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Review on impact of worker's psychosocial environment under operator 4.0 framework.

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Abstract

In manufacturing, emerging digital technologies related to industry 4.0 are playing an assisting role for operators, and just as in previous industrial revolutions the paradigm for operators in the industry is changing. This study has two key goals. The first is to look into the impact of the worker's psychosocial impacts under the operator 4.0 typologies during assembly, training, and maintenance operations, and the second is to look into the potential changes in the operator framework as the industry progresses from 4.0 to 5.0. This study proposed a theoretical framework for assessing psychosocial impacts in operator 4.0 typologies. The proposed framework can be utilized by the company managers, researchers, production engineers, and human resource personnel for the psychosocial risk assessment of the operators in assembly, training, and maintenance operations as self-report questionnaires. This study employed a systematic literature review strategy to answer the study objectives. The findings reveal that the nature of work, the social and organizational environment of work, and individual impacts are all key categories, that might impact operators' psychosocial environments in assembly, training, and maintenance operations under the operator 4.0 typologies.

This study focuses on determining the psychosocial consequences of the operator 4.0 typologies and helps the operators to become more aware, and equipment designers should consider operator psychosocial work conditions when designing new augmented equipment for assisting operators in the work environment. Most advanced technologies are unfamiliar to operators, and they have exhibited a reluctance to accept new technology because it significantly changes their working environment. Which necessitates the training and awareness of operators regarding advanced technologies. Operator 4.0 typologies were introduced with a vision to create a socially sustainable environment for operators. However, the identified psychosocial impacts make it favorable and unfavorable to the operators.

Keywords: operator 4.0, operator 5.0, psychosocial work environment, assembly, augmented reality, discomfort, communication.

Acknowledgments

Certificate of Authenticity

Submitted by Ruksana Adattil to the University of Skövde as a Master Degree Thesis at the School of Engineering.

I certify that all material in this Master Thesis Project which is not my own work has been properly referenced.

Ruksana Adattil

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1 Introduction

This thesis investigates the impact of an operator's psychosocial work environment under the operator 4.0 typologies. For this study, a systematic literature review was used as the strategy. The results of the literature review were qualitatively analyzed, and a theoretical framework for evaluating the psychosocial impact for operators in the operator 4.0 paradigm was proposed. The first chapter contains a description of the problem, as well as study objectives and the overall research method, and the study's goal and limits.

1.1 Problem description

In terms of automation and data sharing technology, the fourth industrial revolution (industry 4.0) highlights recent trends in manufacturing industries. Industry 4.0 is the integration of internet and factory automation to improve productivity and with the use of sensors and artificial intelligence for assisting manufacturing processes linked with machines (Carvalho & Cazarini, 2020). The main characteristics of industry 4.0 consist of Cyber-Physical Systems (CPS), Augmented Reality (AR), Internet of Things (IoT), Internet of Services (IoS), additive manufacturing (3D printing), big data analytics, autonomous robots, cloud computing, and simulations. CPS is linked with sensors in a production environment to link physical variables with the virtual world. IoT promotes communication and data sharing between objects by allowing improved connections of physical objects. IoS provides internet-based manufacturing services such as communication and data sharing. Big data and analytics are more closely linked to predictive manufacturing, which identifies and avoids production disruptions. AR assists workers in many production operations such as assembly, maintenance, and all other types of operations and helps to reduce errors in manufacturing. 3D printing enables industrial systems to succeed in demanding and competitive markets. Cloud computing aids in the provision of huge storage space for data collected from various sensors across the production system. Simulation aids in the realization of physical systems and the estimation of system output based on real-world data, as well as the reduction of errors (Tay et al, 2018). In terms of task functions and interface with running equipment, industry 4.0 changes the role of the human operator. Hence, advanced digital technologies like augmented reality (AR), virtual reality (VR), collaborative robots (cobots), exoskeletons, wearable technology, social networks, and big data analytics created new methods of workforce interaction and data exchange (operator 4.0 typologies) (Romero et al, 2016a). All of these

adapted technologies have an impact on operators' physical, psychological, and social responses in the workplace, either favorably or unfavorably (Di Pasquale et al, 2021). The study regarding industry 4.0 technology integration is still going and the fifth industrial revolution (industry 5.0) is arising (Saniuk et al, 2022). Industry 5.0 is more concerned with human and smart systems (like robots) collaboration. In which machines will take over all repetitive tasks, and allows operators to focus on system monitoring to improve the overall quality of production. Products from industry 5.0 are products with a particular mark of human care and skill and aimed to reduce industrial waste (Paschek et al, 2019).

The goal of this research is to study how the operator 4.0 typologies might affect the operator's psychosocial work environments. Operator 4.0 is a skilled and smart operator who has been assisted with industry 4.0 technologies in their work environment with a vision of creating a more interactive work environment between human operators and machines (Romero et al, 2016a).

1.2 Study objectives

The primary study objectives are:

(i) How does the operator 4.0 framework might affect an operator's psychosocial environment? (ii) How will the operator framework change as the industry transitions from 4.0 to 5.0? A systematic literature review approach is used in the study to answer the study objectives. To find answers to the study objectives, the study expanded to look at the operator 4.0 typologies, the psychosocial work environment of operators, how operator 4.0 affects workers, and how future revolutions would affect the operator 4.0 typologies. A qualitative data analysis approach is used in this study. By reviewing and analyzing non-numerical data from published documents without following strict procedures, qualitative data analysis aids in identifying the study's discussed themes and their findings (Oates, 2005). Figure 1 depicts the entire research procedure. For a systematic literature review, planned to gather peer-reviewed papers from different databases. After that, expressed the possible and expected scenarios of operator 4.0 typologies by identifying operator 4.0 scenarios from the collected works of literature and expressing the thoughts related to the identified scenarios. Then literature review analysis is conducted and based on data analysis draw conclusions and proposed a theoretical framework for the psychosocial risk assessment of operator 4.0 typologies in the studied manufacturing operation. As a self-report questionnaire, the proposed framework can be utilized by industry managers, human resource personnel, production engineers, and researchers to assess the risk of operator 4.0 typologies in the related industrial operation (assembly, training, and maintenance).
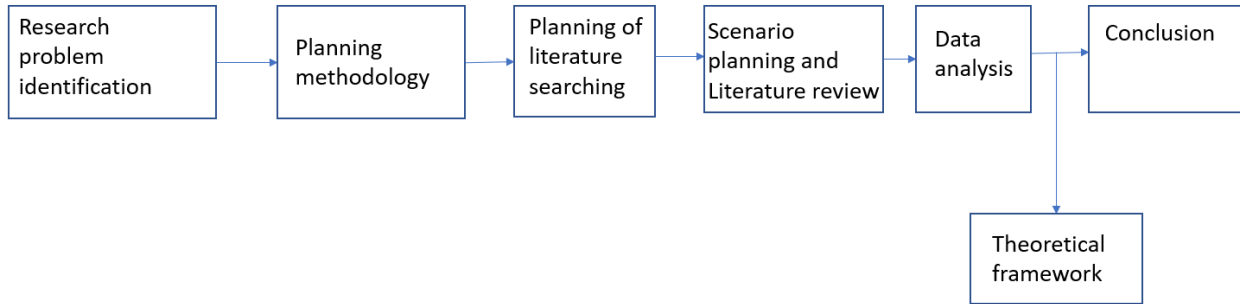
Figure 1: Overall research process

1.3 Goals

The main focus of the study is to investigate the impacts on the operator's physical, psychological, and social responses when operators are assisted with industry 4.0 technologies. The study proposed a theoretical framework for the assessment of the psychosocial impact on workers. The study attempted to investigate the changes in operator environments in the industry as the industry transforms from 4.0 to 5.0. Romero et al (2016a) described different operator typologies to assist with industry 4.0 technology. They are, *augmented operator* (assisted by AR), *virtual operator* (assisted by VR), *collaborative operator* (assisted by cobots), *super-strength operator* (assisted by an exoskeleton), *smarter operator* (assisted by wearable devices), *social operator* (assisted by social networks), and *analytical operator* (assisted by big data analytics) (Romero et al, 2016a). The study attempted to account for the effects of all operator types. However, the majority of the operator scenarios are still in the early stages of their research.

