	●	
Mechanics	Preventing accidents through analysis of camera data	●●	●●●	●●	▲▲

Notes: 1Origin of data: interviews (I) with managers (M) and/or technicians (T), available documentation, communications … (D) and visits (V). 2 The aggregated values provided summarise each aspect's rating in terms of level as a five-point Likert-type item, from very low or none (○), to very high (●●●●). 3 It captures the level of impact on each risk as a nine-point Likert-type item, from a very negative potential influence (-4 or▽▽▽▽), none (-), to a very positive potential influence (+4 or ▲▲▲▲). Source: developed by the authors.

Table 5
Influence of artificial vision on occupational health and safety risks.

Brief description of the projects	*Data source*
AV1 - Quality inspection system for the production of plastic films	I (M), D
AV2 - Automation of the inspection of parts in industrial processes (mainly automotive parts)	I (M), D

Risks	***Main evidence***	***Quality source***	***Theoretical saturation***	***Transferability***	***Influence on risk***
Physicist	Reduction of vision problems, fatigue or muscle stress	●●●[2]	●●	●	▲▲[3]
Chemistry	*No clear and relevant evidence*				
Biological	*No clear and relevant evidence*				
Ergonomic	Avoid awkward positions performed by robots	●●	●●	●●	▲▲
Psychosocial	Stress reduction by avoiding permanent concentration	●●	○	○	–
	Some workers are unprepared for the new jobs and feel depressed	●●	○	●	
	Mistrust of employees due to privacy issues	●●	○	●	
Mechanics	Avoiding accidents through visual communication	●●●	●	●●	▲▲

Notes: 1Origin of data: interviews (I) with managers (M) and/or technicians (T), available documentation, communications … (D) and visits (V). 2 The aggregated values provided summarise each aspect's rating in terms of level as a five-point Likert-type item, from very low or none (○), to very high (●●●●). 3 It captures the level of impact on each risk as a nine-point Likert-type item, from a very negative potential influence (-4 or▽▽▽▽), none (-), to a very positive potential influence (+4 or ▲▲▲▲). Source: developed by the authors.

AV2 introduced quality inspection system in the production of plastic film. They managed to reduce the visual fatigue of employees, and through training were able to redistribute employees to other new jobs related to quality data management.

AV3 developed a communication protocol based on eye-tracking technologies to control a computer through eye movement. The manager states that the technology allows a worker, in the event of an accident, to communicate with the machine by eye movement, to warn someone or to give orders to the robot. Moreover, the reduction of iteration with the machines reduces the mechanical risks. AV2 and AV3 project managers agree that operators working with cameras at their workstations may feel uncomfortable due to privacy concerns. They believe that a strong effort should be made to train and explain the value of these devices so that their use is normalized in companies.

4.4. Big data and Advanced Analytics technology and occupational health and safety risks

BDAA1 aim to find the most optimal response in real time to minimise rescue time for workers or users by exploiting data in risk situations. Also, these solutions can be adapted to possible problems that ships may encounter at sea. They are able to install an on-line system to detect and analyse some different risks, and act properly in emergency situations (see Table 6).

BDAA2 is dedicated to improving the energy consumption of productive machines through data mining. The project technician states that they enable clients to prevent malfunctions and to reduce possible machine accidents. Many times, simply by means of signs

Table 6
Influence of big data and advanced analytics on occupational health and safety risks.

Brief description of the projects	*Data source*
BDAA1 - Data processing to optimise the use of industrial machines	I (M, T), D
BDAA2 - Use of information systems for factory management and optimisation	I (M), D, V
BDAA3 - Massive data analysis to optimise production machine indicators	I (T), D

Risks	***Main evidence***	***Quality source***	***Theoretical saturation***	***Transferability***	***Influence on risk***
Physicist	Minimising rescue time in the event of an accident	●●[2]	●	●	▲▲[3]
	Avoid noise zones that can fatigue employees	●●●	●●	●●●	
Chemistry	*No clear and relevant evidence*				
Biological	*No clear and relevant evidence*				
Ergonomic	*No clear and relevant evidence*				
Psychosocial	Avoiding stress by detecting high noise areas	●●●	●	●●	▲
	Sometimes the adaptation process is stressful	●●	●	●	
Mechanics	Minimising accidents with machines that analyse operating data	●●	●	●●	▲▲
	Risk of a machine being started remotely	●●●	●	●●	

Notes: 1Origin of data: interviews (I) with managers (M) and/or technicians (T), available documentation, communications … (D) and visits (V). 2 The aggregated values provided summarise each aspect's rating in terms of level as a five-point Likert-type item, from very low or none (○), to very high (●●●●). 3 It captures the level of impact on each risk as a nine-point Likert-type item, from a very negative potential influence (-4 or▽▽▽▽), none (-), to a very positive potential influence (+4 or ▲▲▲▲). Source: developed by the authors.

or lights in the plant itself, it is possible to know if there is an operator working on a specific machine, but it is not taken into account that the machine can be started up without being physically on site, invalidating the established safety measures. Therefore, safety protocols must be changed to take into account this new remote casuistry.

BDAA3 collects and automates (using IoT) personal and environmental noise data and information. The manager highlights that they can detect sites with excessive noise levels. This is critical in order to take actions to improve the work conditions and to set actions to reduce noise levels. As a results, the stress is reduced and the comfort of employees is increased. However, sometimes the adaptation process itself is stressful for some workers because they have to modify their daily work.

4.5. Cybersecurity technology and occupational health and safety risks

Both (CS1 and CS2) agree that CS alone does not offer risk minimization. However, both concurred that all I40Ts with machines or physical systems connected to the internet need protection because their entire operations need to avoid CS risks. In Table 7, it is stated how their services can prevent cyber-attacks and their consequences, such as explosions in chemical plants or robots that provokes accidents. The manager of CS2 emphasizes that the lack of security in the project causes tremendous stress at work for fear of having data stolen or fake information being introduced in the system. Also, the manager explains how his clients lost essential orders because of cyber-attacks to their email. The interviewee adds that a cyber-attack could start up an automated machine or impair machine safety systems and put workers at risk. The head of the CS2 project comments that they are also implementing Blockchain technology (it could be a stand-alone technology) for security and believes that it is creating mistrust among workers as it encrypts all traceability information. It is necessary to explain and specify for what purpose and what information is handled.

Table 7
Influence of cybersecurity on occupational risks.

