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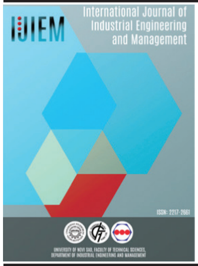

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Review article

Assessing the Psychosocial Impacts of Industry 4.0 Technologies Adoption in the Operator 4.0: Literature Review & Theoretical Framework

R. Adattil[a], P. Thorvald[a], D. Romero[b,*]

[a] *University of Skövde, Skövde, Sweden;*
[b] *Tecnológico de Monterrey, Mexico City, Mexico*

ABSTRACT

Emerging digital and smart technologies, including wearable and collaborative ones, related to the Industry 4.0 paradigm are playing an assisting, collaborative, and augmenting role for the Operator 4.0, and just as in previous industrial revolutions, the nature of work and the workplace for operators on the shop floor is changing. This literature review aims to look into the impact of digital and smart technologies adoption on the workers' psychosocial stage under the light of the Operator 4.0 typology. Based on the review conducted, a theoretical framework for assessing the psychosocial impacts (risks) of Industry 4.0 technologies adoption in Operator 4.0 is proposed. The framework can be utilized by company managers, researchers, production engineers, and human resources personnel for carrying out a psychosocial risk assessment of Operator 4.0 in assembly, maintenance, and training operations as these operations get digitally transformed and smartified based on self-report questionnaires. Findings reveal that the nature of work, the social and organizational environment of work, and related individual factors are key categories that might affect the Operator 4.0 psychosocial stage on the shop floor.

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*Corresponding author:
David Romero
david.romero.diaz@gmail.com

1. Introduction

Regarding automation and data-sharing technology, the *Fourth Industrial Revolution* (or Industry 4.0) highlights recent trends in manufacturing industries. *Industry 4.0* refers to the integration of the Internet and factory automation to improve productivity with the use of smart sensors and Artificial Intelligence (AI) for assisting manufacturing processes linked with machines [1]. The main characteristics, in terms of technologies, of the Industry 4.0 paradigm consist of Cyber-Physical Systems (CPS), Augmented Reality or Virtual Reality (AR/VR), the Internet of Things (IoT), the Internet of Services (IoS), Additive Manufacturing (AM), Big Data Analytics (BDA), Autonomous & Collaborative Robots, Cloud Computing, and Advanced Simulations (like Digital Twins). In terms of task functions and interfaces with running equipment, the Industry 4.0 paradigm changes the

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role of the human operator on the shop floor. This leads to the creation of new forms of workforce interaction (i.e., human-human/machine/robot/AI) and data exchange referred to as the *Operator 4.0 types* [2], which are aided by advanced digital and smart technologies such as AR, VR, collaborative robots (cobots), exoskeletons, wearable devices, social enterprise networks, and big data analytics. All of these (smart) wearable and collaborative technologies impact the *Operator 4.0 physical, psychological, and social responses* in the workplace, either favorably or unfavorably [3]. Hence, the goal of this research work is *to study how the Operator 4.0 typology [2] might affect the operators' psychosocial work environment (i.e. the shop floor)*.

As further context and motivation for this research work, the impact of new technologies on shop floor operators has been a recurring theme in *occupational health physiology* for several decades [4] and more recently the *physical, psychological, and social implications* of novel digital and smart technologies adoption, particularly wearable and collaborative ones, have been a topic of particular interest in the light of the Fourth Industrial Revolution and its technologies [5]-[7]. New shop floor technologies are usually introduced to facilitate physical and cognitive work, but undesirable side effects may occur in the workforce and work environment that were not foreseen upon their adoption such as stress, fatigue, musculoskeletal disorders, etc. [5]-[7]. Thus, modifications to work and working conditions must be studied as part of Industry 4.0 technologies adoption on the shop floor to understand traditional and new emerging occupational health and safety risks for the *Operator 4.0* [6]. Hence, the use of *psychosocial impact assessments* as part of Industry 4.0 technologies adoption initiatives is imperative to address "human sustainability" in modern shop floors in terms of safer work environments and healthier workers, contributing in this way to "human-centric approaches" for digital and smart technologies adoption that aim to enhance operators' productivity at the same time that safeguards their occupational health and safety.

To do so, this research work has conducted a literature review to identify and qualitatively analyze the *operators' psychosocial work environment risks* related to the adoption of the *Operator 4.0 typology* [2] on the shop floor and propose a *theoretical framework* that includes different *psychosocial risk assessment methods* for evaluating the *psychosocial impacts (risks)* of Industry 4.0 technologies adoption in the *Operator 4.0*.

2. Background

2.1 The Operator 4.0 Typology

The Fourth Industrial Revolution, or Industry 4.0, has been considered by many experts as a *technologically focused paradigm* consisting of various digital and physical enabling technologies for the future of manufacturing [1], [8]. While many of these enabling technologies inherently involve "humans" such as AR and VR headsets, wearable IoT devices, and cobots applications as third-hands helping operators in their daily jobs, the focus remains on technologies themselves rather than on their successful application for the assistance, collaboration, or augmentation of human workers [9], [10]. Several attempts at shifting the focus to the "human factor", or rather introducing "human actors" to share the spotlight with technology have been proposed within the Industry 4.0 domain [11]. One of the first and, to date, one of the more widespread of these ideas is the "Operator 4.0 typology" [2]. Other examples of these efforts include the works compiled into the two journal special issues dedicated to the *Operator 4.0 vision* [12], [13].

The *Operator 4.0 typology* was first introduced by Romero et al. [2] as a "human-centric" vision for successfully adopting and implementing Industry 4.0 technologies in a smart factory. They introduced eight *Operator 4.0 types* linked with *Industry 4.0 technologies* with a vision of a "socially sustainable factory" and defined the *Operator 4.0* as "a smart and skilled operator who performs not only cooperative work with robots but also work aided by machines as and if needed by means of human cyber-physical systems, advanced human-machine interaction technologies, and adaptive automation towards human-automation symbiosis work systems" [14]. *Advanced Human-Machine Interaction (HMI)* is provided by human cyber-physical systems to improve the physical, cognitive, and sensing capabilities of operators, and *Adaptive Automation (AA)* aids in task distribution and human-machine interaction in the workplace, as well as in adjusting the level of automation when a significant event or a predetermined function is identified in production [14]. Moreover, the ACE Factories project investigated the concept of *Operator 4.0* in a white paper [15] and introduced five *Operator 4.0 types* based on the original typology by Romero et al. [2]. These are (i) the Augmented and Virtual Operator, (ii) the Social and Collaborative Operator, (iii) the Super-Strong Operator, (iv) the One-of-a-Kind Operator, and (v) the Healthy and Happy Operator. Unlike the original eight *Operator 4.0 types* [2], a

"One-of-a-Kind Operator" can adapt to the changing work environment because each operator has unique talents and skills [15]. Figure 1 presents the original eight *Operator 4.0 types* by Romero et al. [2].

Super-Strength Operator: The operator is supported with exoskeletons to improve his/her physical capabilities. Aimed to support operators with their physical activities and provide physical strength and assistance during manual operations to maintain their endurance and safety [2], [7], [15]-[17]. An *industrial exoskeleton* can be of a passive or powered type. An *industrial exoskeleton* uses hydraulics, electric motors, and pneumatics methods to power itself and thus provide physical power and support for operators in assembly and maintenance operations [18]. One of the considerations with *industrial exoskeletons* is their ability to physically support older workers to compensate for their age-lost strength and endurance in shop floor operations. Assistance for physical strength during assembly and maintenance operations enhances the "social sustainability" of the workforce as well as safety and accident reduction [2], [7], [15]-[17]. According to Perez Luque et al. [18] passive upper-body exoskeletons limit the range of motion for the operator in manufacturing operations aiding his/her occupational health and safety.

Augmented Operator: The operator is assisted with *AR-based technologies* and *AR-enabled devices* such as headsets and handhelds to strengthen an operator's cognitive capabilities. Using *AR-based technologies and devices*, the operator can receive information from the digital world overlaid in his/her actual physical environment and within his/her field of view. In assembly and maintenance operations, AR can aid operators in guiding them in complex assembly sequences and maintenance procedures [2], [7], [15]-[17].

Virtual Operator: The operator is assisted with *VR-based technologies* and *VR-enabled devices* to interact with 3D virtual models such as in the case of virtual product design. Product design engineers can see how different design implications affect a virtual product [2], [7], [15]-[17]. Another strong case for VR is operator training offering a safe and controlled interactive learning environment with emotional realism [2], [7], [15]-[17].