1.4 Limitations

There are various limits to this study that must be examined. This study only used informations from published sources, such as conference papers, book chapters, and journal articles, rather than my own empirical data. The manufacturing industries are mostly using limited operator 4.0 typologies (*collaborative operator*, *augmented operator*, *virtual operator*, and *super-strength operator*) (World Economic Forum, 2022). The operator 4.0 typologies are continually growing in terms of the technologies that will be required to transform an operator 4.0 from a traditional industrial operator. The majority of the application situations are still being researched (Gazzaneo et al, 2020). As a result, finding appropriate industrial scenarios for determining the impact of all operator 4.0 typologies may

be difficult. Hence, this study chose a systematic literature review approach only using information from published sources. Regarding the second study objective, the concept of operator 5.0 is still in its early stages of development, only two relevant articles are available and both of them introduced basic concepts only. Originality in this research can be identified by its research objectives. The psychological and social effects of industry 4.0 technologies that are employed to assist the operator 4.0 typology were covered in this study, as well as physical effects.

2 Background

This chapter covers the study's major theoretical concepts. That is the operator 4.0 typologies and the psychosocial characteristics of the workplace.

2.1 Operator 4.0 typologies

The concept of the operator 4.0 typologies was introduced by Romero et al (2016a) as a vision for the successful implementation of industry 4.0 technologies in a smart factory and its implications for the human operator. They introduced these operator typologies linked with industry 4.0 with a vision of a socially sustainable factory (Romero et al, 2016a). Romero et al (2016a) defined 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*" (Romero et al, 2016a, p. 2). Advanced human-machine interaction is provided by human cyber-physical systems to improve the physical, cognitive, and sensing skills of operators (Romero et al, 2016a). Adaptive automation aids in task distribution and human-machine interaction in the workplace, as well as adjusting the level of automation when a significant event or predetermined function is identified in production (Romero et al, 2016b). ACE Factories investigated the concept of operator 4.0 in a white paper (Casla et al, 2019). Casla et al (2019) introduced six operator 4.0 typologies based on Romero et al's (2016a) typologies. They are the *Augmented and virtual operator*, the *social and collaborative operator*, the *super-strong operator*, the *one-of-a-kind of operator*, and the *healthy and happy operator*. A *one-of-a-kind operator* can adapt to changing work environments because each operator has unique talents and skills (Casla et al, 2019). Romero et al (2016a) presented typologies of operators in the operator 4.0 paradigm assisted with industry 4.0 technologies are described in Figure 2.

Figure 2: Operator typology in operator 4.0 paradigm (Romero et al, 2016a)

Super-strength operator: The operator is supported with exoskeletons to improve the physical capabilities of the operator. The exoskeleton was intended to support workers' physical activity, give strength and support during manufacturing operations, and ensure their safety. The industrial exoskeleton can be a passive or powered (or active) type. A powered (or active) type industrial exoskeleton uses hydraulics, electric motors, and pneumatics methods to power the exoskeleton and thus provide physical strength and assistance for operators in manufacturing operations (Thorvald et al, 2021). One of the considerations with exoskeletons is their ability to physically support older workers to compensate for their strength in the manufacturing operation. Assistance for physical strength during manufacturing activities enhances the social sustainability of the human workforce and safety, as well as accident reduction (Romero et al, 2016a).

Augmented operator: The operator assisted with AR-based technologies and AR-enabled devices such as smart glass, head-mounted devices, and smartphones to strengthen an operator's cognitive abilities (Vanneste et al, 2020; Zolotová et al, 2020). Using AR-based technologies and devices operator can transmit information from the digital world to the physical world, and the data is overlaid in the actual environment within the operator's field of view. Apart from data exchange, AR functions as a digital assistant for operators in their manual activities, reducing errors by eliminating the need for printed instructions. In maintenance, AR can aid operators and this is also where the most successful applications of the technology have been shown. AR can provide information to the operators during manufacturing tasks using smart glasses such as Microsoft HoloLens and Google Glass among others. Another effective way is using AR through AR enabled devices like smartphones (Thorvald et al, 2021).

Virtual operator: The operator-assisted with VR to increase the cognitive interactions and skills of the operator such as minimizing the operator's reliance on memory and human error in operation (Zolotová et al, 2020; De Assis Dornelles et al, 2022). The 3D model created using Computer-Aided Design (CAD) can be converted into a 3D virtual model in Virtual Product Design (VPD) using VR in an interactive and immersive virtual environment. By evaluating the effects of various design aspects, this virtual model helps operators to make better design-stage decisions (Romero et al, 2016a). According to Thorvald et al (2021) in virtual training VR completely immerse the operator into the virtual environment, while AR simply provides physical measures by overlaying a virtual world in their field of view (Thorvald et al, 2021).

Healthy operator: The operator aided by wearable sensors to improve and monitor operator's physical and cognitive capacities throughout industrial tasks by measuring the biometrics of the operators such as heart rate and blood pressure readings. Apple Watch, Android Wear, and Fit-bit are examples of commercially accessible wearable solutions for collecting biometrics data of operators. Wearables can track the operator's position and motions in addition to biometric factors. Wearable data assists smart operators in analyzing operators physical and mental workloads, as well as improving their physical and mental well-being (Romero et al, 2016a). Romero et al (2018) mention that *healthy operators* are more concerned with improving operator's occupational health and safety. Wearables data can be analyzed for notifying operators when they are exposed to hazardous environments or risky operations, stopping equipment in the event of an emergency, and analyzing workers physical and mental stress for tasks (Romero et al, 2018). Romero et al (2018) also claim that in terms of physical ergonomics, body sensors linked to a smart exoskeleton aid to reduce workers' physical workload. The physical strain on the operator is also reduced by modifying the workload depending on measurements from the operator's body sensors. Misuse of operator data, which includes the operator's personal information, is one threat associated with a *healthy operator* (Romero et al, 2018).

Smarter operator: The operator is assisted by Intelligent Personal Assistants (IPA) for operator cognitive interaction. IPA is an Artificial Intelligence (AI)-based software assistance that typically provides voice assistance when interacting with the operator. IPA assists operators with manufacturing tasks such as reading instructions, providing commands for searching tools, scheduling and reminding operational tasks, and troubleshooting suggestions. Siri (Apple), Hey Google (Android), and Alexa (Amazon) are all examples of IPA (Romero et al, 2016a). The smarter operator can use computers, smartphones, and personal assistants to get information like maintenance manuals and instructions (Thorvald et al, 2021).

Collaborative operator: The operator is aided by collaborative robots (cobots) in order to improve operator's physical abilities. In the work environment, cobots will take over or assist in the repetitive and non-ergonomic tasks (Romero et al, 2016a). Romero et al (2016a) mention that assistance with cobots improves the job satisfaction of the operators (Romero et al, 2016a). Challenges in the collaborative work environment include considering the safety aspects of operators in the shared work environment with a cobot and providing adequate communication between humans and machines (Thorvald et al, 2021).