Brief description of the projects	Data source
CS1 - Armouring of the entire IT system of an automotive company	I (T), D
CS2 - Securing the IT system of a machine tool company including Blockchain technology	I (T), D

Risks	***Main evidence***	***Quality source***	***Theoretical saturation***	***Transferability***	***Influence on risk***
Physicist	Avoiding accidents due to cyber-attacks that control robots	●●●[2]	●	●●	▲▲[3]
Chemistry	Preventing chemical leaks or explosions due to cyber-attacks	●●	●●	●●●	▲
Biological	Preventing leaks through cyber-attacks	●●	●	●●	▲
Ergonomic	No clear and relevant evidence				
Psychosocial	Reduce employee stress by reducing the fear of losing information or orders due to cyber-attacks	●●●	●	●	▲▲
	Mistrust of workers in the use of blockchain technology	●●●	●	●●	
Mechanics	Preventing accidents due to cyber-attacks that control machines	●●	●●	●●●	▲▲

Notes: 1. Origin of data: interviews (I) with managers (M) and/or technicians (T), available documentation, communications … (D) and visits (V). 2. The aggregated values provided summarise each aspect's rating in terms of level as a five-point Likert-type item, from very low or none (○), to very high (●●●●). 3. It captures the level of impact on each risk as a nine-point Likert-type item, from a very negative potential influence (-4 or▽▽▽▽), none (-), to a very positive potential influence (+4 or ▲▲▲▲). Source: developed by the authors.

4.6. Internet of things technology and occupational health and safety risks

IoT1 develops devices that fit on workers' wrists to digitize their movements. The CEO of the supplier comments that the technology allows them to detect falls or workers' vital signs in order to respond as soon as possible. It also makes it possible to analyse the workers' usual posture in order to improve their ergonomics (see Table 8).

IoT2 monitors the lube oil of wind turbines through sensors. The project manager stresses that once installed, it is not necessary to access the wind turbine to know its status, hence avoiding dangerous tasks by workers such as oil collection.

IoT3 installs sensors to obtain online information about the status of the machines. Using that information, they also add other devices with signals and alarms to alert the operators of danger, thus reducing the risk of accidents (2% reduction in the last two years).

IoT4 also uses wireless sensors for the constant monitoring of all the elements involved in the production process. According to the technician, they are making better use of plant space to reduce internal movement of workers. In addition, the technology is able to locate and identify both operators and internal transport vehicles. It enables them to detect risks and act instantly to prevent accidents (90% accident reduction).

IoT5 supplies devices, designed for operators, which have a safety system connected to the network covering several areas. The project technician states that the devices are capable of detecting falls, ergonomic problems and of collecting data over a period of time to assess different risks. He adds that they often detect hidden risk factors that were not detected with traditional technologies.

IoT6 is focused on the design and development of devices to improve the safety of workers in the industrial sector. They use multiple sensors and location systems to analyse the use of personal protective equipment (mainly helmets) and working conditions in a remote location. The system warns of hazards.

IoT7 is dedicated to gas monitoring and solvent leak detection. The manager states that measuring the quality of indoor air in industrial plants or in elevators allows them to accurately detect the most harmful particles, for both machinery and personnel, and send out warnings. IoT project managers do not believe that any significant NERs will be generated beyond having to install sensors at risk points such as wind turbines.

4.7. Robotics technology and occupational health and safety risks

RB1 provides solutions using sensing technologies and flexible application software. They eliminate the need for programming and are intuitive for operators. The technician believes that by removing human contact with dirty and dangerous applications in work, such as abrasive material removal, many injuries could be prevented. Furthermore, the technician adds the possibility of eliminating the need for employees to access hazardous environments with chemical or biological risks and added that this is especially important in times of pandemics. However, as it can be noticed in Table 9, some workers get stressed and do not cooperate for fear of losing their jobs. In addition, the repetitive movement of robots creates NERs related with collisions or entrapments, when they interact with humans. In addition, if they teleoperate the robots and cobots, it is more difficult to control the position of objects or people within the workspace, so it can lead to unsafe situations.

Table 8
Influence of the Internet of Things on occupational health and safety risks.

Brief description of the projects				Data source	
IoT1 - Devices to monitor the supply chain				I (T), D	
IoT2 - Sensor monitoring in wind turbine lubricating oil				I (M), D	
IoT3 - Capturing industrial machine data via sensors				I (M), D	
IoT4 - Sensorisation of industrial machines to optimise mainly energy consumption				I (T), D	
IoT5 - Using wireless sensors to monitor the entire value chain (from supplier to customer)				I (T), D	
IoT6 - Monitoring workers' movement using sensors to optimise routes and movements				I (T), D	
Risks	***Main evidence***	***Quality source***	***Theoretical saturation***	***Transferability***	***Influence on risk***
Physicist	Detection of falls and risk situations through heat mapping	●●[2]	●	●●	▲▲▲[3]
	Improvement of working comfort (air quality, temperature)	●●●	●●●	●●●●	
	Reduction of internal travel for employees	●●●	●●●	●●●●	
	Identification of hidden risks	●●	●	●	
Chemistry	Detection of particular hazards in the workplace	●●	●	●●●	▲▲
Biological	*No clear and relevant evidence*				
Ergonomic	Improving ergonomics by collecting information on employees' movements	●●	●	●●	▲▲
Psychosocial	*No clear and relevant evidence*				
Mechanics	Reducing potentially hazardous maintenance work	●●	●	●●	▲▲▲
	Preventing accidents with machines, employees and transport vehicles	●●	●	●●	

Notes: 1Origin of data: interviews (I) with managers (M) and/or technicians (T), available documentation, communications … (D) and visits (V). 2 The aggregated values provided summarise each aspect's rating in terms of level as a five-point Likert-type item, from very low or none (○), to very high (●●●●). 3 It captures the level of impact on each risk as a nine-point Likert-type item, from a very negative potential influence (-4 or▽▽▽▽), none (-), to a very positive potential influence (+4 or ▲▲▲▲). Source: developed by the authors.

Table 9
Influence of robotic technology on occupational health and safety hazards.