Healthy Operator: The operator is equipped with *wearable sensors* such as activity trackers to (self)monitor his/her physical and cognitive fitness throughout different industrial activities and tasks by measuring his/her biometrics like heart rate and oxygen levels so any physical and cognitive activity intensity is kept within well-being standards [2], [7], [15]-[17]. Furthermore, *wearables* with body position sensors can monitor the operator's body postures aiding in ergonomically optimum body postures in physically demanding jobs. Hence, *wearables (aggregated) data* could assist shop floor managers in analyzing operators' physical and mental workloads to improve their physical and mental well-being [2], [7], [15]-[17].

Smarter Operator: The operator is assisted by one or more *Intelligent Personal Assistants (IPAs)*. *IPAs* could assist operators with assembly and maintenance activities by providing step-by-step (voice) instructions for completing a complex assembly sequence or repair or by offering suggestions for troubleshooting problems [2], [7], [15]-[17]. Siri (Apple), Hey Google (Android), and Alexa (Amazon) are all examples of IPAs.

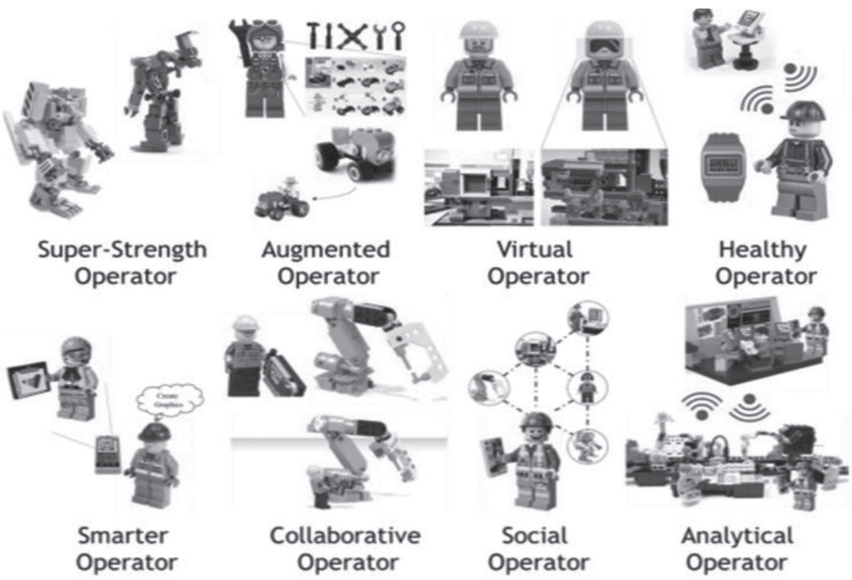

Figure 1. The Operator 4.0 Typology [2]

Collaborative Operator: The operator is aided by *collaborative robots* to improve his/her physical capabilities. In the work environment, *cobots* will take over or assist in the repetitive and non-ergonomic tasks of a job [2], [7], [15]-[17]. Romero et al. [2] mention that assistance with *cobots* improves the job satisfaction of the operators. Challenges in collaborative human-cobot work environments include considering the safety aspects of operators in the shared workspace with a *cobot* and providing adequate communication between humans and cobots [2], [7], [15]-[17].

Social Operator: The operator is supported by *social networking* to improve his/her cognitive interaction on the shop floor by facilitating real-time communication between human and non-human co-workers like cobots and IPAs. This enhanced communication allows operators to share ideas and improve problem-solving skills with the help of technology [2], [7], [15]-[17]. Romero et al. [2] argue that improved communication between co-workers helps to improve workforce engagement and data sharing as well as participation in decision-making.

Analytical Operator: The operator is assisted with *big data analytics* to strengthen his/her decision-making capabilities. *Big data analytics* collects a significant amount of data from sensors linked to various operations, which can then be analyzed to predict expected and unexpected disruptions in production [2], [7], [15]-[17]. The vision of introducing an "Analytical Operator" is to improve forecasts in manufacturing operations and better understand the performance of shop floor operations [2], [7], [15]-[17]. Romero et al. [2] mention, for example, that "Collaborative Operators" analyze data to ensure safe proximity to their cobot co-workers, "Healthy Operators" analyze their biometrics to better self-manage their physical and cognitive efforts, and "Smarter Operators" collaborate with their IPAs to combine their knowledge to troubleshooting problems. According to Ruppert et al. [16], the "Analytical Operator" uses IoT-based technologies to provide real-time feedback to the other Operator 4.0 types. Feedback may include task instruction support, hazard environment alerting, event noticing, and health-related parameter detection through displays, headsets, and handhelds.

2.2 Psychosocial Characteristics of the Work Environment

According to Rugulies [19], *psychosocial work environment* refers to "how the individual experiences and responds to his or her surroundings and thus the individual becomes the focus". Several things have an impact on the *psychosocial work environment* as depicted in Fig. 2 [20]. The type of work, the way of completing such work, the physical and cognitive demands of the job, and the tools used for working are all examples of these factors. *Workers' health and performance* may be affected by factors related to the *psychosocial work environment*. Some of the *risk factors* linked with a *psychosocial work environment* include work schedules, working hours, and other issues such as wage-related discrimination in the workplace [20].

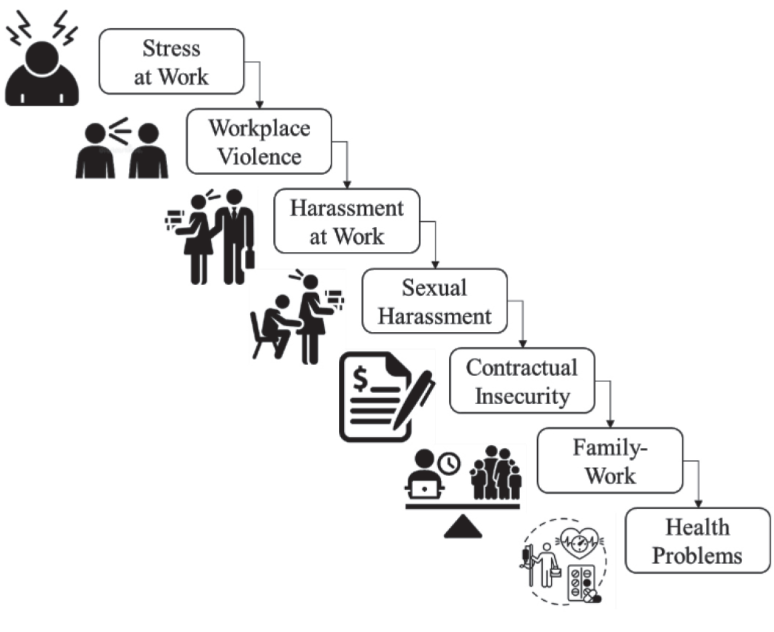

Figure 2. Factors Affecting the Psychosocial Work Environment of Operators [20]

Danasekaran & Govindasamy [21] said that *psychosocial impacts* related to the work environment make an impact on an operator's physical and psychological health, which impacts as a consequence the productivity of the organization. Moreover, *workplace stress* is one of the *psychosocial impacts* and happens for example when job demand is beyond the skill of operators. *Workplace stress* of operators leads to psychological problems like anxiety, occupation stress, depression, and later to health diseases including musculoskeletal disorders, hypertension, and gastrointestinal disorders. *Workplace stress* has societal consequences such as relationship conflict, increased bad behavior (i.e., drug and alcohol abuse), and economic loss [21].

Tables 1 and 2 summarize the sources of psychosocial factors and the related impacts of those factors based on the literature review conducted in this research work, using the well-established classification suggested by [22]. Both tables highlight the factors that are known determinants of *psychosocial stress* and *harmful to workers' health* [22, see also 23].

Table 1, in particular, presents a range of upstream determinants on *psychosocial health* in the workplace [22], addressing the *job characteristics* of occupations, for instance, their emotional demand nature [24], their level of participation in decision-making [25], or their level of pressure in work tasks [26], and the *changing nature of work* as the socio-economic and technological changes and the re-organization of work in relation to progress [27].

On the other hand, Table 2, presents a set of prominent sources of stress coming from *interpersonal relationships* within the *social and organizational context of work* (i.e., the workplace) [22], such as workplace discrimination [28], workplace bullying [29], workplace violence [30], and harassment [31], and *individual risks factors* that can predispose workers to *psychosocial perils* related to personality [32], gender, [33], deprivation [34], and non-work factors [35].

Lovelock [22] defines *psychosocial impact* as "the aspects of design and management of work and its social organizational contexts that may have the potential for causing psychological or physical harm". Lovelock further mentions other health effects of workplace stress including thyroid issues, migraine, and headaches. Individual issues and organizational factors can both contribute to workplace stress. Job demand, job satisfaction, social support, and absenteeism are all individual aspects that contribute [22].