Social operator: The operator is supported by social networking sites in order to improve operator cognitive interaction by improving real-time communication between coworkers. This better communication allows operators to share ideas and improve problem-solving skills. Certain manufacturing industries use public social media platforms like Facebook, Twitter, and LinkedIn to exchange data (Romero et al, 2016a). Romero et al (2016a) argue that improved communication between coworkers helps to improve operator engagement and data sharing, as well as participation in decision-making (Romero et al, 2016a). To communicate with other operators and machines, *social operators* use advanced Human-Machine Interaction (HMI) tools such as industrial social networks or messaging applications. As a result, a social factory is formed. According to Romero et al (2017), operators use social networks to communicate accurate information, provide support, and interact with one another to come up with new ideas. The *social operator* can use social networking sites for data sharing, and multimedia-based real-time communication, including audio or video-based real-time communication (Romero et al, 2017).

Analytical operator: The operator is assisted by big data analytics to strengthen the cognitive capacities of the operators. 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 the production (Romero et al, 2016a). The vision of introducing an *analytical operator* is to improve forecast in manufacturing operations and understand the performance of shop floor operations (Thorvald et al, 2021). Romero et al (2016a) mention that *collaborative operators* (analyze data to ensure safe proximity of the operator to cobot), *healthy operators* (analyze biometrics of operator), and *smarter operator* (collaborated with IPA) are all mixed with the *analytical operator* (Romero et al, 2016a). According to Ruppert et al (2018) operator 4.0 uses IoT-based technologies to provide feedback to different types of operators. These types of feedback can include task instruction support, hazard environment alerting, event noticing, and health-related parameter detection. Operator displays, headsets, smartphones, and smart tablets can all deliver this feedback (Ruppert et al, 2018).

2.2 Psychosocial characteristics of the work environment

Rugulies (2019) defined a psychosocial work environment as," *it basically refers to how the individual experiences and responds to his or her surroundings and thus the individual becomes the focus*" (Rugulies, 2019, p.1). The definition of Rugulies (2019) means that the psychosocial work environment is the response of operators in the workplace. According to Evangelista et al (2021), there are a number of things that have an impact on the psychosocial work environment. Figure 3 depicts these variables. The type of work, the way of completing work, the physical and educational demands of the job, and the tools used for work 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 (Evangelista et al, 2021). According to Stansfeld and Candy (2006), increasing anxiety associated with work creates mental problems in workers. Anxiety in the workplace is linked to a lack of social support among employees, job insecurity, poor participation in decision-making, and increased job demands (Stansfeld & Candy, 2006).
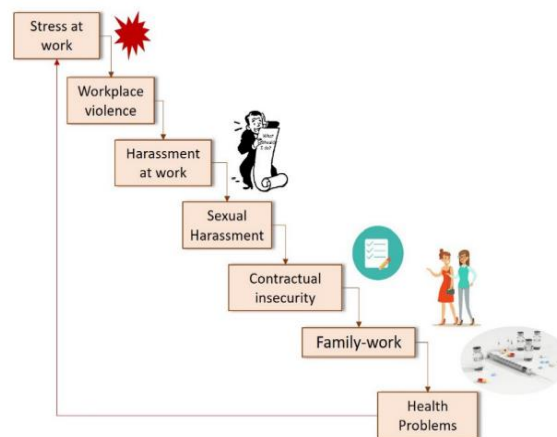
Figure 3: Factors affecting the psychosocial environment of workers (Evangelista et al, 2021)

Danasekaran and Govindasamy (2019) mention that psychosocial impacts related to the work environment make an impact on operator's physical and psychological health, which impacts the productivity of the organization. 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 health diseases including musculoskeletal disorders, hypertension, and gastrointestinal disorders. Workplace stress has societal consequences such as relationship conflict, increased bad behavior (drug and alcohol abuse), and

economic loss (Danasekaran & Govindasamy, 2019). Figures 4 and 5, summarize the sources of psychosocial factors and related impacts of that factors.

JOB CHARACTERISTICS AND THE NATURE OF WORK

Job contents/demands	High physical, mental and or emotional demands, lack of variety, short work cycles, fragmented or meaningless work, under-utilisation, high uncertainty, continuous exposure to people through work
Workload/workplace	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 (space, light, noise, thermal)

Figure 4: Sources and impacts of psychosocial factors in the work environment related to job characteristics (Lovelock, 2019)

SOCIAL AND ORGANISATIONAL CONTEXT OF WORK

Organisational culture and function	Poor communications, low levels of support for problem solving and personal development, lack of definition on organisational objectives
Interpersonal relationships at work	Social or physical isolation, poor relationships with superiors, interpersonal conflict, lack of social support
Role in organisation	Role ambiguity, role conflict, responsibility
Career development	Career stagnation and uncertainty, under promotion or over promotion, poor pay, job insecurity, low social value to work

INDIVIDUAL RISK FACTORS

Individual differences	Coping style, personality, hardiness, resilience
Home-work interface	Conflicting demands of work and home, low support at home, dual career problems

Figure 5:Sources and impacts of psychosocial factors in the work environment related to organizational and individual factors (Lovelock, 2019)

Lovelock (2019) defined 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, 2019, p. 10). Lovelock (2019) mentioned 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 to workplace stress (Lovelock, 2019).

2.3 Summary

The background of this study includes the concept of operator 4.0 typologies and psychosocial work environment characteristics. Romero et al (2016a) introduced eight operator 4.0 typologies assisted with industry 4.0 technologies. The eight operator 4.0 typologies are *super-strength operator, augmented operator, virtual operator, healthy operator, analytical operator, social operator, collaborative operator, and smarter operator* (Romero et al, 2016a). Psychosocial impacts in the work environment are related to the job characteristics and nature of work, social relation in the work environment, and individual factors in the work environment (Lovelock, 2019).

3 Methodology

This chapter includes the overall research method of this study. The first part includes research design, which includes research strategy. The second part includes the overall data generation method of the literature review.

3.1 Research design

Qualitative, quantitative, and hybrid research methods are the most commonly used research methods. This study takes a qualitative method for data analysis. Oates (2005) states that all data other than numerical data is qualitative data and qualitative data analysis necessitates the researcher's abilities. Because the qualitative data analysis lacks a set of procedures (Oates, 2005). The researcher must find concepts and theories that are relevant to the research objectives during qualitative data analysis. A systematic literature review is the chosen strategy for this study. The systematic literature review can be defined as a "*review process used to collect articles, and then a qualitative approach is used to assess them*" (Snyder, 2019, p. 335). The qualitative analysis of published materials such as research articles, conference papers, and conference proceedings was used for this study's analysis. The accessibility of the above-mentioned sources does not interfere with the study because they are available at any time without any ethical issues. A literature review can provide a strong understanding

of relevant subjects such as operator 4.0, psychosocial work environments, worker impacts in the operator 4.0 typology, and changes in the operator paradigm as the industry transitions from 4.0 to 5.0.

3.2 Data generation method

A systematic literature review was the chosen data collection method for this study. Fink described literature review as, "*a systematic, explicit, and reproducible method for identifying, evaluating and synthesizing the existing body of completed and recorded work produced by researchers, scholars, and practitioners*" (Fink, 2019, p. 36). That is, systematic literature review helps to analyze and evaluate the published documents of researchers.

Snyder (2019) mentioned that there are three types of literature reviews. They are systematic, semi-systematic, and integrative literature reviews. A systematic literature review was chosen for this research. The purpose of this research was to learn more about the operator 4.0 typology, the psychosocial environment of workers, and the impact of workers on the operator 4.0 typology. A systematic review collects data that is only relevant for answering research objectives with the least amount of bias and helps to make conclusions (Snyder, 2019).