Brief description of the projects				*Data source*	
RB1 - Robotic solutions with flexible sensing technologies and application software				I (M, T), D	
RB2 - Implementation of intelligent robots in production processes				I (T), D	
Risks	***Main evidence***	***Quality source***	***Theoretical saturation***	***Transferability***	***Influence on risk***
Physicist	Reduction of diseases such as white finger vibration (WFV)	●●[2]	●●	●●	▲▲[3]
Chemistry	Reducing contact with hazardous materials	●●	●●●	●●●	▲▲
Biological	Possibility to work from more secure locations	●●	●	●	▲
Ergonomic	Avoid bad posture	●●	●●	●●●	▲▲
Psychosocial	Avoiding jobs that cause stress when performed by robots	●	●	●	–
	Stress caused by workers' fear of job loss	●	●●	●●●	
	Difficulty in adapting to change leads to worsening moods	●	○	○	
Mechanics	Reduced contact with machines	●	●	●	▲
	The movement of robots creates some new risks	●●	●●	●●	

Notes: 1Origin of data: interviews (I) with managers (M) and/or technicians (T), available documentation, communications … (D) and visits (V). 2 The aggregated values provided summarise each aspect's rating in terms of level as a five-point Likert-type item, from very low or none (○), to very high (●●●●). 3 It captures the level of impact on each risk as a nine-point Likert-type item, from a very negative potential influence (-4 or▽▽▽▽), none (-), to a very positive potential influence (+4 or ▲▲▲▲). Source: developed by the authors.

RB2 also uses flexible sensing technologies and supply programmed services. The technician of RB2 comments that the technology helps enormously in preventing diseases like vibration white finger among workers. Based on self-learning algorithms, cobots increased mobility and decision-making autonomy, and they could make their actions less predictable for the workers collaborating with them. This may result in an increased risk of accidents through collision or arising from the equipment used by cobots. He also believes that the technology helps workers suffer less stress because robots do the most unpleasant jobs and improve employee ergonomics by avoiding bad posture. However, some workers have trouble adapting to changes in their jobs and this causes mood deterioration.

4.8. *Virtual and augmented reality technology and occupational health and safety risks*

VAR1 trains industrial workers to be aware of danger. Table 10 shows that the technology simulates the implications of not using properly the personal protective equipment in the case of accidents. The simulations seek to create a real effect. For example, they can see the consequences of a cut hand with the blood to make workers aware of the danger. In the words of the project manager, many companies have been thinking for many years that they know well the dangers of their processes, but they appreciate the danger more fully with the use of simulation. In a study of a previous project, they detected that workers trained using virtual reality have fewer accidents on average per worker than those trained in the traditional way. The average number of accidents in the group trained with

Table 10
Influence of virtual and augmented reality on health and safety risks in the workplace.

Brief description of the projects				*Data source*	
VAR1 - Training of persons who can use fire extinguishers				I (M), D	
VAR2 - Comprehensive support for the digitization of water treatment plant maintenance processes				I (T), D	
VAR3 - Training to optimise procedures in industry				I (T), D, V	
VAR4 - Virtual training for training for work with some element of risk				I (T), D	
Risks	***Main evidence***	***Quality source***	***Theoretical saturation***	***Transferability***	***Influence on risk***
Physicist	Training to contribute to hazard awareness for workers	●●[2]	●●	●●	▲▲[3]
	Reduced transport risk by being able to give virtual orders for machine start-up or maintenance	●●	●	●●	
	Physical discomfort from the use of technology	●●	●	●	
	Danger of accidents due to leaving the area of use in the plant	●●	●●	●●	
Chemistry	*No clear and relevant evidence*				
Biological	*No clear and relevant evidence*				
Ergonomic	Improving ergonomics through e-learning	●●	●	●●	▲▲
Psychosocial	Training to expose potential psychosocial risks at work	●●	○	●	–
	Spectacle anxiety	●	○	○	
Mechanics	Training to avoid misuse of machines	●●	●●	●●●	▲▲

Notes: 1Origin of data: interviews (I) with managers (M) and/or technicians (T), available documentation, communications … (D) and visits (V). 2 The aggregated values provided summarise each aspect's rating in terms of level as a five-point Likert-type item, from very low or none (○), to very high (●●●●). 3 It captures the level of impact on each risk as a nine-point Likert-type item, from a very negative potential influence (-4 or▽▽▽▽), none (-), to a very positive potential influence (+4 or ▲▲▲▲). Source: developed by the authors.

VAR was a 33% smaller as the manager revealed in their information system. On the contrary, in the words of the VAR1 responsible, the use of glasses can cause anxiety due to increased interaction with the virtual environment. It can also cause mild discomfort, such as dizziness or tiredness, and loss of balance in some people in case of intensive use. It is important to use for less than 25 min continuously with breaks of 15 min.

VAR2 project has a platform of a mutual insurance company for training. The supplier CEO believes that they can considerably improve workers' safety in dangerous situations and raise awareness of psychosocial risks. On the negative side, the VAR2 responsible states that it is necessary to create a protocol to ensure the ability (consultation with doctors) of each worker to use this technology. It is not recommended for people who suffer, for example, from binocular vision anomalies, heart disease or other serious medical conditions. It is also not recommended to use the virtual reality glasses if the worker is tired, sleep deprived or with other common problems. Therefore, a mini-test before use is important.

The company VAR3 validates the maintenance or machine set-up designs remotely in 3D. This reduces the necessary transport (even at an international level), which decreases the risk of accidents on route. Furthermore, the training techniques offered to deal with risk situations are very helpful as an awareness-raising action to reduce accidents. In addition, this technology allows to evaluate the processes avoiding entering risk areas. The manager believes the importance of delimiting the area of use in the plant, option that this technology incorporates (see Fig. 1).

5. Discussion

As stated in several papers published in the academic literature [21,23,25] I40Ts has a big impact in OHS risks. In general, all the I4OTs analysed help to reduce physical, and mechanical risks and most of them, to improve the ergonomics of the workers (except CS) as it can be seen in Fig. 2.

According to Kaivo-Oja et al. [45] each I40T could decrease physical risks (medium-high reductions), albeit in different ways. Specifically, IoT is the technology that has the most positive impact on reducing physical risks. As regards chemical risks, positive evidences have been identified in their reduction by means of CS, IoT and RB (as Pisa et al. [49] stated) technologies. However, negative evidences have been detected for AM that increase the chemical risks (medium level). As far as biological risks are concerned, only evidences of reduction related with CS and RBs have been found but there is not much evidence. In times of COVID, teleworking is becoming a usual practice and the CS is more necessary. As mentioned by Siemieniuch et al. [52], an improvement in the impact of I40T on workers' ergonomics has been detected, except in the case of CS technology, with AM having the most positive impact. In some cases, the prevention of psychosocial risks and the reduction of stress have been identified as the contribution of AI, AV, CS, RB and VAR technologies. Finally, evidences of influences on the reduction of mechanical risks in industry that confirms the studies of Beetz et al. [56], Mattsson et al. [57] and Mueller et al. [58] have been detected. IoT has the most positive impact on mechanical risks.