3. Research Methodology

This research work was set to explore the relationship between the *Operator 4.0 typology* [2] and the *psychosocial work environment* [19]-[22] where it is envisioned. To do that, a *literature review* was the selected approach [36]. The *qualitative analysis* of published materials such as journal articles, conference papers, and book chapters was used for this study's analysis. The accessibility of the above-mentioned sources

Table 1. Sources and Impacts of Psychosocial Factors in the Work Environment Related to Job Characteristics [22]

Job Characteristics and the Nature of Work	
Job Content/Demands	• High physical, mental, and/or emotional demands. • Lack of variety. • Short work cycles. • Fragmented or meaningless work. • Under-utilization • High uncertainty. • Continuous exposure to people through work.
Workload/Workplace Stress	• Work overload or underload. • Machine pacing time pressure. • Deadlines
Work Schedule	• Shift working. • Inflexible work schedules. • Unpredictable hours • Long or unsocial hours.
Job Control	• Low participation in decision-making. • Lack of control over workloads.
Physical Environment and Equipment Issues	• Inadequate or faulty equipment. • Poor environmental conditions (viz.: space, light, noise, and thermal).

Table 2. Sources and Impacts of Psychosocial Factors in the Work Environment related to Organizational and Individual Factors [22]

Social and Organizational Context of Work	
Organizational Culture and Function	• Poor communications. • Low levels of support for problem-solving and personal development. • Lack of definition of organizational objectives.
Interpersonal Relationships at Work	• Social or physical isolation. • Poor relationship with superiors. • Interpersonal conflict. • Lack of social support.
Role in Organization	• Role ambiguity. • Role conflict. • Responsibility.
Career Development	• Career stagnation and uncertainty. • Under-promotion or over-promotion. • Poor pay. • Job security. • Low social value to work.
Individual Risk Factors	
Individual Difference	• Coping style. • Personality. • Hardiness. • Resilience.
Home-Work Interface	• Conflicting demands of work and home. • Low support at home. • Dual career problems.

does not interfere with the study because they are available at any time without any ethical issues.

Fink [37] categorizes the process of conducting a *literature review* in five steps, which were the ones followed for this study's analysis: (i) determining the study problem, (ii) collecting data – using keywords, (iii) screening the data, (iv) analyzing the findings, and (v) writing the review.

3.1 Study Problem

This *literature review* aims to investigate the combined concepts of the "Operator 4.0" and "psychosocial work environment" to assess the psychosocial impacts (risks) of Industry 4.0 technology adoption in the Operator 4.0 typology to propose a theoretical assessment framework.

3.2 Data Collection – Using Keywords

This study data collection was done by secondary sources collected from academic databases, namely Scopus, Web of Science, and Google Scholar, and published in English. Its period was from 2016 (the year when the "Operator 4.0" term was coined) to 2023 and covers only journal articles, conference papers, and book chapters. The primary analysis of the publications studied was done by an understanding of their keywords and themes to provide answers to the study problem.

As a starting point, the phrase "Impact of Industry 4.0 technologies adoption in the Operator 4.0 psychosocial stage in his/her work environment" was used to reveal primary keywords for searching: "Industry 4.0", "Technology Adoption", "Operator 4.0", "Psychosocial Stage", and "Work Environment". Other similar phrases were discovered after defining the primary keywords, which helped in the selection of appropriate publications for creating this literature review. Across the reading of the scientific literature, other terms linked to the primary keywords were discovered. Table 3 lists all primary and related keywords used as query strings.

Boolean expressions and keywords are used to search for documents. Mainly used Boolean expressions are, AND and OR. Some of the search strings are: "*Operator 4.0* AND *Impacts*", "*Operator 4.0* AND *Psychosocial Work Environment* AND *Impacts*", "*Augmented Reality* AND *Worker* AND *Challenges*", "*Operator 4.0* AND *Psychological* AND *Impacts* OR *Cognitive* AND *Challenges*", "*Cyber-Physical System* AND *Social Impacts*", "*Industry 4.0* AND *Impacts* OR *Social Challenges*", "*Operator 4.0* OR *Industry 4.0* AND *Social Interaction*", "*Exoskeleton* AND *Ben-*

Table 3. Primary (First Row) and Related Keywords used in Query Strings

Keyword 1	Keyword 2	Keyword 2	Keyword 3	Keyword 4	Keyword 5
Industry 4.0	Technology Adoption	Operator 4.0	Psychosocial Stage	Work Environment	
Industry 4.0	Operator 4.0	Psychosocial Work Environment	Physical Ergonomics	Cognitive Ergonomics	
Worker	Worker's Health	Physical Capabilities	Exoskeleton	Benefits	Musculoskeletal Disorder
Human Factors	Cognitive Capabilities	Augmented Reality	Social Interaction	Benefits	Difficulties
Human Factors	Cognitive Capabilities	Virtual Reality	Social Interaction	Benefits	Difficulties
Cyber-Physical Systems	Smart Operator	Social Operator	Healthy Operator	Physical Capabilities	Cognitive Capabilities

efits", and "*Operator 4.0* AND CHALLENGES". Only articles from the years 2016 to 2023 are considered. The search results are filtered using three levels of sorting. The first level of sorting is based on keywords, the second level is based on the abstract and conclusion, and the third level is based on reading the entire text to see whether it is relevant to this study. The study's inclusion criteria should include a publication year between 2016 and 2023, as well as published articles or conference papers that cover the physical, psychological, and social effects of Industry 4.0 technology on operators. Publications that cover Industry 4.0-related technologies such as cyber-physical systems, artificial intelligence, and automation are also listed for review, as they are part of the Operator 4.0 typology and should be considered. If the publication year is earlier than 2016, it will not be added to the literature review. The final selection of relevant publications is based on the number of citations, year of publication, keywords, objectives, study area, and results.

3.3 Screening of Data

The search results were filtered using three levels of screening. The first level of screening was based on only keywords, the second level was based on the abstracts and conclusions reading, and the third level was based on the reading of the full text. Furthermore, the study's inclusion criteria were only publications covering the physical, psychological, and social effects of Industry 4.0 technologies adoption in the Operator 4.0, published in English. The final selection of relevant publications was based on their year of publication, keywords, objectives, study area, and results.

135 publications were found in the first search iteration in Scopus, Web of Science, and Google Scholar databases using different query strings (see Table 3). At first, 36 duplicated entries were removed, leaving only 102 items. The 102 publications were then filtered using the three levels of screening mentioned above. After their screening process, 24 relevant publications were left, and 4 additional publications were found from the references using "snowballing". The inclusion/exclusion criteria for the 28 publications selected to write this literature review (see Table 4) were based on the focus of documents discussing the psychosocial impacts (risks) of Industry 4.0 technologies adoption in the workforce. Of the 28 publications, 24 were journal articles, followed by two conference papers, one book chapter, and one master's degree thesis.

3.4 Analyzing the Findings

Inspired by the literature review conducted, the next subsections describe different scenarios found in the publications studied [3], [5]-[7], [18], [38]-[60] that should be taken into account for the designing of a *theoretical framework* for "Assessing the Psychosocial Impacts (Risks) of Industry 4.0 Technologies Adoption in the Operator 4.0".

3.4.1 Scenarios Definition

A *scenarios planning* exercise was first carried out in which different shop floor scenarios that the Operator 4.0 may face when adopting Industry 4.0 technologies in assembly, maintenance, and training operations were defined using as a reference those found in the literature review conducted [3], [5]-[7], [18], [38]-[60]; these were:

Table 4. List of Publications Selected for this Literature Review

No #	Authors	No #	Authors
1	Arana-Landín et al. (2023) [6]	15	Chacón et al. (2020) [48]
2	Ciccarelli et al. (2023) [7]	16	Danielsson et al. (2020) [49]
3	Zorzenon et al. (2022) [5]	17	Drouot et al. (2020) [50]
4	Baumgartner et al. (2022) [38]	18	Hariharan et al. (2020) [51]
5	de Simone et al. (2022) [39]	19	Kaasinen et al. (2020) [52]
6	Kumar & Lee (2022) [40]	20	Perez Luque et al. (2020) [18]
7	Storm et al. (2022) [41]	21	Trebuna et al. (2023) [53]
8	de Assis Dornelles et al. (2021) [42]	22	Liao et al. (2019) [54]
9	di Pasquale et al. (2021) [3]	23	Miller et al. (2019) [55]
10	Ekandjo et al. (2021) [43]	24	Kadir et al. (2018) [56]
11	Enrique et al. (2021) [44]	25	Maurice et al. (2018) [57]
12	Nazareno & Schiff (2021) [45]	26	Romero et al. (2018) [58]
13	Reiman et al. (2021) [46]	27	Wesslen (2018) [59]
14	Bortolini et al. (2020) [47]	28	van Zoonen et al. (2017) [60]