There are several steps to the literature review process. Snyder described four steps of literature review and they are, "*Designing the review, conducting the review, analyzing the review, and writing the review*" (Snyder, 2019, p. 336). Fink categorizes the process of literature evaluation in a different way than Snyder. They involve determining the study problem, collecting data using keywords, screening the data, analyzing the findings, and writing a review. One of the main goals of a literature review is to inform researchers about existing studies on the topic they have chosen (Fink, 2019). Oates took a new approach to the literature review procedure. To put it another way, a literature review includes searching for relevant sources, analyzing and critically evaluating those sources, and finally writing a review (Oates, 2005).

The systematic literature review of this study data collection is done by secondary sources collected from academic databases. Several databases are chosen for the collection of data from 2016 to 2022. The primary analysis of the document is done by an understanding of the keywords and themes of the document. After primary analysis content analysis of the document is done for understanding the themes, and ideas delivered by the sources for writing a literature review and are relevant to provide answers to the research questions.

4 Literature review process

A literature review process is included in this chapter. The search procedure, selection, and sorting methods are all covered in detail. The literature search method started with the definition of search terms, followed by a database search using those keywords.

4.1 Define keywords

One of the first and most important steps of data collection of the published journal articles are defining keywords for searching. The phrase "*review on the impact of worker's psychosocial environment under operator 4.0 framework*" revealed primary keywords. Operator 4.0, industry 4.0, work environment, effects, and ergonomics are the primary keywords (Table 1).

Table 1: Primary keywords from the phrase (Step 1)

Keyword 1	Keyword 2	Keyword 3	Keyword 4	Keyword 5
Industry 4.0	Operator 4.0	Work environment	Impacts	Ergonomics

Other similar phrases are discovered after defining primary keywords, which helps in the selection of appropriate articles for creating a literature review. Across the reading of the content, other terms linked to the primary keyword are discovered. Table 2 lists terms that are related to primary keywords.

Table 2: Related keywords from phase (Step 2)

Keyword 1	Keyword 2	Keyword 3	Keyword 4	Keyword 5
Industry 4.0	Operator 4.0	Work environment	Impacts	Ergonomics
Industry 5.0	Operator 5.0	Psychosocial work environment	Challenges	Physical
Exoskeleton	Worker	Workers health	Benefits	Cognitive
Augmented reality	Human factor	Social interaction	Difficulties	Musculoskeletal disorder
Virtual reality	Smart operator		Psychological	
Cyber-physical system	Social operator		Physical	
	Healthy operator		Mental	

The databases used include Academic Search Premier, Google Scholar, DiVA Skövde, PubMed, Scopus, ScienceDirect, SpringerLink, and Web of Science. 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 *benefits*", and "*Operator 5.0* AND *challenges*". Only articles from the years 2016 to 2022 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 2022, as well as published articles or conference papers that covers 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 operator 4.0 and should be considered. If the publication year is earlier than 2016, it won't be added for literature review. The final selection of relevant publications is based on the number of citations, year of publication, keywords, objectives, study area, and results.

4.2 Database search

An overview of the database search is shown in Figure 6. Academic Search Premier, DiVA Skövde, Google Scholar, PubMed, ScienceDirect, Scopus, SpringerLink, and Web of Science are the chosen databases for search using above mentioned primary and related keywords. Selection of articles by database search includes searching publications in different databases using above mentioned keywords and also includes articles from the references of collected articles (Figure 6).
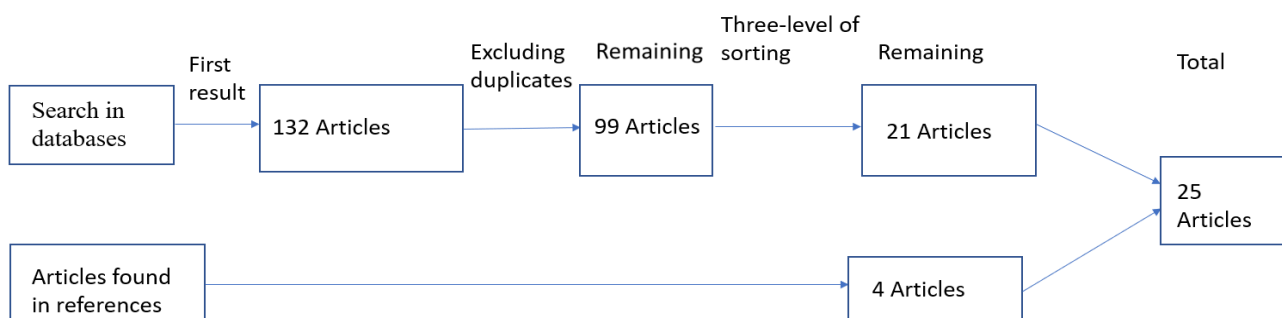

Figure 6: Database search overview

132 articles were found in the first search process, from the databases mentioned above. At first, 33 duplicated entries were removed, leaving 99 items. The articles were then sorted into three levels, the keywords being used to sort the first level. Reading the abstract is the second level of sorting. Reading whole articles is the third level of sorting. After three levels of sorting, there are 21 relevant papers left, and four articles are found from the references. So, a total of 25 articles were left to write a literature review. Figure 7 shows a list of those 25 articles and consists of a majority of journal articles (21), and less amount of conference papers (2), a book chapter, and two master's degree theses. ScienceDirect had the most articles for study out of all the databases. Figure 7 shows the articles that were chosen for review from 2016 to 2022. However, the majority of articles are from 2019 to 2022. [11], [17], and [25] are the most cited publications from the literature review list, with 126, 103, and 119 citations, respectively. Others have not cited [21] and [22] because these are recent publications.

Number	Authors	Number	Authors
1	Baumgartner et al (2022)	14	Kadir et al (2018)
2	Bortolini et al (2020)	15	Kumar and Lee (2022)
3	Chacón et al (2020)	16	Liao et al (2019)
4	Christensen et al (2019)	17	Maurice et al (2018)
5	Danielsson et al (2020)	18	Miller et al (2019)
6	De Assis Dornelles et al (2021)	19	Nazareno and Schiff (2021)
7	De Simone et al (2022)	20	Perez Luque et al (2020)
8	Di Pasquale et al (2021)	21	Reiman et al (2021)
9	Drouot et al (2020)	22	Romero et al (2018)
10	Ekandjo et al (2021)	23	Storm et al (2022)
11	Enrique et al (2021)	24	Van Zoonen et al (2017)
12	Hariharan et al (2020)	25	Wesslén (2018)
13	Kaasinen et al (2022)	26	

Figure 7: Literature list for review

The database search resulted in 25 articles for literature review. The collected articles include journal articles, conference papers, a white paper, and master's degree theses.

5 Scenario planning for theoretical framework design

This section includes planned and chosen scenarios for the designing of the theoretical framework for the psychosocial impact assessment of operator 4.0 typologies. The scenarios represent possible and

expected situations involving operator 4.0 typologies in assembly, maintenance, and training operations. Possible scenarios are identified from the literature and planned scenarios are thoughts or expectations related to identified scenarios. The following are the planned scenarios:

1) Assembly operations:

- *Augmented operator*: AR can provide instructions to operators by projecting or by voice assistance. AR also provides instruction using AR-based handheld equipment like smartphones and tablets (Romero et al, 2016a).

- *Virtual operator*: Training assembly tasks for operators (Romero et al, 2016a).

- *Super-strength operator*: During any overhead task that happens during assembly, the exoskeleton can provide adjustable lift assistance and arm support for the operators (Romero et al, 2016a).