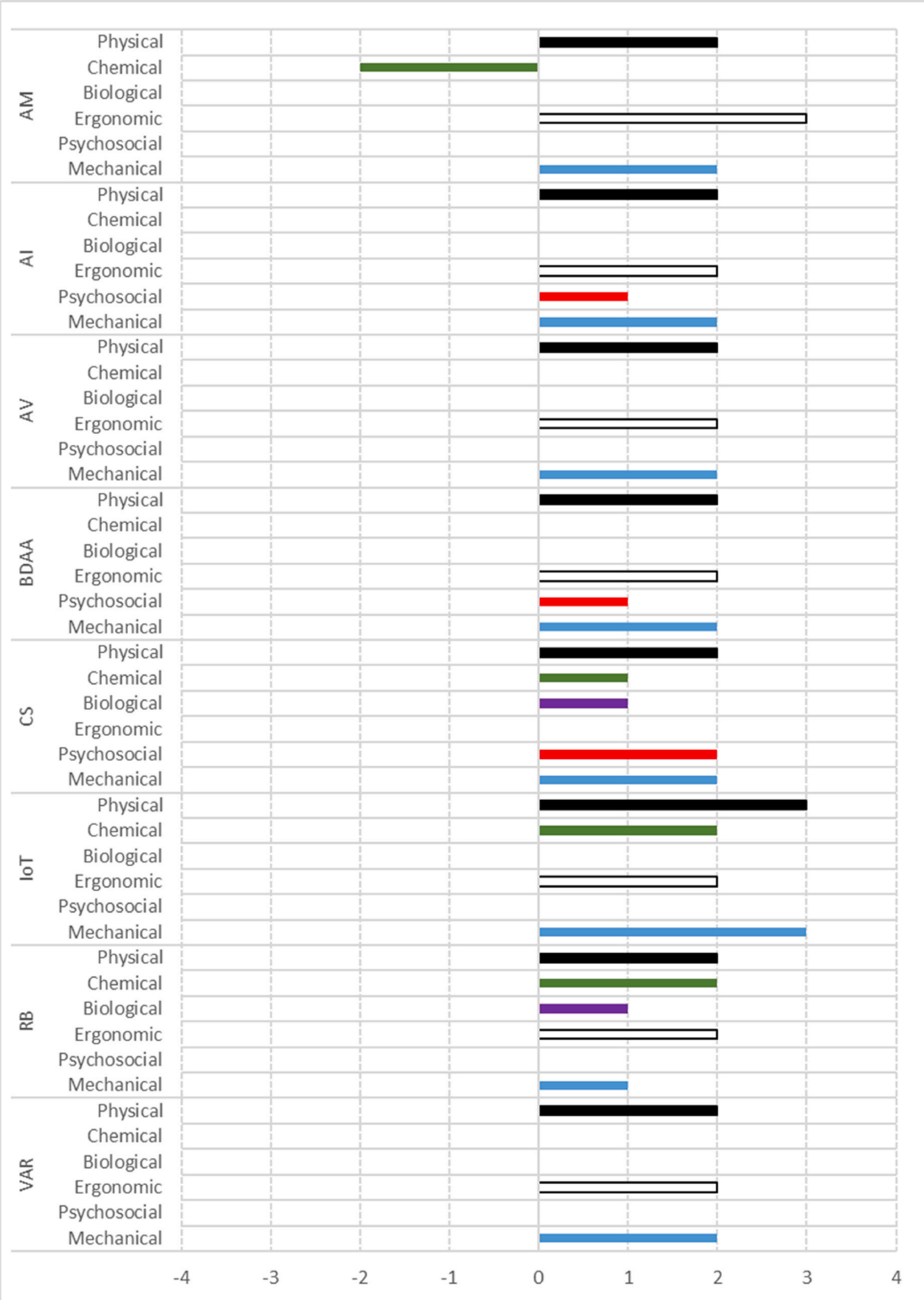
On the other hand, in line with the contribution of Stacey et al. [74], NERs have been detected in all technologies except in IoT technology. In addition, some evidences of new psychosocial risks are quite strong for all the technologies, except for AM. Mainly, the adaptation process can increase the stress or anxiety level of the employees for different reasons: fear of losing their jobs, loss of control over their future work, dangerous situation due to the use of glasses or the feeling of being more controlled. This is important, since these risks are often difficult to detect in workers and it is necessary to train and have clear protocols for their correct identification. In more than one technology (BDAA, RB and VAR), evidences of new mechanical risks have also been found. Mainly, they are related with the remote start-up of machines or with the danger of workers leaving the comfort zone in the factory using virtual glasses. Finally, new low-intensity chemical (AM) and biological (AI) point risks have been identified. For example, certain toxic additives, used for AM processes, can provoke allergic reactions.

6. Conclusions and limitations

The 21st century has been marked by an increase in the speed of technological developments worldwide. These developments have created a greater need for companies to change their processes and adapt to new social and market needs. In general, these changes are associated with an increase in the technological level of companies, which often contributes to changes in the employees' working conditions. However, in general, companies and academic literature have focused on the influence of the implementation of I40Ts on competitiveness and not on OHS issues.

However, this research confirms the need to investigate in more detail the effects of the integration of Industry 4.0-based applications on OHS and to generate knowledge in this field, as pointed out by Serap [96]. This article sheds light on the lack of existing academic work on a topic as relevant to society as the safety and well-being of workers. Moreover, the study contributes to analyse the consequences of these integrations on OHS using the same pattern of evaluation and research pattern for all technologies. Specifically, the risks and opportunities generated by the integration of these technologies on OHS are evaluated. In addition, the main influences that each technology may have on traditional risks and on NERs are also researched. These contributions are made in an area that requires increasingly rapid changes in the manner of working and with shorter adaptation periods.

Their most relevant influences of all the technologies are those affecting the indicators of physical and mechanical risks. In addition, the evidences of influences in the improvements of the ergonomic of the workers should be highlighted. For these reasons, it is confirmed that the implementation of I40Ts can be used as a measure to improve OHS management. As it has been shown, each



(caption on next page)

Fig. 2. Influence of Industry 4.0 technologies on occupational health and safety. Notes: level of impact on each risk as a nine-point Likert-type item, from a very negative potential influence -4 to a very positive potential influence +4. Source: developed by the authors.

technology generates different OHS effects and for this motive, it is necessary to design its implementation appropriately. However, they create NERs that have to be managed. It is necessary to draw up guidelines in order to minimise the specific consequences of each of the NERs detected in the implementation of each I40T. These NERs depends of the I40T adopted and its form of application. Therefore, the results obtained in this research could have implications for managers of industrial companies, workers of OHS departments and policy makers.