Assembly Operations Scenarios based on the Operator 4.0 Typology:

- *Super-Strength Operator:* During any overhead task that happens during an assembly operation, an industrial exoskeleton can provide adjustable lift assistance and arm support for an assembly operator.
- *Augmented Operator:* AR devices such as headsets (e.g., smart glasses) or handhelds (e.g., smartphones) can provide instructions to assembly operators by projection to improve their work quality and work productivity.
- *Virtual Operator:* Training complex and/or dangerous assembly operations in VR interactive (training) environments offers assembly operators a safe and controlled learning environment with emotional realism.
- *Healthy Operator:* Wearable sensors can be used to monitor posture movement and biosignals such as heart rate during work to safeguard assembly operators' occupational health and safety.
- *Smarter Operator:* IPAs can provide voice assistance on instructions on how to complete a sequence of complex assembly tasks, and how to correctly use a tool for assembly activities to improve assembly operators' work quality and productivity.
- *Collaborative Operator:* Cobots can be used in assembly operations to perform repetitive and non-ergonomic tasks, safeguarding this way assembly operators' occupational health and safety.
- *Social Operator:* Real-time communication between assembly operators can help to improve the quality of their work by sharing best assembly practices.
- *Analytical Operator:* Big data analytics can be used to analyze the data collected from various assembly operators to propose ways to improve the quality of their work, including their occupational health and safety during assembly work.

Maintenance Operations Scenarios based on the Operator 4.0 Typology:

- *Super-Strength Operator:* Industrial exoskeletons can provide physical support for maintenance operators when manipulating (e.g., lifting) heavy parts to be replaced in a machine as part of a repair operation.
- *Augmented Operator:* AR headsets and handheld devices can be used to provide maintenance operators with relevant information on how to diagnose and replace a faulty part in a machine.
- *Virtual Operator:* Training dangerous maintenance operations in VR interactive (training) environments offers maintenance operators a safe and controlled learning environment with emotional realism.
- *Healthy Operator:* Wearable devices such as smartwatches, acting as digital Andons, can deliver alerts and notifications to maintenance operators for promoting preventive and predictive maintenance practices.

- *Smarter Operator:* IPAs can provide voice assistance on instructions on how to conduct maintenance, repair, and overhaul operations in a machine according to standard operating procedures.
- *Collaborative Operator:* Cobots can used to perform dangerous tasks during a maintenance operation.
- *Social Operator:* Real-time communication between maintenance operators can help to improve the mean-time-to-repair of a machine by collaborative troubleshooting the equipment.

Training Scenarios based on the Operator 4.0 Typology:

- *Augmented Operator:* AR headsets and handheld devices can be used to guide assembly and maintenance operators in their training by providing overlaid instructions (step-by-step) in their field of view.
- *Virtual Operator:* Training complex or dangerous assembly and maintenance operations in VR interactive (training) environments offers assembly and maintenance operators a safe and controlled learning environment with emotional realism.
- *Healthy Operator:* Wearable sensors can be used to track assembly and maintenance operators' performance during their training.
- *Smarter Operator:* IPAs can provide voice assistance to assembly and maintenance operators during their training.
- *Social Operator:* Social networking sites are used to share training-related information for operators such as training schedules and instructions.

3.4.2 Scenarios Analysis

The *qualitative analysis* of the scenarios defined was carried out in a two-step approach. The first step was to identify the most important *psychosocial impact categories* in the publications studied in this literature review, and then the second step was to map the scenarios defined in each of these *psychosocial impact categories*.

From all the publications studied in this literature review, initially, *11 psychosocial impact categories* were identified (see Tables 1 and 2). These *categories* were then clustered due to their "relatability" into *six psychosocial impact categories* (see Table 5 – first column), which were then clustered again to end up with three main psychosocial impact categories related to the eight *Operator 4.0 types* (see Table 5 – third column, and Figure 3): (i) nature of work, (ii) social and organizational context of work, and (iii) related to individual factors.

Table 5 presents all the publications studied in this literature review mapped into the *six psychoso-*

Table 5. Psychosocial Impacts Categories Identified from the Literature Review

Psychosocial Impact Categories Identified	References	Main Categories
Impacts on: • Job Content/Demand • Job Control • Physical Environment and Equipment Issues	Arana-Landín et al. (2023) [6]; Ciccarelli et al. (2023) [7]; Zorzenon et al. (2022) [5]; Baumgartner et al. (2022) [38]; de Simone et al. (2022) [39]; Kumar & Lee (2022) [40]; de Assis Dornelles et al. (2021) [42]; di Pasquale et al. (2021) [3]; Ekandjo et al. (2021) [43]; Enrique et al. (2021) [43]; Reiman et al. (2021) [46]; Bortolini et al. (2020) [47]; Danielsson et al. (2020) [49]; Drouot et al. (2020) [50]; Hariharan et al. (2020) [51]; Perez Luque et al. (2020) [18]; Liao et al. (2019) [54]; Kadir et al. (2018) [56]; Maurice et al. (2018) [57]; Romero et al. (2018) [58]; Wesslen (2018) [59]; van Zoonen et al. (2017) [60]	Nature of Work
Impacts on: • Organizational Culture and Interpersonal Relationships (at Work) • Career Development	Ciccarelli et al. (2023) [7]; Baumgartner et al. (2022) [38]; de Simone et al. (2022) [39]; Storm et al. (2022) [41]; de Assis Dornelles et al. (2021) [42]; di Pasquale et al. (2021) [18]; Ekandjo et al. (2021) [43]; Enrique et al. (2021) [44]; Kaasinen et al. (2020) [52]; Miller et al. (2019) [55]; Kadir et al. (2018) [56]; Maurice et al. (2018) [57]; van Zoonen et al. (2017) [60]	Social and Organizational Context of Work
Impacts on: • Workload/Workplace Stress	Arana-Landín et al. (2023) [6]; Ciccarelli et al. (2023) [7]; Zorzenon et al. (2022) [5]; Baumgartner et al. (2022) [38]; de Simone et al. (2022) [39]; Kumar & Lee (2022) [40]; di Pasquale et al. (2021) [18]; de Assis Dornelles et al. (2021) [42]; Nazareno & Schiff (2021) [45]; Kaasinen et al. (2020) [52]; Liao et al. (2019) [54]; Kadir et al. (2018) [56]; Maurice et al. (2018) [57]; van Zoonen et al. (2017) [60]	Individual Factors

cial impact categories related to the eight *Operator 4.0 types*.

This literature review revealed *three main psychosocial impact categories* for the *Operator 4.0* when *adopting Industry 4.0 technologies*. These *psychosocial impact categories* include those connected to (i) the nature of work, (ii) the social and organizational context of work, and (iii) related individual factors, and each has some subcategories as can be depicted in Figure 3 and will is further explained in the next subsections.

Impacts related to the Nature of Work

Impacts on Job Content/Demands

Job Content/Demands – make a psychosocial impact on the uncertainty of the job, on its work cycles, in its physical and cognitive workload, and in its workflow.

Reiman et al. [46] mention that increasing technology use has resulted in more complex skills needs and changes in the working environment as technology advances. Maurice et al. [57] claim that according to both factory workers and non-factory workers, human-robot collaboration reduces the physical workload of the *Collaborative Operator* and that this reduction in the physical effort also results in other related psychosocial impacts for the operators. According to de Simone et al. [39] and di Pasquale et al. [3], when cobots are introduced, among other reasons, to improve physical ergonomics, these minimize physical overwork in the operators. Hence, cobot applications decrease work cycles for operators and the *Collaborative Operators'* operation time is reduced even further. Kadir et al. [56] mention that the assistance of cobots reduces the operation workflow for operators, such as reduced physical activity. Since the *Collaborative Operator* is not subjected to repetitious and physically demanding tasks, operators can maintain their occupational health for more productive years as part of the workforce [5], [7]. Furthermore, Arana-Landín et al. [6] highlight that while cobots can help in many ways the *Collaborative Operators* to suffer less work stress and bad postures by doing the most unpleasant tasks of their job, some operators may have trouble adapting to the changes in their new "collaborative" job tasks, and this may cause mood deterioration.

In the case of *Super-Strength Operators*, industrial exoskeletons provide physical assistance to reduce operators' physical workload in assembly tasks [18], [59]. The study by Perez Luque et al. [18] mentions that passive-upper-body exoskeletons limit the operators' movement (i.e., stretching) in assembly operations. Providing wearable equipment creates other psychosocial impacts for operators as the *Super-Strength Operators* feel an increase in their physical burden in terms of qualitative workload by the long-term wear of, for instance, an industrial exoskeleton [3].