- *Healthy operator*: Wearable sensors can be used to measure posture movement and bio signals such as heart rate related to operators (Romero et al, 2016a).

- *Collaborative operator*: Cobots can be utilized in assembly operations to perform non-ergonomic tasks (Romero et al, 2016a).

- *Smarter operator*: By voice assistance, provides instructions on how to complete tasks, and how to utilize the tool for assembly activities (Romero et al, 2016a).

- *Analytical operator*: Big data analysis is used to analyze data collected from various operators in manufacturing operations (Romero et al, 2016a).

- *Social operator:* Real time communication between operators to share ideas (Romero et al, 2016a).

2) Maintenance operation:

- *Augmented operator*: AR hand held devices such as smartphone can use in maintenance information, where hand held device provide information for maintenance operation (Thorvald et al, 2021).

- *Virtual operator*: Virtual training of operators (Thorvald et al, 2021).

- *Super-strength operator*: Exoskeletons provide physical support for maintenance operators.

- *Healthy operator*: Wearable devices such as smartwatches can deliver instructions and notifications to operators for preventive maintenance.

- *Collaborative operator*: Cobots can used to perform repetitive tasks (Romero et al, 2016a).

- *Smarter operator*: Digital assistance can provide maintenance instructions to technicians and engineers during maintenance operations (Romero et al, 2016a).
- *Social operator*: Used to share maintenance information and problems.

3) Training:
- *Augmented operator*: AR is used to guide operators in their training operations by providing instructions.
- *Virtual operator*: VR can train operators in a virtual environment (Thorvald et al, 2021).
- *Healthy operator*: Wearables can be used to track operator performance in training.
- *Smarter operator*: To provide instructions during training.
- *Social operator:* Social networking sites are used to share training-related information for operators such as training schedules and instructions.

In scenario planning expected and possible situations of operator 4.0 typologies are expressed. Scenarios related to all operator 4.0 typologies are planned and identified in assembly operation. But for training and maintenance operations limited operator 4.0 typologies scenarios are expressed.

6 Analysis and results

This chapter includes the data analysis procedure of the literature review prepared based on 25 articles and results obtained from the data analysis of the literature review.

6.1 Analysis

The review's qualitative analysis is carried out in a two-step approach inspired by Schnell and Holm (2021). The first stage is to identify the categories of psychosocial impacts from the literature review and then map articles into the relevant categories. In the second step, categories are again refined once more by mapping similar ones. It is described in more depth below.

Step 1: From the papers mentioned in Figure 7, noted significant concepts and categories relating to the study objective (Appendix A shows the studied technology and manufacturing operation in selected papers).

Step 2: Associated each of the above categories with relevant articles. Initially, 22 categories were identified based on 23 articles (Appendix B). The categories were then mapped to relevant categories to refine the results, which remained in six psychosocial impact categories (Appendix C). The

categories were then remapped to refine the results, which maintained three categories of psychosocial impacts related to operator 4.0 typologies (Appendix D).

Following the investigation, three main categories of psychosocial impacts with related subcategories were discovered, each of which is linked to a different operator 4.0 typology. In Table 3, all of the psychosocial impact categories and subcategories are listed. Articles with internal reference numbers (refer to Figure 7) are matched to categories and subcategories.

Table 3: Categories of psychosocial impacts identified from the literature review.

Category of psychosocial impact	Impacts in subcategories	Number of articles	Article number
Related with nature of work	Job content/demand, operator control over task, equipment issues	20	[16]; [8]; [7]; [22]; [20]; [25]; [17]; [22]; [15]; [14]; [5]; [10]; [1]; [6]; [24]; [9]; [2]; [9]; [12]; [21]
Related with social and organisational context of work	Work place culture and relationship, career devolopment	12	[10]; [24]; [13]; [23]; [18]; [11]; [6]; [1]; [17]; [8]; [7]; [14]
Related with individual factors	Work place stress	12	[19]; [13]; [6]; [7]; [17]; [1]; [14]; [8]; [15]; [24]; [16]

This literature study revealed three main categories of psychosocial impacts. Impacts include those connected to the nature of work, related to the social and organizational context of work, and related to individual factors. Figure 8 depicts the psychosocial impacts of operator 4.0 typologies with considering the categories and subcategories. Results are described in detail in section 6.2.
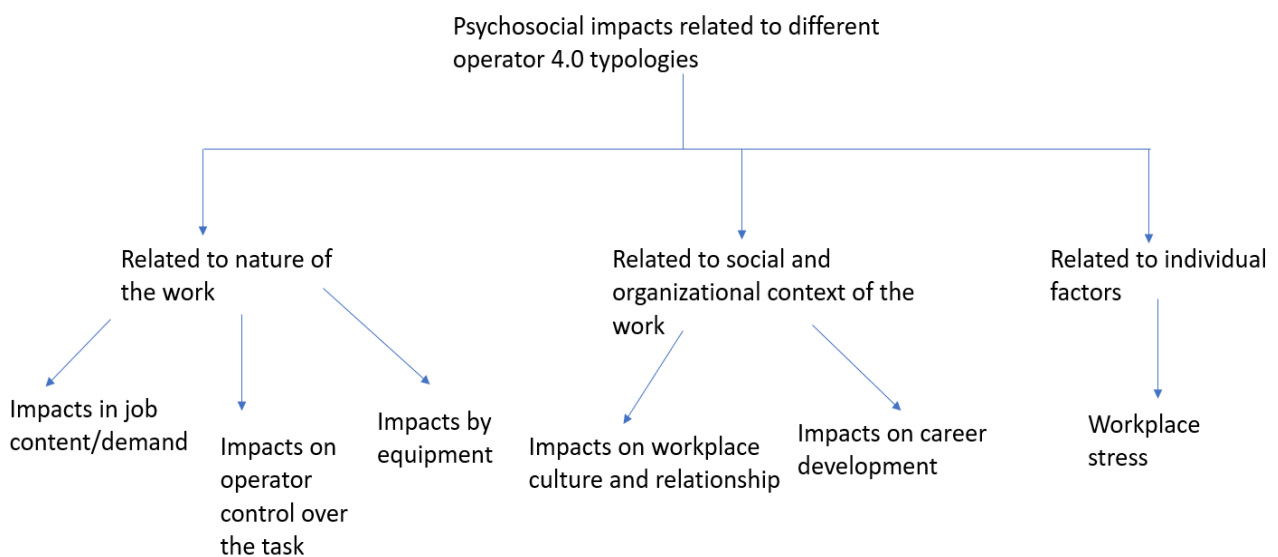

Figure 8: Psychosocial impact sources from literature review related to different operator 4.0 typologies

6.2 Results

This section provides a detailed description of three major categories of psychosocial impacts associated with operator 4.0 typologies resulting from the analysis. All of these psychosocial effects of operators are examined in various production processes. This study assessed various operator 4.0 typologies in assembly, training, and maintenance operations.

6.2.1 Impacts related to the nature of the work

The nature of work-related psychosocial impacts is discussed in this section. Job content/demand, operator task control, and equipment-related impacts are related to the impacts of the nature of work.

Job content/demand: Job content/demand makes an impact on uncertainty in the task, impacts on work cycles in the task, impacts in physical and cognitive workload, and workflow. Reiman et al (2021) mention that increased technology has resulted in more complex manufacturing needs and working environment change as technology advanced. But emphasized with soft skills such as communication skills along with technological skill (Reiman et al, 2021).