Managers and workers responsible for OHS at work should take into account the NERs [97]. Some of these NERs are related to the stress and anxiety created by the necessary changes in the processes. Sometimes, these risks are hidden from workers or the management team. Therefore, from the initial stages of the implementation process, it is necessary to prevent them. This prevention requires improved communication and training to involve workers in the change. In this regard, it would be advisable to select good practices of I40T implementations, including management guidelines, with specific information about the NERs to be taken into consideration in the management systems of the companies.

The main reasons to promote the implementation of I40Ts of the policy makers are related with the improvement of the competitiveness [4,5] and the results of this article add some evidences of the positive influences of I40Ts on the OHS risks in different industries, contributing to improving the OHS of workers. In addition, SMEs need more encouragement to use I40Ts from policy-makers, as large firms generally have fewer problems to make the necessary investment. Otherwise, the gap that separates SMEs and large firms in OHS issues will widen in the future.

Nevertheless, the limitations of this study should not be overlooked. The sample of companies analysed to carry out in the first phase was low. To cover this gap, the qualitative methodology has been included in the design of the research. Another point is that it would be necessary to collect the opinions of all the stakeholders in the diffusion of the I40Ts in the different industrial sub-sectors.

7. Open issues

Future lines of research should address these limitations. For example, the influence of each I40T should be analysed with a larger sample and at a future stage in the dissemination of the I40Ts. It would also be interesting to carry out this research in different industrial sectors and take into account the NERs. In addition, the perspective of each stakeholder (workers, managers, suppliers, policy makers or consultants) concerning these I40T implementations needs to be studied in depth to find ways to improve the OHS in companies.

In addition, there is already talk of Industry 5.0 where it seems that new technologies will serve to put the focus on citizenship. This opens new avenues of study to continue analyzing the immersion of 4.0 technologies such as artificial intelligence or collaborative robots in work environments.

Author contribution statement

Germán Arana-Landín: Conceived and designed the experiments; Analysed and interpreted the data; Wrote the paper.

Iker Laskurain-Iturbe, PhD: Conceived and designed the experiments; Performed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Mikel Iturrate: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data.

Beñat Landeta-Manzano: Performed the experiments; Analysed and interpreted the data; Contributed reagents, materials, analysis tools or data.

Funding statement

This study was funded by the Basque Autonomous Government (Research Group GIC-IT1691-22) and Euskampus foundation within the ZIRBOTICS and SOFIA projects (Misiones Euskampus 1.0 y 2.0).

Data availability statement

The data that has been used is confidential.

Declaration of interest's statement

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

We acknowledge the technical and human support provided by Centre de Documentation et de Recherches Européennes

(Université de Pau et des pays de l'Adour) and the Environmental Sustainability and Health Institute (Technological University Dublin).

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.heliyon.2023.e13720.