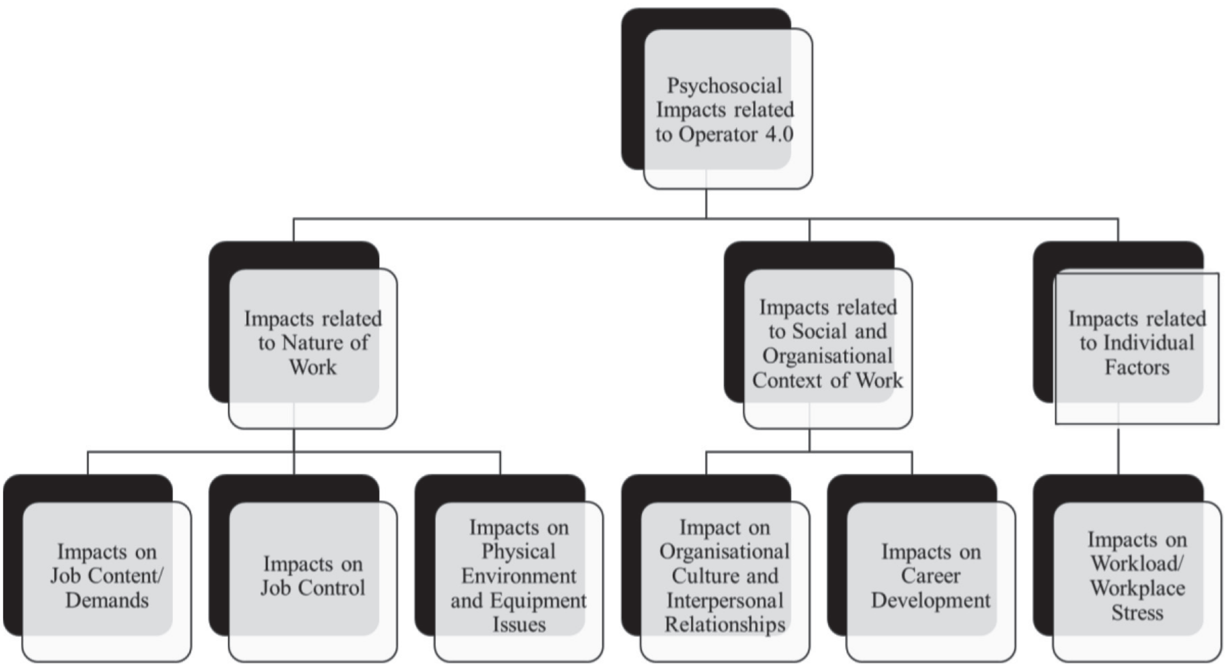

Figure 3. Categorized Psychosocial Impacts related to the Operator 4.0

A survey of IPA users by Liao et al. [54] states that IPAs are not adequately designed concerning usability and machine-to-human interaction. Hence, task uncertainty emerges because IPAs respond differently to what the *Smarter Operator* expects.

Romero et al. [58] mentioned that monitoring operators' physical and cognitive workload by detecting biomechanical events such as acceleration and cognitive events like stress can help to maintain a *Healthy Operator* in his/her work environment. Smart exoskeletons in which body smart sensors are fixed on the exoskeleton for ergonomic assessments help to evaluate the risk of musculoskeletal disorders in the *Super-Strength Operator* [58]. Hence, continuous monitoring of the operators' health also requires the creation of a database to store big data for its later analysis in favor of making data-driven decisions to improve the occupational health and safety of operators [58].

The transformation from paper-based instructions to multimedia instructions mixed with AR and VR has been shown to reduce the "cognitive" workload of the *Augmented Operator* and the *Virtual Operator* during their assembly, maintenance, and/or training operations. AR and VR technologies/devices provide enriched operation-related relevant information for operators and help them to improve their cognitive abilities and engage in decision-making [5], [6]. Also, memory and comprehension are improved, and thus the cognitive workload is reduced too [3]. Furthermore, in complex assembly and maintenance operations, all information can be provided by AR devices, and thus the *Augmented Operators* do not have to remember all of the information needed during an assembly or repair process, as a result, the cognitive workload of operators is lessened [5], [6]. Similarly, the cognitive workload of the *Virtual Operator* is also reduced. Presenting accurate task-relevant information using VR environments instead of written documents during training increases *Virtual Operators'* cognitive capabilities during their drills [5], [6], [42]. Nevertheless, for achieving these positive outcomes mentioned for the *Augmented Operator* and the *Virtual Operator*, AR and VR solutions should be properly designed to avoid operational inefficiency and discomfort [5].

A recent study by Kumar & Lee [40] shows that real-time data monitoring in human-machine collaborative smart working environments provides a significant amount of information related to machinery equipment for analysis to the *Analytical Operator 4.0*. Hence the operator's cognitive workload is increased when a great amount of information is provided to him/her even with the help of Big Data Analytics technology [5], [6], [40].

Impacts on Job Control

Job Control – refers to an operator's involvement in decision-making and problem-solving activities as well as to work engagement. Each of the *Operator 4.0 types* has various consequences in terms of job control.

Industrial exoskeletons support the *Super-Strength Operators* without taking away the control of the job task at hand during assembly and maintenance operations since the operator can continue the operation even if the exoskeleton gets damaged between the tasks of an operation [3], [57].

The *Collaborative Operators'* control over their job tasks is positively affected as a cobot takes over their repetitive and physically difficult tasks. Hence, the *Collaborative Operators'* control over their entire job has been reduced for good [5]-[7]. Moreover, it is recommended to consider the "voice of the operators" as part of any human-robot task allocation decision for increased job satisfaction [61]. One drawback of some human-robot collaborative operations is that if the cobot breaks down, the *Collaborative Operator* alone may not be able to continue the operation, creating in some cases frustration in him/her [57].

Danielsson et al. [49] argue that AR glasses influence *Augmented Operators* as their small field of view creates difficulties in understanding instructions for inexperienced operators with the glasses and reduces operator efficiency.

Considering the *Smarter Operators*, IPAs improve social interactions between operators and shop floor managers by facilitating collaboration and providing task direction as well as assisting in better decision-making and increasing decision-making participation. IPAs help operators with all parts of their job tasks, including problem-solving, communication, and work scheduling which helps operators to forecast their working hours. As a result, when operators employ IPAs to provide total support, they may lose control of their duties. As a result, implementing IPAs in a specific organization changes the routines, task control, and task autonomy of operators [43].

Van Zoonen et al. [60] claim that introducing social media in the workplace can both raise and decrease work engagement. That is social media improves communication between *Social Operators*, and work engagement increases as a result of effective communication and co-worker accessibility. But social media also increases the volume of data transmitted in the form of texts and e-mails. Hence, the work engagement of operators is depleted as a result of this accumulated information [60]. An interview on Prima power by Kaasinen et al. [52] concluded that any easily accessible social media platform acts as a knowledge-sharing tool in training by providing communication within the community as well as with machine providers for better problem-solving.

Regarding *Analytical Operators*, visual analytics in big data analysis helps operators to analyze the data collected from various operations in less time, which helps to improve the decision-making efficiency of shop floor operators [5]-[7], [46].

Impacts on Physical Environment and Equipment Issues

Physical Environment and Equipment Issues – refer to any discomfort and health issues that are caused by physical (work) environment and equipment-related problems.

The *Super-Strength, Augmented, Virtual, and Healthy Operators* have equipment-related impacts due to their supporting hardware. Considering *Super-Strength Operators*, the long-term use of industrial exoskeletons in assembly operations has been shown to cause discomfort to the operators because the biomechanical workload moves from the designated muscles. The *Super-Strength Operators* are frequently bothered by their exoskeletons' weight, and these may potentially induce psychological issues such as clumsy feelings and discomfort for the operators when worn for an extended period [18]. Furthermore, operators are aware that industrial exoskeletons can assist older operators by providing additional strength to support them, but they still seem hesitant to accept this technology because they also feel that carrying additional weight in the long term creates discomfort and injury [3].

Bortolini et al. [47] proposed a Motion Analysis System (MAS) for tracking the performance of operators in assembly operations by wearable sensors and cameras. They mention that measurement from sensors can be analyzed from an ergonomic perspective using ergonomic indices such as Rapid Upper Limb Assessment (RULA) and Rapid Entire Body Assessment (REBA). Those assessments help to improve the operators' physical and cognitive ergonomics, such as assessing the risk of musculoskeletal disorders and thus improving the work environment [47]. Maurice et al. [57] state that using wearable sensors for the measurement of bio-signals and posture movements aids *Healthy Operators* in self-assessment and self-correcting measures and lessens their risk of musculoskeletal disorders. However, the usage of wearable sensors for extended periods causes discomfort for the operators and operation with improved physical and cognitive ergonomics might increase the time to complete an operation [3].