Maurice et al (2018) also mention that according to both factory workers and non-factory workers, human-robot collaboration minimizes the physical workload of the *collaborative operators* (Maurice et al, 2018). Reduction in physical work for operators also makes other related impacts for operators. According to De Simone et al (2022) and Di Pasquale et al (2021) cobots are introduced to improve operator physical ergonomics by minimizing physical overwork. Hence cobot decreases work cycles for operators and *collaborative operator's* operation time is reduced even further (De Simone et al, 2022; Di Pasquale et al, 2021). Kadir et al (2018) mention that, assistance with cobot (Universal Robot-UR5) reduces 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 health for years (Kadir et al, 2018).

For *super-strength operators*, the exoskeleton provides physical assistance to reduce the physical workload in assembly tasks (Perez Luque et al, 2020; Wesslén, 2018). But the study by Perez Luque et al (2020) mentions that passive upper-body exoskeleton (MATE exoskeleton) limits the *super-strength operators'* movement (stretching) in assembly operation (Perez Luque et al, 2020). But providing additional equipment to wear creates other impacts for operators. According to Di Pasquale et al (2021), *super-strength operators* feel an increase in their physical burden in terms of qualitative workload for operators by the long-term wearing of an exoskeleton (Di Pasquale et al, 2021).

A survey of IPA users by Liao et al (2021) states that the IPA is not adequately deployed with enough machine-to-human interaction. Hence, task uncertainty emerges because IPA responds differently than the *smarter operator* expects (Liao et al, 2021). Romero et al (2018) mentioned the assessment and the data analytics linked with *healthy operator* helps to monitor physical workload (by detecting biomechanical events such as acceleration and stress) and cognitive workload (by biometrics monitoring such as heart rate monitoring) and so maintain operator well-being in the work environment. Smart exoskeletons, in which body sensors are fixed on the exoskeleton for the ergonomic assessment and helps to assess the risk of musculoskeletal disorder in *super-strength operator*. But continuous monitoring necessitates the formation of a database to store data for analysis of operators (Romero et al, 2018).

AR and VR make an impact on the operator's cognitive workload. Di Pasquale et al (2021) mention that, the transformation from paper instructions to multimedia instructions mixed with AR and VR was shown to reduce *augmented operator* and *virtual operator* cognitive load during operations. Since AR and VR provide only operation-related relevant information for operators and help to improve operators' cognitive abilities and engagement in decision-making. Also, memory and comprehension are improved, and thus the cognitive load is reduced (Di Pasquale et al, 2021). De Assis Dornelles et al (2022) mention that, in manufacturing operations, all information can be provided by AR technologies. Hence *augmented operators* do not have to remember all of the data during the process. As a result, the cognitive workload of operators is lessened. Same way cognitive workload of the *virtual operator* is also reduced. They mention that presenting accurate (task-relevant) information using VR technologies (instead of written documents) increases *virtual operators'* cognitive capacities during operations (De Assis Dornelles et al, 2022).

However, a recent study by Kumar and Lee (2022) mentions that real-time data monitoring in human-machine collaborated smart working environments (AR/VR or human-cobot collaborated environment) provides a significant amount of information related to the machine for analysis. Hence the operator's mental load is increased when a great amount of information is provided (Kumar & Lee, 2022).

Operator task control: Another impact in the category of nature of work-related is impacted in operator task control. Impact on job control, decision-making involvement, problem-solving skills, and work engagement all are related to the impact of operator task control. Each operator typology has various consequences in terms of task control. Di Pasquale et al (2021) and Maurice et al (2018) state that the exoskeleton supports the *super-strength operator* without losing operator control over operations in

the manufacturing industry. Because the operator can continue the operation even if the exoskeleton gets damaged between operations (Di Pasquale et al, 2021; Maurice et al, 2018). Maurice et al (2018) also mention that the *collaborative operator's* control over the work by the cobot is affected differently. Since the cobot has taken over repetitive and physically difficult tasks, the operator's control over the entire task has been reduced. The operation interrupts if a breakdown of cobot happens and the operator alone cannot continue the operation (Maurice et al, 2018).

Danielsson et al (2020) mention that augmented reality smart glass influences the operators. Since the small field of view related to video-based AR smart glass creates difficult-to-understand instructions for inexperienced operators and reduces operator efficiency (Danielsson et al, 2020).

Considering *smarter operators*, according to Ekandjo et al (2021), IPA improves social interactions between operators and managers by facilitating collaboration and providing task direction, as well as assisting in better decision-making and increasing decision-making participation. However, IPA (Alexa, Siri, and Google Assistant) helps operators with all parts of their tasks, including problem-solving, communication, and work scheduling (which helps operators to forecast their working hours). As a result, when operators employ IPA to provide total support, they lose control of their duties. As a result, implementing IPA in a specific organization changes the routines, task control, and task autonomy of operators (Ekandjo et al, 2021).

Van Zoonen et al (2017) claim that introducing social media in the workplace can both raise and decrease work engagement. That is social media improves communication between operators, and work engagement increases as a result of effective communication and co-worker accessibility. But social media increases the volume of data transmitted in the form of texts and emails. Hence work engagement of operators is depleted as a result of this accumulated data (Van Zoonen et al, 2017). An interview on Prima power by Kaasinen et al (2020) concluded that any easily accessing social platform act as a knowledge sharing tool in training, by providing communication within the community as well as with machine providers for better problem-solving (Kaasinen et al, 2020). Regarding *analytical operators,* De Assis Dornelles et al (2022) mention that, 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 operators (De Assis Dornelles et al, 2022).

Equipment-related impacts: Discomfort and health issues are caused by equipment-related impacts. *Super-strength operators*, *augmented and virtual operators*, and *healthy operators* have equipment-related impacts due to their supporting hardware. Perez Luque et al (2020) claim that long-term use of

exoskeletons in assembly activities has been shown to cause discomfort for *super-strength operators* because the biomechanical load moves from the designated muscle to others by the operator's posture adjustments and the weight of the hardware. The *super-strength operator* is frequently bothered by the exoskeleton's weight. The exoskeletons may potentially induce psychological issues such as clumsy feelings and discomfort for operators when worn for an extended period (Perez Luque et al, 2020). Di Pasquale et al (2021) also mention that the operators are aware that the exoskeleton can assist older operators by providing additional strength to support them. However, older operators are reluctant to accept this technology because they feel that carrying additional weight in long term creates discomfort and injury (Di Pasquale et al, 2021).

Considering *healthy operators*, Bortolini et al (2020) proposed a Motion Analysis System (MAS) for tracking the performance of operators in assembly operation by wearable sensors and cameras. They mention that measurement from sensors can be analyzed from an ergonomic perspective by means of ergonomic indices such as Rapid Upper Limb Assessment (RULA) (McAtamney & Corlett, 1993) and Rapid Entire Body Assessment (REBA) (Hignett & Mcatamney, 2000). Those assessment helps to improve the operator's physical and cognitive ergonomics, such as assessing the risk of musculoskeletal disorder and thus improving the work environment (Bortolini et al, 2020). Maurice et al (2018) state that using wearable sensors for the measurement of bio-signals and posture movements aids the *healthy operator* in self-assessing and self-correcting assessments, as well as preventing the risk of musculoskeletal disorders (Maurice et al, 2018). But Di Pasquale et al (2021) mention that, the operator's performance in physical and cognitive ergonomics aspects is improved by means of data analyzed from wearable sensors. But the usage of wearable sensors for an extended period of time causes discomfort for the operators and operation with improved physical and cognitive ergonomics might increase the time to complete the operation (Di Pasquale et al, 2021).