References

[1] H. Kagermann, J. Helbig, A. Hellinger, W. Wahlster, Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry; Final Report of the Industrie 4.0 Working Group. Forschungsunion, 2013.
[2] M. Ghobakhloo, The future of manufacturing industry: a strategic roadmap toward Industry 4.0, J. Manuf. Technol. Manag. 29 (6) (2018) 910–936, https://doi.org/10.1108/JMTM-02-2018-0057.
[3] K. Schwab, The Fourth Industrial Revolution, Currency, 2017.
[4] A. Adriaensen, W. Decré, L. Pintelon, Can complexity-thinking methods contribute to improving occupational safety in industry 4.0? A review of safety analysis methods and their concepts, Saf. Now. 5 (4) (2019) 65, https://doi.org/10.3390/safety5040065.
[5] I.D.L. Bogle, A perspective on smart process manufacturing research challenges for process systems engineers, Engineering 3 (2) (2017) 161–165, https://doi.org/10.1016/J.ENG.2017.02.003.
[6] A. Jamwal, R. Agrawal, M. Sharma, A. Giallanza, Industry 4.0 technologies for manufacturing sustainability: a systematic review and future research directions, Appl. Sci. 11 (12) (2021) 5725.
[7] M. Anshari, M.N. Almunawar, Adopting open innovation for SMEs and industrial revolution 4.0, J. Sci. Tech. Policy Manag. (2021).
[8] H.M. Elhusseiny, J. Crispim, SMEs, barriers and opportunities on adopting industry 4.0: a review, Procedia Comput. Sci. 196 (2022) 864–871.
[9] V. Alonso, A. Dacal-Nieto, L. Barreto, A. Amaral, E. Rivero, Industry 4.0 implications in machine vision metrology: an overview, Procedia Manuf. 41 (2019) 359–366.
[10] L.S. Dalenogare, G.B. Benitez, N.F. Ayala, A.G. Frank, The expected contribution of Industry 4.0 technologies for industrial performance, Int. J. Prod. Econ. 204 (2018) 383–394, https://doi.org/10.1016/j.ijpe.2018.08.019.
[11] D. Fettermann, C.G.S. Cavalcante, T.D.D. Almeida, G.L. Tortorella, How does Industry 4.0 contribute to operations management? J. Indust. Prod. Eng. 35 (4) (2018) 255–268, https://doi.org/10.1080/21681015.2018.1462863.
[12] I. Gibson, D.W. Rosen, B. Stucker, Additive Manufacturing Technologies, vol. 17, Springer, New York, 2014.
[13] D. Preuveneers, E. Ilie-Zudor, The intelligent industry of the future: a survey on emerging trends, research challenges and opportunities in Industry 4.0, J. Ambient Intell. Smart Environ. 9 (3) (2017) 287–298, https://doi.org/10.3233/AIS-170432.
[14] R. Schmidt, M. Möhring, R.C. Härting, C. Reichstein, P. Neumaier, P. Jozinović, Industry 4.0 - potentials for creating smart products: empirical research results, in: Lecture Notes in Business Information Processing, 2015, pp. 16–27, https://doi.org/10.1007/978-3-319-19027-3_2.
[15] F. Brocal, C. González, D. Komljenovic, P.F. Katina, M.A. Sebastián, Emerging risk management in industry 4.0: an approach to improve organizational and human performance in the complex systems, Complexity (2019).
[16] D. Marchand, K. Weiss, B. Zouhri, Emerging risks and quality of life: towards new dimensions of wellbeing? in: G. Fleury-Bahi, et al. (Eds.), Handbook of Environmental Psychology and Quality of Life Research, International Handbooks of Quality-of-Life, 2017. http://10.1007/978-3-319-31416-7_29.
[17] L. Botti, C. Mora, A. Regattieri, Integrating ergonomics and lean manufacturing principles in a hybrid assembly line, Comput. Ind. Eng. 111 (2017) 481–491.
[18] D.C. Darabont, R.I. Moraru, A.E. Antonov, C. Bejinariu, Managing new and emerging risks in the context of ISO 45001 standard, Calitatea 18 (S1) (2017) 1–11.
[19] ISO, ISO 45001:2018 – Occupational Health and Safety Management Systems – Requirements with Guidance for Use, International Organization for Standardization, Geneva, Switzerland, 2018.
[20] A. Badri, B. Boudreau-Trudel, A.S. Souissi, Occupational health and safety in the industry 4.0 era: a cause for major concern? Saf. Sci. 109 (2018) 403–411, https://doi.org/10.1016/j.ssci.2018.06.012. B.V.
[21] J. Smallwood, C. Allen, Practitioners' perceptions of the potential impact of Industry 4.0 on construction health and safety, J. Eng. Des. Technol. (2022) (ahead-of-print).
[22] A. Kumar, R. Agrawal, V.A. Wankhede, M. Sharma, E. Mulat-Weldemeskel, A framework for assessing social acceptability of industry 4.0 technologies for the development of digital manufacturing, Technol. Forecast. Soc. Change 174 (2022), 121217.
[23] M. Javaid, A. Haleem, R.P. Singh, R. Suman, E.S. Gonzalez, Understanding the adoption of Industry 4.0 technologies in improving environmental sustainability, Sust. Operat. Computers (2022).
[24] A. Adem, E. Çakit, M. Dağdeviren, Occupational health and safety risk assessment in the domain of Industry 4.0, SN Appl. Sci. 2 (5) (2020) 1–6.
[25] R. Zorzenon, F.L. Lizarelli, B.D.A. Daniel, What is the potential impact of industry 4.0 on health and safety at work? Saf. Sci. 153 (2022), 105802.
[26] M. Bortolini, E. Ferrari, M. Gamberi, F. Pilati, M. Faccio, Assembly system design in the Industry 4.0 era: a general framework, IFAC-PapersOnLine 50 (1) (2017) 5700–5705, https://doi.org/10.1016/j.ifacol.2017.08.1121.
[27] I. Laskurain-Iturbe, G. Arana-Landín, B. Landeta-Manzano, N. Uriarte-Gallastegi, Exploring the influence of industry 4.0 technologies on the circular economy, J. Clean. Prod. 321 (2021), 128944.
[28] M. Rubmann, M. Lorenz, P. Gerbert, M. Waldner, J. Justus, P. Engel, M. Harnisch, Industry 4.0: the future of productivity and growth in manufacturing industries, Boston Consult. Group 9 (1) (2015) 54–89.
[29] T. Stock, G. Seliger, Opportunities of sustainable manufacturing in industry 4.0, Procedia CIRP 40 (2016) 536–541, https://doi.org/10.1016/j.procir.2016.01.129.
[30] J. Lee, H. Davari, J. Singh, V. Pandhare, Industrial Artificial Intelligence for industry 4.0-based manufacturing systems, Manufact. Letters 18 (2018) 20–23, https://doi.org/10.1016/j.mfglet.2018.09.002.
[31] J.A.A. Daza, Aplicaciones del procesamiento automático de imágenes en la ingeniería de tráfico", Instituto Mexicano del Transporte Sanfandila, 2018.
[32] Y. Lecun, Y. Bengio, G. Hinton, Deep learning, Nature 521 (2015) 436–444, https://doi.org/10.1038/nature14539.
[33] K. Witkowski, Internet of things, big data, industry 4.0 - innovative solutions in logistics and supply chains management, Procedia Eng. 182 (2017) 763–769, https://doi.org/10.1016/j.proeng.2017.03.197.
[34] L. Thames, D. Schaefer, Cybersecurity for Industry 4.0 Springer Series in Advanced Manufacturing. Analysis for Design and Manufacturing, Springer, 2017.
[35] C. Wittenberg, Human-CPS Interaction - requirements and human-machine interaction methods for the Industry 4.0, IFAC-PapersOnLine 49 (19) (2016) 420–425, https://doi.org/10.1016/j.ifacol.2016.10.602.
[36] I. Lee, K. Lee, The internet of things (IoT): applications, investments, and challenges for enterprises, Bus. Horiz. 58 (4) (2015) 431–440, https://doi.org/10.1016/j.bushor.2015.03.008.
[37] B. Siciliano, O. Khatib, Springer Handbook of Robotics, 2016 (Springer).
[38] G.C. Burdea, P. Coiffet, Virtual Reality Technology, 2003, ISBN 978-0-471-36089-6. Wiley Interscience.
[39] V. Paelke, Augmented reality in the smart factory: supporting workers in an industry 4.0. environment, in: 19th IEEE International Conference on Emerging Technologies and Factory Automation, ETFA 2014, 2014, https://doi.org/10.1109/ETFA.2014.7005252.