Considering the *Augmented* and *Virtual Operators*, one of the equipment impacts related to the adoption of AR and VR technologies is their hardware weight, especially when head-mounted [5]. Video-based head-mounted displays, such as the Microsoft HoloLens, produce more vision-related discomfort for operators, such as motion sickness and because of their imbalanced center of mass, head-mounted displays in AR cause pain in the head and neck [49]. Using AR devices such as video-based glasses, optical glasses, video-based tablets, and spatial projectors could allow *Augmented Operators* to experience hands-free operation [44] but at the same time, the weight of video-based glasses could create physical ergonomics problems for operators. Virtual objects overlaid in the real environment interrupt if the tablet camera gets easily disturbed by operator hand movement and long-term usage of VR-based head-mounted devices causes discomfort and vision difficulties for operators, such as blurry images [44]. AR also seems to have certain pain and physical ergonomics issues when combined with the wearing of prescription glasses [3], [44]. However, investigations of operator experience of an AR system suggest that AR-based instructions via projected displays, head-mounted displays, and other AR technologies help to reduce head and eye movement for operators [51].

Another equipment-related impact experienced by *Augmented* and *Virtual Operators* is vision-related problems by long-term exposure to AR and VR [5]. *Augmented Operators* and *Virtual Operators* experience vision-related health issues such as motion sickness and long-term use of AR-based digitally enhanced equipment causes headaches. One of the vision problems related to the *Augmented Operator* is occlusion issues, where the *Augmented Operator* feels the real object is far away from the virtual one and experiences eye strain as a result of this illusion [42]. The *Virtual Operator* employs VR equipment such as head-mounted displays and projected screens. However, long-term usage of VR technology can cause eye strain and vision problems [42]. Studies of optometric testing of both paper and digital instructions show that staring at AR screens and equipment causes eyesight to degrade and eye pain [50].

Impacts related to the Social and Organizational Context of Work

Impact on Organizational (Workplace) Culture and Interpersonal Relationships (at Work)

Organizational (Workplace) Culture and Interpersonal Relationships (at Work) – Workplace communication and social relationships, workplace isolation, and discrimination are related to the impacts of organizational (workplace) culture and interpersonal relationships (at work).

IPAs seem to improve collaboration with coworkers and provide task direction in the work environment. This teamwork also enhances operators' and supervisors' social interactions [43].

Communication and isolation in the workplace can affect *Social Operators*. Using social media as a platform provides more effective communication between individuals with less effort and time, but it also causes workplace conflict due to shared data. Operators can stay focused on their work and help others by using public social media in the workplace. However, collaborating with the organization's community increases job pressure for operators, leads to emotionally uncomfortable conversations with others, and can thus generate an unfavorable work environment [60].

AR-enabled portable devices such as tablets and smartphone devices can connect with company supervisors or managers remotely – the *Augmented Operators*. This increases peer support for operators doing autonomous tasks and supposedly minimizes the cognitive load on the task. It could also help to boost the operator's work satisfaction and productivity [7], [42]. But at the same time, using head-mounted devices isolates an operator from others in the same manner as AR users lose eye contact with non-users, resulting in operators being socially separated in their work environment [7], [55]. During operator training, the interaction between the physical and virtual reality is often minimal and as a result, the *Virtual Operator* can feel physically isolated in the work environment [7], [44].

Cobot implementation can affect the work environment for both the *Collaborative Operator* and the cobot; it minimizes operator engagement and socially isolates operators in the workplace by potentially reducing the number of human operators. However, differently-abled personnel, such as those with autism or other abilities, may benefit from this type of socially isolated work environment [7], [41].

Impacts on Career Development

Career Development – Career opportunities and job insecurity are two factors that affect career development for the Operator 4.0.

Collaborative and *Smarter Operators* have a greater impact on career opportunities. When comes to *Smarter Operators*, an IPA helps operators to advance their careers by providing a continuous learning platform with pictures and videos that provide new and more knowledge about manufacturing operations [7], [43]. In a human-robot collaborative environment, *Collaborative Operators* are encouraged to study programming and machine-learning techniques to improve human-robot interactions and broaden operators' career opportunities [7], [39]. Cobots are often brought in to undertake repetitive and dangerous tasks, giving the *Collaborative Operator* more time to do other more value-added things and get a chance to acquire new skills and take on new tasks such as quality control, production planning, etc. [56], but the introduction of cobots can create job insecurity in operators, according to a study with both factory and non-factory workers [57]. Several publications [3], [38], [57] mention that the introduction of cobots raises concerns among operators about job security and the transfer of their technical skills to a machine.

Impacts related to Individual Factors

Impacts on Workload/Workplace Stress

Excessive Workload/Workplace Stress – both can interrupt work-life balance, cause mental discomfort in operators, and cause disruption in the workplace.

Operators may experience mental stress for a variety of reasons [5]-[7]. Changes in the work environment towards the job (i.e., variation in job type and skill level) resulting from automation might for example create stress for operators [5-7], [45]. The *Healthy Operator* may experience mental stress as a result of continuous assessment and data collection via wearable sensors can develop a negative attitude as operators might not be in control of the data which in turn causes stress [52]. Furthermore, collecting personal data increases anxiety in *Healthy Operators* as they feel that the information accessed can be used to promote or dismiss them [58]. The previously mentioned study with factory and non-factory workers highlights that assessment creates work performance under stress. Non-factory workers also point out that continuous real-time data monitoring poses a threat to privacy because the collected information includes a productivity track for the operators [57].

According to interviews with non-factory workers, the *Collaborative Operator* may experience mental stress due to a loss of task control in a collaborative work environment [57]. While cobots allow the operator to concentrate on more vital tasks this also creates a new source of anxiety for the operator, because if they were to perform a less difficult duty at a slower speed, their official status might be questioned, and they would experience mental stress as a result of the slower speed, feeling that they had a low level of participation in decision-making [38]. Furthermore, the possibility of a collision in the collaborative work environment creates trust issues and anxiety, and while safety measures disable cobots when a human presence is detected, operators are not necessarily aware of this mechanism [38], [41]. Another source of mental stress for the *Collaborative Operator* is when irregularities occur in the workplace and cobots are unable to adjust to the circumstances. Because of the added responsibilities for quality monitoring, operators become frustrated and lose trust in cobots [56]. A close work environment for the cobot and the operator causes psychological stress for the *Collaborative Operator*, causing concerns about safety and operation speed. Cobots work fast and efficiently, finishing tasks in less time, and operators share the same workspace with cobots functioning at different speeds, causing mental pressure on the operators regarding their work performance [39].

Instructions in AR on a projected screen, voice assistance, or hand-held device can all divert the *Augmented operator's* attention away from the task at hand, extending the time it takes to perform it. As a result, performance strain or stress increases. Also, using social media in manufacturing industries can cause people to become distracted from their jobs, compromising their health and productivity, and also sometimes *Social Operators* are fearful to share ideas on social networking platforms since they feel that they will be judged based on their ideas, attitudes, or complaints on social media [42]. Conflict in the work-life balance is another influence linked to individual factors. Users can publish both personal and professional information on public social networking networks and thus, introducing social media platforms for data sharing in the workplace can cause conflict in work-life balance [60]. Most IPAs are always listening to operators; hence operators are worried that the IPA is always listening in on them and that their privacy will be invaded [54].

Summary of the Psychosocial Impacts on the Operator 4.0 Types: Positive & Negative Outcomes

Table 6 presents a summary of the psychosocial impacts on the eight Operator 4.0 types in terms of their positive and negative outcomes.

4. Towards a Theoretical Framework for the Operator 4.0 Psychosocial Risk Assessment

This section provides an overview of different *psychosocial risk assessment methods* to develop and propose a *theoretical framework for* "Assessing the Psychosocial Impacts (Risks) of Industry 4.0 Technologies Adoption in the Operator 4.0".

In this research work, a *psychosocial risk assessment method* is defined as a "systematic intervention process that aims at improving the psychosocial working conditions and thus the wellbeing (i.e. occupational health, safety, and productivity) of a worker by screening his/her work and work environment and making interventions to reduce or eliminate if possible any related psychosocial risks" [62].

4.1 Psychosocial Risk Assessment Methods

The European Union Information Agency for Occupational Safety and Health (EU-OSHA) has published a guide that outlines comprehensive recommendations for assessing psychological effects in the workplace [63]. The EU-OSHA guide reviews different perspectives of psychosocial impacts in the workplace and concludes that psychosocial impact as physical, psychological, and social consequences may be influenced by the social and environmental surroundings in which operators operate [63]. According to the EU-OSHA guide [63], *psychosocial risk assessment* can be conducted in a four-phase procedure. The first phase of the procedure is to identify the psychosocial effects and risks associated with the workplace. The company managers or human resource personnel related to the company can conduct the assessment in the workplace by including all individuals in the workplace and using proper techniques. The second phase is to assess the consequences and prioritize them based on the related risks. Prioritization is based on the possible adverse consequences and after prioritizing, preventative action should be taken to reduce the effects and risks (third phase). The situation linked with psychosocial consequences is then reviewed (fourth phase).