Considering *augmented and virtual operators* one of the equipment impacts related to AR and VR is the hardware weight of AR and VR. Danielsson et al (2020) mention that head-mounted video displays like the Microsoft HoloLens cause operators to experience vision-related discomfort like motion sickness as a result of the unbalanced centers of mass of hardware. Head-mounted displays for AR may cause pain in the head and neck (Danielsson et al, 2020). Enrique et al (2021) mention that using AR devices such as video-based glasses, optical glasses, video-based tablets, and spatial projectors makes operators experience hands-free operation. But the weight of video-based glasses creates physical ergonomics problems for operators. Virtual object overlaid in environment interrupt if the tablet camera gets disturbed by operator hand movement. Long-term usage of VR-based head-

mounted devices causes discomfort and vision difficulties for operators, such as blurry images (Enrique et al, 2021). According to Di Pasquale et al (2021) and Enrique et al (2021), AR has certain pain and physical ergonomic issues if the *augmented operator* is currently wearing prescription glasses (Di Pasquale et al, 2021; Enrique et al, 2021). However, investigations of the operator's experience with an AR system by Hariharan et al (2020) suggest that AR-based instructions via projected displays, head-mounted displays, and other augmented technologies such as AR-enabled devices help to reduce head and eye movement for operators. While utilizing machines with hand-held AR devices such as tablets and mobile phones, the operator's movement is restricted (Hariharan et al, 2020).

Another equipment-related impact experienced by *augmented* and *virtual operators* is vision-related problems by long-term exposure to AR and VR. De Assis Dornelles et al (2022) claim that *augmented operator*s and *virtual operators* experience vision-related and other health issues such as motion sickness. 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. The *virtual operator* employs VR equipment such as head-mounted displays and projected screens. However, long-term usage of VR technology causes eye strain and vision problems in the *virtual operator* (De Assis Dornelles et al, 2022). According to Drouot et al (2021), studies of optometric testing of both paper and digital instructions show that staring at AR screens and equipment causes operators' eyesight to degrade and their eyes to suffering (Drouot et al, 2021).

6.2.2   Impacts related to the social and organizational context of work

The social and organizational context of work-related psychosocial consequences is discussed in this section. The social and organizational context of work is influenced by workplace culture and relationships, as well as career development.

Workplace culture and relationships: Workplace communication and social relationships, workplace isolation, and discrimination are related to the impacts of the workplace culture and relationships. Ekandjo et al (2021) mention that, IPA improves collaboration with co-workers and gives task direction in the work environment. This teamwork also enhances operators' and supervisors' social interactions (Ekandjo et al, 2021). One of the scenarios related to IPA is using voice commands to engage with operators and offering information and directions for human-machine interactions (Romero, 2016a). But, De Assis Dornelles et al (2022) mention that, the voice assistant in the majority

of IPA is accessed using only a few languages. Which results in job discrimination based on language (De Assis Dornelles et al, 2022).

Communication and isolation in the workplace can affect *social operators*. According to Van Zoonen et al (2017), using social media as a platform provides for 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 generates an unfavorable work environment for operators (Van Zoonen et al, 2017).

Considering *augmented and virtual operators*, De Assis Dornelles et al (2022) mention that AR-enabled portable devices such as tablets and smartphone devices can connect with superiors remotely. This increases peer support for operators doing autonomous tasks and minimizes the cognitive load on the task. It also helps to boost the operator's work satisfaction and productivity (De Assis Dornelles et al, 2022). But Miller et al (2019) claim that, as a result of losing eye contact with non-users, operators wearing AR headsets feel less socially connected to other operators (Miller et al, 2019). According to Enrique et al (2021), VR cannot be used in situations where an operator requires to interact with the real world (Enrique et al, 2021).

Considering *collaborative operators*, Storm et al (2022) claim that cobot implementation affects the work environment for both the operator and the cobot, minimizes operator engagement, and socially isolates *collaborating operators* in the workplace by reducing human operators in the work environment. But differently-abled personnel, such as those with autism or other abilities, may benefit from this type of socially isolated work environment (Storm et al, 2022).

Career development: Career opportunities and job insecurity are two factors that affect career development in operator 4.0 typologies. *Collaborative and smarter operators* have a greater impact on career opportunities. When comes to *smarter operators*, Ekandjo et al (2021) state that 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 (Ekandjo et al, 2021). De Simone et al (2022) mention that, in a human-robot collaborative environment, operators are encouraged to study programming and machine learning techniques in order to improve human-robot interactions, and broadening operators career opportunities (De Simone et al, 2022). Kadir et al (2018) also mention that cobots are employed to undertake repetitive and complex tasks, giving the

collaborative operator more time to do other things and get chance to acquire new skills and take on new tasks such as quality control, production planning (Kadir et al, 2018). But the introduction of cobots creates job insecurity in operators, according to a study done by Maurice et al (2018) with factory workers and non-factory workers (Maurice et al, 2018). Maurice et al (2018), Di Pasquale et al (2021), and Baumgartner et al (2022) mention that, the introduction of cobots raises concerns among operators about job security and the transfer of operators' technical skills to a machine. Job insecurity arises due to physical jobs being reduced from operators to the cobots in the collaborative work environment (Maurice et al, 2018; Di Pasquale et al, 2021; Baumgartner et al, 2022).

6.2.3 Impacts related to the individual factors

In this part, the individual-related psychosocial impacts are discussed. Workplace stress is one of the individual-related psychosocial impacts.

Workplace stress: Workplace stress interrupts work-life balance, causes mental stress in operators, and causes disruption in the workplace. Operators may experience mental stress for a variety of reasons. Nazareno and Schiff (2021) mention that changes in the work environment towards the job (variation in job type and skill level) resulting from automation might create stress for operators (Nazareno & Schiff, 2021). The *healthy operator* may experience mental stress as a result of continuous assessment. According to Kaasinen et al (2020) data collection via wearable sensors develops a negative attitude among *healthy operators*. Since operators are unaware of the use of real-time data measured from them and causes them stress (Kaasinen et al, 2020). Romero et al (2018) claim that constant monitoring increases anxiety in *healthy operators* as they believe that the accessed health data might be used to promote or dismiss them (Romero et al, 2018). Maurice et al's (2018) study with the factory and non-factory workers mention that the assessment creates work performance stress for the operator when an operator is unable to follow the instructions and suggestions regarding the operations. Non-factory workers also point out that continuous real-time data monitoring poses a threat to privacy as the collected information includes a productivity track of the operators (Maurice et al, 2018).

Collaborative operators experience mental stress due to different reasons. According to non-factory workers interviewed by Maurice et al (2018), the *collaborative operator* may experience mental stress due to a loss of task control in a collaborative work environment (Maurice et al, 2018). Baumgartner et al (2022) mention that, cobot performs manufacturing operations with higher speed of performance than operators, allowing the operator to concentrate on more vital tasks by ensuring ergonomic aspects. However, this creates a new source of anxiety for the operator, because if he or she were to perform a

less difficult duty at a slower speed, his or her official status would be questioned, and he or she would experience mental stress as a result of the slower speed, and he or she would feel that he or she had a low level of participation in decision-making (Baumgartner et al, 2022). Baumgartner et al (2022) and Storm et al (2022) mention that the safety measures disable cobots when a human presence is detected however operators are not necessarily aware of this mechanism, which causes trust concerns and anxiety to operators about the possibility of a collision in the collaborative work environment (Baumgartner et al, 2022; Storm et al, 2022). Another source of mental stress for the *collaborative operator* was mentioned by Kadir et al (2018). According to Kadir et al (2018), when irregularities occur in the workplace cobots are unable to observe and adjust to the circumstance since they follow a set of instructions in manufacturing activities. Because of these added responsibilities for quality monitoring, operators become frustrated and lose trust in cobots (Kadir et al, 2018). De Simone et al (2022) claim that 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 for the operators regarding their work performance (De Simone et al, 2022).