[40] D. Podgórski, K. Majchrzycka, A. Dąbrowska, G. Gralewicz, M. Okrasa, Towards a conceptual framework of OSH risk management in smart working environments based on smart PPE, ambient intelligence and the Internet of Things technologies, Int. J. Occup. Saf. Ergon. 23 (1) (2017) 1–20, https://doi.org/10.1080/10803548.2016.1214431.
[41] B.H.W. Guo, T.W. Yiu, V.A. González, Predicting safety behavior in the construction industry: development and test of an integrative model, Saf. Sci. 84 (2016) 1–11, https://doi.org/10.1016/j.ssci.2015.11.020.
[42] P.V. Moore, OSH and the future of work: benefits and risks of artificial intelligence tools in workplaces, in: International Conference on Human-Computer Interaction, Springer, Cham, 2019, pp. 292–315, https://doi.org/10.1007/978-3-030-22216-1_22.
[43] M. Fallaha, Z.M. Cinar, O. Korhan, Q. Zeeshan, Operator 4.0 and Cognitive Ergonomics, Springer, Cham, 2020, pp. 217–228, https://doi.org/10.1007/978-3-030-42416-9_20.
[44] J.R. Gisbert, C. Palau, M. Uriarte, G. Prieto, J.A. Palazón, M. Esteve, O. López, J. Correas, M.C. Lucas-Estañ, P. Giménez, A. Moyano, L. Collantes, J. Gozálvez, B. Molina, O. Lázaro, A. González, Integrated system for control and monitoring industrial wireless networks for labor risk prevention, J. Netw. Comput. Appl. 39 (1) (2014) 233–252, https://doi.org/10.1016/j.jnca.2013.07.014.
[45] J. Kaivo-Oja, P. Virtanen, H. Jalonen, J. Stenvall, The effects of the internet of things and big data to organizations and their knowledge management practices, Lect. Notes Bus. Info. Proces. 224 (2015) 495–513, https://doi.org/10.1007/978-3-319-21009-4_38.
[46] Z. Li, Y. Wang, K.S. Wang, Intelligent predictive maintenance for fault diagnosis and prognosis in machine centers: industry 4.0 scenario, Advan. Manufact. 5 (4) (2017) 377–387, https://doi.org/10.1007/s40436-017-0203-8.
[47] F. Longo, L. Nicoletti, A. Padovano, Smart operators in industry 4.0: a human-centered approach to enhance operators' capabilities and competencies within the new smart factory context, Comput. Ind. Eng. 113 (2017) 144–159, https://doi.org/10.1016/j.cie.2017.09.016.
[48] N. Uriarte-Gallastegi, B. Landeta-Manzano, G. Arana-Landín, I. Laskurain-Iturbe, Environmental benefits and weaknesses of additive manufacturing processes in the business sector. key players influencing the environmental impact of digital manufacturing technologies, Dyna 95 (2020) 587–590, https://doi.org/10.6036/9657.
[49] R. Pisa, T. Cupido, J.B. Steinman, N.H. Jones, T.M. Kapoor, Analyzing resistance to design selective chemical inhibitors for AAA proteins, Cell Chemical Biol. 26 (9) (2019) 1263–1273.e5, https://doi.org/10.1016/j.chembiol.2019.06.001.
[50] D.S. Ogunyale, R.V. Mayorga, A Fuzzy Inference Systems Approach for Risk Evaluation of Dairy Products Manufacturing Systems, vol. 2, 2017. http://www.iaras.org/iaras/journals/ijcsr.
[51] T. Ahmad, Corona virus (COVID-19) pandemic and work from home: challenges of cybercrimes and cybersecurity, SSRN Electron. J. (2020), https://doi.org/10.2139/ssrn.3568830.
[52] C.E. Siemieniuch, M.A. Sinclair, M.J.C. Henshaw, Global drivers, sustainable manufacturing and systems ergonomics, Appl. Ergon. 51 (2015) 104–119, https://doi.org/10.1016/j.apergo.2015.04.018.
[53] T.P. Carvalho, F.A. Soares, R. Vita, R.D.P. Francisco, J.P. Basto, S.G. Alcalá, A systematic literature review of machine learning methods applied to predictive maintenance, Comput. Ind. Eng. 137 (2019), 106024, https://doi.org/10.1016/j.cie.2019.106024.
[54] J.M. Müller, D. Kiel, K.-I. Voigt, What drives the implementation of industry 4.0? The role of opportunities and challenges in the context of sustainability, Sustainability 10 (1) (2018) 247, https://doi.org/10.3390/su10010247.
[55] M.L. Cantonnet, J.C. Aldasoro, J. Iradi, New and emerging risks management in small and medium-sized Spanish enterprises, Saf. Sci. 113 (2019) 257–263, https://doi.org/10.1016/j.ssci.2018.11.032.
[56] M. Beetz, G. Bartels, A. Albu-Schaffer, F. Balint-Benczedi, R. Belder, D. Bebler, S. Haddadin, A. Maldonado, N. Mansfeld, T. Wiedemeyer, R. Weitschat, J. H. Worch, Robotic agents capable of natural and safe physical interaction with human co-workers, IEEE Int. Conf. Intellig. Robots Sys. (2015) 6528–6535, https://doi.org/10.1109/IROS.2015.7354310.
[57] S. Mattsson, J. Partini, Å. Fast-Berglund, Evaluating four devices that present operator emotions in real-time, Procedia CIRP 50 (2016) 524–528, https://doi.org/10.1016/j.procir.2016.05.013.
[58] E. Mueller, X.-L. Chen, R. Riedel, Challenges and requirements for the application of industry 4.0: a special insight with the usage of cyber-physical system, Chin. J. Mech. Eng. 30 (5) (2017) 1050–1057, https://doi.org/10.1007/s10033-017-0164-7.
[59] G.W. Vogl, B.A. Weiss, M. Helu, A review of diagnostic and prognostic capabilities and best practices for manufacturing, J. Intell. Manuf. 30 (1) (2019) 79–95, https://doi.org/10.1007/s10845-016-1228-8.
[60] J.A. Palazon, J. Gozalvez, J.L. Maestre, J.R. Gisbert, Wireless solutions for improving health and safety working conditions in industrial environments, in: 2013 IEEE 15th International Conference on E-Health Networking, Applications and Services, Healthcom, 2013, pp. 544–548, https://doi.org/10.1109/HealthCom.2013.6720736.
[61] S.S. Kamble, A. Gunasekaran, S.A. Gawankar, Sustainable Industry 4.0 framework: a systematic literature review identifying the current trends and future perspectives, Process Saf. Environ. Protect. 117 (2018) 408–425, https://doi.org/10.1016/j.psep.2018.05.009.
[62] ESENER, Third European Survey of Enterprises on New and Emerging Risks (ESENER 3), 2019. European Agency for Safety and Health at Work. Available at: https://osha.europa.eu/en/publications/third-european-survey-enterprises-new-and-emerging-risks-esener-3/view.
[63] R.K. Mehta, Integrating physical and cognitive ergonomics, IIE Trans. Occup. Ergon. Hum. Factors (2016), https://doi.org/10.1080/21577323.2016.1207475, 83–7.
[64] D. Romero, P. Bernus, O. Noran, J. Stahre, Å.F. Berglund, The operator 4.0: human cyber-physical systems & adaptive automation towards human-automation symbiosis work systems, IFIP Adv. Inf. Commun. Technol. 488 (2016) 677–686, https://doi.org/10.1007/978-3-319-51133-7_80. , Springer New York LLC; 2016.
[65] M. Alvesson, A. Spicer, A Stupidity-Based theory of organizations, J. Manag. Stud. 49 (7) (2012) 1194–1220.
[66] M. Alvesson, A. Spicer, The Stupidity Paradox: the Power and Pitfalls of Functional Stupidity at Work, 2016 (Profile Books).
[67] R. Paulsen, Slipping into functional stupidity: the bifocality of organizational compliance, Hum. Relat. 70 (2) (2017) 185–210.
[68] P.E. Love, J. Smith, F. Ackermann, Z. Irani, The praxis of stupidity: an explanation to understand the barriers mitigating rework in construction, Prod. Plann. Control 29 (13) (2018) 1112–1125.
[69] J.M. Bradshaw, V. Dignum, C. Jonker, M. Sierhuis, Human-agent-robot teamwork, IEEE Intell. Syst. 27 (2) (2012) 8–13.
[70] F.G. Filip, A decision-making perspective for designing and building information systems, Int. J. Comput. Commun. Control 7 (2) (2014) 264–272.
[71] EU-OSHA, Digitalisation and occupational safety and health (OSH), Eur. Agen. Safety Health Work (2019). Available at: https://osha.europa.eu/en/publications/digitalisation-and-occupational-safety-and-health-osh-eu-osha-research-programme/view.
[72] EU-OSHA, Impact of artificial intelligence on occupational safety and health, Eur. Agen. Saf. Heal. Work (2021). Available at: https://osha.europa.eu/en/publications/impact-artificial-intelligence-occupational-safety-and-health/view.
[73] P. Ellwood, J. Reynolds, M. Duckworth, Green jobs and occupational safety and health: foresight on new and emerging risks associated with new technologies by 2020, Luxemb Eur. Agen. Saf. Heal Work (2014).
[74] N. Stacey, P. Ellwood, S. Bradbrook, J. Reynolds, H. Williams, Key trends and drivers of change in information and communication technologies and work location Foresight on new and emerging risks in OSH Working report, Eur. Agen. Saf. Heal. Work (2017).
[75] I. Dumitraşcu-Băldău, D.D. Dumitraşcu, Occupational emerging risks affecting international virtual project Team Results, in: MATEC Web of Conferences vol. 121, 2017, 07003 (EDP Sciences).
[76] F. Brocal, C. González, M.A. Sebastián, Technique to identify and characterize new and emerging risks: a new tool for application in manufacturing processes, Saf. Sci. 109 (2018) 144–156, https://doi.org/10.1016/j.ssci.2018.05.005.
[77] A.R. Ramos-Rodríguez, J. Ruíz-Navarro, Changes in the intellectual structure of strategic management research: a bibliometric study of the Strategic Management Journal, Strat. Manag. J. 25 (10) (2004) 1980–2000, 981-1004.
[78] SPRI, BIND 4.0 | Industry 4.0 Accelerator Program in Basque Country, 2022. Source: https://bind40.com/.