Table 6. Summary of Psychosocial Impacts on the Operator 4.0 Types: Positive & Negative Outcomes

Positive Psychosocial Outcomes of the Operator 4.0 Types	Negative Psychosocial Outcomes of the Operator 4.0 Types
Super-Strength Operator: • Reduction of physical workload. • Does not impact operator control.	Super-Strength Operator: • Long-term wear creates discomfort. • Older workers feel discriminated against for carrying extra weight.
Augmented Operator: • Reduction of cognitive load through information presentation. • Reduction of head and eye movement. • Hands-free operation. • Offers opportunity for collaboration. • Offers improved participation in decision-making.	Augmented Operator: • AR smart glasses reduce operator efficiency. • Head-mounted displays create visual discomfort and headaches. • Handheld devices limit movement.
Virtual Operator: • Improves cognitive capabilities.	Virtual Operator: • VR head-mounted displays create discomfort, eye strain, and vision problems. • Physically isolated work environment.
Healthy Operator: • Monitoring of physical and cognitive workload can assist operators' well-being. • Assessment of risk for musculoskeletal disorders. • Provides self-evaluation.	Healthy Operator: • Long-term wear of sensors causing discomfort. • Mental stress related to continuous assessment. • Privacy concerns.
Social Operator: • Improved communication between peers. • Improved problem-solving skills.	Social Operator: • Potential for workplace conflict due to shared data. • Distraction by social media. • Fear of embarrassment from sharing ideas on social platforms. • Conflicts in work-life balance.
Collaborative Operator: • Reduction of physical workload. • Career development.	Collaborative Operator: • Reduction of task control. • Job insecurity. • Mental stress on loss of task control, risk of collision, performance, and increased responsibilities.
Smarter Operator: • Improved participation in decision-making. • Offers continuous learning platform.	Smarter Operator: • Loss of task control.
Analytical Operator: • Improvement of decision-making efficiency through data accessibility.	Analytical Operator: • Risk of information overload.

According to the EU-OSHA guide [63], Online interactive Risk Assessment (OiRA), Stress prevention at work checkpoints, and The Scandinavian QPS Nordic questionnaire are different types of *psychosocial risk assessment methods*, and these methods use questionnaires, interviews, surveys, observations, checklists, and templates for the psychosocial impact assessment [63].

4.2 Theoretical Assessment Framework Design

This subsection describes the process for designing the proposed *theoretical framework for* "Assessing the Psychosocial Impacts (Risks) of Industry 4.0 Technologies Adoption in the Operator 4.0". It was designed by relating the eight Operator 4.0 types to the risks that might affect operators' psychosocial work environment (i.e. the shop floor) when adopting Industry 4.0 technologies by using a *qualitative analysis* of the scientific literature on already existing and proven psychosocial risk assessment methods.

4.2.1 Selection of Psychosocial Risk Assessment Methods

Based on the following inclusion criteria for an explorative review of the scientific literature, three psychosocial risk assessment methods were selected to be related to the eight Operator 4.0 types. The inclusion criteria were:

- The psychosocial risk assessment method should not predate the year 2000 aiming for contemporary assessment methods.
- The psychosocial risk assessment method should be free of cost.
- The psychosocial risk assessment method should be simple to use.
- The psychosocial risk assessment method should have a minimum condition for use, meaning there are a minimum number of criteria for managers, researchers, production engineers, and human resource personnel to access the method.
- The selected existing psychosocial risk assessment methods should contain satisfying assessment criteria to relate to the psychosocial impacts of the Operator 4.0 types when adopting Industry 4.0 technologies.

Considering the results of the explorative literature review conducted in the Google Scholar database and the aforementioned inclusion criteria, the following psychosocial risk assessment methods were selected.

International Labor Organization (ILO) Stress Checkpoints

ILO launched its "stress checkpoints" method in 2012, and it is an easy tool for operators to assess their psychosocial impacts as a *self-report questionnaire* with 50 checkpoints. Job control, work-life balance, workplace social support, job security, job expectations, workplace physical environment, and communication and information impacts are all examined at each checkpoint. Furthermore, at each checkpoint, operators can answer with a "Yes, No, or Priority". If any operator responds with a "Yes" or a "Priority", they can also make comments about that impact. Following the evaluation, managers, human resource personnel, and occupational safety, health and environment practitioners meet with representatives from the operators to discuss the assessment's conclusions to reduce psychosocial impacts. This tool is free to download from the Apple[1] and Google Play[2] stores as "ILO Stress Checkpoints". The tool is in English. There are no restrictions when it comes to using this method [64].

Online interactive Risk Assessment (OiRA)

The "Online interactive Risk Assessment (OiRA)" method was created by the EU-OSHA [63] for psychosocial risk evaluation. This tool is easy to download for free from the OiRA web page[3] and is aimed at managers based on their industrial sector. It is offered in different languages. Its application can assist companies in developing risk assessment tools specific to their industrial sector [63].

Work Design Questionnaire (WDQ)

The "Work Design Questionnaire (WDQ)" is primarily used to assess the effects of work-related characteristics [64]. It was developed by Morgeson & Humphrey [65] in 2006, and it takes the form of a *self-report questionnaire* with 77 questions, and the operator can grade each question on a 1 to 5 scale to indicate whether the operator agrees or disagrees with the proposition. Questionnaires address job task characteristics such as autonomy in the task, superior feedback in the task, task complexity, and knowledge demand in information processing. Social aspects of the job activity include social assistance in the task and feedback from others. It also takes into account ergonomics, physical demands in the task, operator working conditions, and the impact of the operator's equipment. However, managers must satisfy the criteria to use this method/tool for psychosocial risk assessment. That is, it is mandatory to notify the tool's authors if someone is utilizing or translating the tool into other languages, and it is also suggested to share the results with the authors. English, Dutch, German, Polish, and Spanish are among the languages that the tool[4] can be translated into [64], [65].

4.2.2 The Theoretical Assessment Framework

A *theoretical framework* for "Assessing the Psychosocial Impacts (Risks) of Industry 4.0 Technologies Adoption in the Operator 4.0" is presented in Table 7.

All the *psychosocial risk assessment methods* considered in the proposed *theoretical assessment framework* already exist and are validated *self-report questionnaires* for operators, which can help them address their psychosocial impacts when adopting Industry 4.0 technologies and allow them to make suggestions regarding those impacts. The proposed *theoretical*

[1] https://apps.apple.com/us/app/stress-prevention-checkpoints/id878562165
[2] https://play.google.com/store/apps/details?id=com.aimermedia.ilo_checkpoints.stress&hl=en_US&pli=1
[3] https://oiraproject.eu/en
[4] http://www.morgeson.com/wdq.html

Table 7. A Theoretical Framework for Assessing the Operator 4.0 Psychosocial Impacts (Risks)

Operator 4.0 Type	Psychosocial Assessment Method	Manufacturing Operation
Augmented Operator Virtual Operator Healthy Operator Super-Strength Operator	Work Design Questionnaire (WDQ) [65]	Assembly, Maintenance, and Training Operations
Analytical Operator	Online interactive Risk Assessment (OiRA) [63]	Assembly Operations
Collaborative Operator Smarter Operator Social Operator	International Labor Organization (ILO) Stress Checkpoints [64]	Maintenance Operations Training Operations

framework relates those already existing risk assessment methods/tools to the psychosocial impacts of Industry 4.0 technologies adoption in the eight Operator 4.0 types. All these *psychosocial risk assessment methods/ tools* do not need any other technical skills for operators to "self-assess" their psychosocial impacts when adopting Industry 4.0 technologies.

According to the results of the literature review analysis conducted in this research work, when *Augmented, Virtual, and Healthy Operators* (in assembly, maintenance, and training operations), and *Super-Strength Operators* (in assembly operations) are considered for *psychosocial impact assessment*, psychosocial impacts related to job control, social support, and equipment-related impacts should be considered. In WDQ, these assessment criteria are included. Hence WDQ can be used for the *psychosocial risk assessment* of *Super-Strength, Augmented, Virtual, and Healthy Operators*.

Considering the *Collaborative Operator* (in assembly operations) for *psychosocial impact assessment*, psychosocial impacts related to job demand, job control, organizational impacts related to work environment changes, workload, and work time should be considered. All these psychosocial impacts are included in the ILO's "stress checkpoints" tool. The impact on job demands (in checkpoints 6 to 10), job control (in checkpoints 11 to 15), work environment (in checkpoints 21 to 23), and workload and working time (in checkpoints 26 to 30). Hence, for the *psychosocial impact assessment* of the *Collaborative Operator* (in assembly operations), the ILO "stress checkpoints" tool is ideal.

For the case of the *Social Operator* (in training operations) for *psychosocial impact assessment*, psychosocial impacts related to social support for operators, data communication between operators, and work-life balance should be considered. On the other hand, for the instance of the *Smarter Operator* (in maintenance operations) for *psychosocial impacts assessment*, psychosocial impacts related to social support for operators, data communication between operators, job control, and co-worker support should be considered. All those possible psychosocial impacts of the *Social Operator* (in training operations) and the *Smarter Operator* (in maintenance operations) are included in the ILO's "stress checkpoints" assessment criteria. The impacts related to social support (in checkpoints 16 to 20), data communication (in checkpoints 46 to 50), work-life balance (in checkpoints 26 to 30), and job control (in checkpoints 11 to 15). Hence the *Social and Smarter Operators* can use the ILO's "stress checkpoints" as a psychosocial impact assessment tool.

The psychosocial impacts of the *Analytical Operator* (in assembly operations) were identified by studying limited works available in the scientific literature [66]. These psychosocial impacts are mainly related to "cognitive" workload (i.e., risk of information overload in big data work environments). The identified impacts can be examined using the OiRA tool since it offers support for cognitive ergonomics evaluations and information and communication technologies sector workers.

5. Theoretical and Managerial Contributions

5.1 Theoretical Contributions

As stated in all the publications qualitatively analyzed in this literature review [3,5-7,18,38-60], Industry 4.0 technologies can have either favorable or unfavorable *psychosocial impacts (outcomes)* on the workforce and its work environment depending on their adoption approach. This research work aims to contribute to the limited but growing body of knowledge on the study of the *psychosocial risks* faced by shop floor operators when adopting digital and smart technologies as part of their work and work environment, particularly wearable and collaborative ones. Furthermore, this research work places particular emphasis on the identification of free and easy-to-use *psychosocial risk assessment methods* [63]-[65] for evaluating the *psychosocial impacts (risks)* of Industry 4.0 technologies adoption in the *Operator 4.0* and proposes a "Theoretical Framework for Assessing the Operator 4.0 Psychosocial Impacts (Risks)" (see Table 7) to identify the potential favorable and unfavorable *psychosocial working conditions* of the eight *Operator 4.0 types* (see Table 6) to maximize those favorable conditions and aim at eliminating or at least reducing those unfavorable ones through interventions that should be based on well-founded assessments of the operators' working conditions.

5.2 Managerial Contributions

Psychosocial risk assessments are becoming increasingly important for managers, researchers, production engineers, and human resource personnel due to new labor legislation and occupational health and safety standards, such as the ISO 45003:2021[5] on "Guidelines for Managing Psychosocial Risks at Work", compelling employers to implement *psychosocial risk management frameworks* at their organizations. The proposed "Theoretical Framework for Assessing the Operator 4.0 Psychosocial Impacts (Risks)" (see Table 7) is of particular relevance for the manufacturing sector at a time when its industries are making great efforts to digitalize and smartify their shop floors towards smart factories to remain competitive in the Industry 4.0 era [12], [13]. Such digitalization and smartification efforts include the adoption of assisting, collaborative, and augmentation technologies, referred to here as the *Operator 4.0 typology* [2], which aim to aid the occupational health, safety, and productivity of the workforce [62]. Nevertheless, caution is advised as these technologies are introduced at the workplace to facilitate physical and cognitive work (i.e. increase productivity), since their adoption without a "human-centric approach" may lead to undesired "negative" *psychosocial outcomes* in the workforce and its work environment (see Table 6). Hence, the proposed framework in this research work aims to identify the *psychosocial impacts (risks)* related to the adoption of the *Operator 4.0 typology* [2], which is the first step to determining the needed interventions before, during, and after a new shop floor technology adoption to avoid *negative psychosocial outcomes* and capitalize on the *positive ones* towards a healthier, safer, and more productive workforce and work environment.

6. Discussion and Conclusions

This research work began with one main goal, to study how the *Operator 4.0 typology* [2] might affect the operators' psychosocial work environment (i.e. the shop floor). A *literature review approach* was used to answer this question. The review considered the eight *Operator 4.0 types* in assembly, maintenance, and training operations. The available literature shows that the *Operator 4.0 typology* is continually growing in terms of the digital and smart technologies that will be required to transform a traditional industrial operator into an "Operator 4.0". Of the 28 collected scientific publications, seven of them included studies of AR in assembly operations and three in maintenance and training operations (i.e., the *Augmented Operator*). Moreover, there is a limited number of studies related to the *Smarter, Social, and Analytical Operators types* in manufacturing operations studying their psychosocial impacts.

Furthermore, this research work shows that only Alexa, Siri, and Hey Google are being studied as IPAs for *Smarter Operators*, and it was not possible to find any industry-specific IPA [2], [43], [54]. Impact related to social networks were of the public kind such as Facebook, Twitter, and LinkedIn as they were used in the workplace and not related to industry-specific networking platforms (i.e., the *Social Operator*) [2], [60].

The scientific literature further shows that operators might be hesitant to accept new digital and smart technologies in their workplace and fear of the "new" can be induced by many reasons. For example, operators in collaborative work environments are afraid of working with cobots because they believe that introducing cobots will transfer their technical expertise to a machine [3]. Another concern for the *Collaborative Operators* is their safety in a collaborative workplace. Because operators can be unaware of the cobots' built-in security mechanisms (ISO/TS 15066:2016). These safety measures disable cobots when a human presence is detected. Operators, on the other hand, are first unaware of the situation, causing trust concerns [67].

5 https://www.iso.org/standard/64283.html

Operator objections to accepting IPAs are linked to risks in privacy and boil down to being uncomfortable should an IPA record their behavior during the day (i.e., the *Smarter Operator*). This information could be misused by management or potentially through malicious attacks on company data [68]. Moreover, smart wearables come with several difficulties such as battery life, user convenience, data processing limitations, and device connectivity problems, to mention a few technological challenges [69]. In addition, a social difficulty with wearables is operator discomfort from long-term use as well as privacy and security concerns. According to the studies revised in this literature review, smartwatches can be hacked, and hand movement information reproduced, and this information can be utilized to retrieve personal or professional security keys [70]. For the *Super-Strength Operators*, industrial exoskeletons provide ergonomically balanced work postures, however, they are less acceptable for older personnel as they add to their overall body weight [42].

A hybrid form of the *Operator 4.0 typology* [2] was introduced by Romero et al. [58]. They mention a hybrid form of the *Super-Strength and Healthy Operators* in which an Operator 4.0 wears a "smart exoskeleton" in which body sensors in the industrial exoskeleton help to assess any potential risk of musculoskeletal disorder during job tasks. They also mentioned, "Adaptive Cobots" (i.e., *Collaborative Operator + Healthy Operator*), in which cobots adapt to the collaborative operation based on the measurement of the operator's movements based on body sensors so the cobot can change in an intelligent way behavior [58]. Finally, they also revealed an *Analytical Operator* mixed with any other Operator 4.0 type to improve shop floor and workforce performance based on big data analytics [58].

Considering the *psychosocial risk assessment* of *hybrid Operator 4.0 types*, for such cases, it is recommended to use WDQ as the risk assessment tool since it is the only one that can assess equipment-related impacts.

While there are several research works in the scientific literature on the potential benefits of adopting Industry 4.0 technologies for Operator 4.0 in support of their daily work (e.g., assembly and maintenance operations) and training, there are fewer regarding their potential "negative" impacts when such technologies are not properly adopted and designed. Therefore, this literature review and theoretical assessment framework contribute to the disciplines of technology and engineering management, with a focus on technology adoption approaches, with a set of risk assessment methods for evaluating the psychosocial impacts of different human-technology interactions referred to here as the "Operator 4.0 types".

6.1 Further Research

New digital and smart technologies, particularly wearable and collaborative ones, have the power to change shop floor operators' work and work environments for the better or the worse depending on their adoption approach. Hence, further research should be undertaken to develop and test more *psychosocial risk assessment methods* specialized in the different Industry 4.0 technologies that the *Operator 4.0* may adopt to facilitate his/her physical and cognitive work (i.e. increase his/her productivity) and improve his/her occupational health and safety at his/her work environment (i.e. the smart factory). The ultimate goal and challenge, as we transition from the Industry 4.0 to the Industry 5.0 era [71], [72], is to develop successful "human-centric technological adoption approaches" that aim for healthier, safer, and more productive workforces and work environments towards the "Socially Sustainable Factories of the Future" [12].

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