[79] European Comission, Winners of the EEPA Prize and Small and Mid-cap Awards Announced during the SME Assembly | Internal Market, Industry, Entrepreneurship and SMEs, 2020. Available at: https://ec.europa.eu/growth/content/winners-EEPA-prize-small-mid-cap-awards-announced-sme-assembly_en. (Accessed 3 February 2021). Accessed:.
[80] A. Schumacher, S. Erol, W. Sihn, A maturity model for assessing industry 4.0 readiness and maturity of manufacturing enterprises, Procedia CIRP 52 (2016) 161–166, https://doi.org/10.1016/j.procir.2016.07.040.
[81] M.K. Malhotra, V. Grover, An assessment of survey research in POM: from constructs to theory, J. Oper. Manag. 16 (4) (1998) 407–425, https://doi.org/10.1016/s0272-6963(98)00021-7.
[82] K.M. Eisenhardt, Building theories from case study research, Acad. Manag. Rev. 14 (4) (1989) 532–550.
[83] R.K. Yin, Case Study Research and Applications: Design and Methods. Sage Publications, 2017.
[84] B.G. Glaser, A.L. Strauss, Discovery of Grounded Theory: Strategies for Qualitative Research. Routledge, 2017.
[85] M.B. Miles, A.M. Huberman, J. Saldaña, Qualitative Data Analysis: A Methods Sourcebook. Sage Publications, 2018.
[86] N.K. Denzin, The work of little children, Sociol. Educ. 12 (1978) 316.
[87] T.O. Nyumba, K. Wilson, C.J. Derrick, N. Mukherjee, The use of focus group discussion methodology: insights from two decades of application in conservation, Methods Ecol. Evol. 9 (1) (2018) 20–32.
[88] M. Gibbert, W. Ruigrok, B. Wicki, What passes as a rigorous case study? Strat. Manag. J. 29 (13) (2008) 1465–1474.
[89] V.A. Thurmond, The point of triangulation, J. Nurs. Scholarsh. 33 (3) (2001) 253–258.
[90] J.W. Creswell, V.L.P. Clark, Designing and conducting mixed methods research, Aust. N. Z. J. Publ. Health 31 (4) (2007) 388, https://doi.org/10.1111/j.1753-6405.2007.00096.x.
[91] N.V. Ivankova, J.W. Creswell, S.L. Stick, Using mixed-methods sequential explanatory design: from theory to practice, Field Methods 18 (1) (2006) 3–20, https://doi.org/10.1177/1525822X05282260.
[92] S.F. Turner, L.B. Cardinal, R.M. Burton, Research design for mixed methods: a triangulation-based framework and roadmap, Organ. Res. Methods 20 (2) (2017) 243–267.
[93] L. Spencer, J. Ritchie, J. Lewis, L. Dillon, Quality in Qualitative Evaluation: a Framework for Assessing Research Evidence, 2004.
[94] C. Blome, T. Schoenherr, Supply chain risk management in financial crises-A multiple case-study approach, Int. J. Prod. Econ. 134 (1) (2011) 43–57.
[95] A.M. Riege, Validity and reliability tests in case study research: a literature review with "hands-on"applications for each research phase, Qual. Mark. Res. Int. J. 6 (2) (2003) 75–86.
[96] T.E.P.E. Serap, The impact of industry 4.0 on occupational health and safety, Int. J. Advan. Eng. Pure Sci. 33 (1) (2021) 122–130.
[97] J. Tupa, J. Simota, F. Steiner, Aspects of risk management implementation for industry 4.0, Procedia Manuf 11 (2017) 1223–1230, https://doi.org/10.1016/j.promfg.2017.07.248.