De Assis Dornelles et al (2022) mention that, for the *augmented operators* in the manufacturing industry, instructions on a projected screen, voice assistance, and hand-held device assistance can all divert the 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 mention that 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 (De Assis Dornelles et al, 2022). Conflict in the work-life balance is another influence linked to individual factors. Van Zoonen et al (2017) claim that users can publish both personal and professional information on public social networking networks. Hence introducing social media platforms for data sharing in the workplace cause conflict in work-life balance (Van Zoonen et al, 2017). According to Liao et al (2019), most digital assistants 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 (Liao et al, 2019).

The results indicate that all planned scenarios are not available for studying the psychosocial impacts of operator 4.0 typologies from published information. Based on the results of the literature review analysis, Table 4 indicates the studied manufacturing operations related to the operator 4.0 typology.

Table 4: Operator 4.0 typology and studied manufacturing operation in the literature review

Operator 4.0 typology	Manufacturing operation
Collaborative operator	
Analytical operator	
Super-strength operator	Assembly operation
Augmented operator	
Virtual operator	
Healthy operator	Assembly, Training, and Maintenance operation
Social operator	Training operation
Smarter operator	Maintenance operation

6.2.4 Summary of the result of literature review analysis

Table 5 indicates the summary of results studied in mentioned (Table 4) manufacturing operations.

Table 5: Summary of results

Psychosocial impacts related to operator 4.0 typologies			
Operator 4.0 typology	**Pros**	**Cons**	**Between pros and cons**
Healthy operator	➢ Helps to maintain well-being of operator by monitoring physical and cognitive workload of operator. ➢ Help to assess risk of musculoskeletal disorders.	➢ Long term wear of sensors create discomfort for operators. ➢ Mental stress related to continuous assessment.	

	➢ Provide self-evaluation.	➢ Privacy concern related to collected data.	27
Augmented operator	➢ Reduce cognitive work load in operator. ➢ AR-based instructions help to reduce head and eye movement for operator. ➢ AR based devices makes operators hands free in operation. ➢ AR hand held devices improve collaboration between operators and superiors. ➢ Improved participation in decision making.	➢ Video based augmented reality smart glass reduce operator efficiency. ➢ Video based head mounted displays create visual discomfort, pain, and headache for operators. ➢ AR hand held devices limits the operator movement. ➢ Distraction in the work environment increase performance stress.	
Virtual operator	➢ Improve operator cognitive capabilities in manufacturing operations.	➢ Virtual reality head mounted displays create discomfort, eye strain and vision problem for operators. ➢ Creates physically isolated work environment.	
Super-strength operator	➢ Helps to reduce physical work load for operators.	➢ Long term wear creates discomfort and burden for operators.	

	➤ Does not make impact in operator control over operation.	➤ Elder operators feel discriminated in work environment by carrying extra weight.	28
Collaborative operator	➤ Reduces physical workload for operators. ➤ Create career development for operators.	➤ Operator's feel reduced control over the entire task. ➤ Creates socially isolated work environment. ➤ Creates job insecurity. ➤ Create mental stress regarding loss of task control, risk of collision, performance, and increased responsibilities.	
Analytical operator	➤ Improve operator decision making efficiency by analyzing data quickly. ➤ Build database to store data.	➤ Real-time monitoring causes information overload and increase cognitive load for the operator.	
Smarter operator	➤ Improved participation in decision making. ➤ Provide continuous learning platform for operators.	➤ Chance of uncertainty in the operation. ➤ Operator lose control in the operation.	

		➢ Possibility of language-based discrimination in the work environment.	29
Social operator	➢ Improve communication between co-workers. ➢ Improve problem solving skill of operators.	➢ Chances of workplace conflict due to shared data. ➢ Chance to get distracted with social media. ➢ Fearful to share ideas on social networking platforms. Since they feel that they will be judged based on their ideas. ➢ Chances of conflict in work life balance.	➢ Impact on work engagement of operators.

7 Theoretical framework for psychosocial risk assessment

This chapter includes an overview of psychosocial risk assessment methods and a theoretical framework designed for psychosocial risk assessment for operator 4.0 typologies based on the impact resulting from the studied manufacturing operations. the psychosocial risk assessment framework for operator 4.0 typologies was proposed by relating the psychosocial impacts of operator 4.0 typologies to an already existing psychosocial risk assessment method developed by other researchers and organizations.

7.1 Psychosocial risk assessment methods

Psychosocial risk assessment is aimed to prevent accidents and health problems in the work environment. Figure 9 indicates the methodology of psychosocial risk assessment (European Commission, 2018).

Figure 9: Methodology of psychosocial risk assessment (European Commission, 2018)

The European Union information agency for occupational safety and health (EU-OSHA) has published a guide that outlines comprehensive recommendations for assessing psychosocial impacts in the workplace (European Commission, 2018). The EU-OSHA guide reviewed different perspectives of psychosocial impacts in the workplace and mentioned psychosocial impact as physical, psychological, and social consequences that may be influenced by the social and environmental surroundings of the operators. According to the EU-OSHA guide psychosocial risk assessment can conduct in a four-phase procedure (Figure 9). The first phase in the technique is to identify the psychosocial effects and risks associated with the workplace. The company managers or human resource personnel related to company can conduct the assessment in the workplace by including all individuals in the workplace and using proper techniques. The second stage is to assess the consequences and prioritize them based on the related risks and the possible adverse consequences. Then take action to reduce those impacts and risks after prioritizing the identified psychosocial risks. That is, take preventative measures to limit the causes of risk and their consequences. The situation linked with psychosocial consequences is then reviewed. In this case, the company managers or human resource personnel related to company should assess each situation to determine the consequences and risks, and make appropriate changes to avoid psychosocial consequences for each operator. According to the EU-OSHA guide, Online interactive

Risk Assessment (OiRA) tool, Stress prevention at work checkpoints, and the Scandinavian QPS Nordic questionnaire are different types of psychosocial risk assessment methods. These methods are using questionnaires, interviews, surveys, observations, checklists, and templates for the psychosocial impact assessment (European Commission, 2018).

7.2 Theoretical framework design

This section includes the design of a psychosocial risk assessment framework for operator 4.0 typologies by relating the possible psychosocial impacts of operator 4.0 typologies resulting from a qualitative analysis of the literature review to an already existing psychosocial risk assessment method developed by other researchers and organizations. Chapter 5 introduced some identified and expected scenarios related to operator 4.0 typologies in assembly, maintenance, and training operations for the design of the psychosocial impact assessment framework. But the analysis results show that all operator 4.0 typologies are not studied in assembly, maintenance, and training operations (refer Table 4). The framework is proposed based on the findings of the literature review analysis by combining the operator 4.0 typology with an already existing psychological risk assessment tool proposed by researchers and organizations. The steps for designing the psychological risk assessment framework are as follows:

1. Select the risk assessment method related to operator 4.0 typology: The method has been selected by relating possible psychosocial impacts of operator 4.0 typology to the already existing risk assessment methods based on literature review analysis results.
2. Design theoretical framework: This step includes designing the theoretical framework based on the selected psychosocial risk assessment methods.

7.2.1 Selection of risk assessment method

Based on the following inclusion criteria, a psychosocial risk assessment method connected to operator 4.0 typology is chosen among the various already existing assessment methods. The inclusion criteria are,

1. The risk assessment method should not be older than 2000.
2. The method should be free of cost. That is, the method does not charge any subscription charge when it is downloaded from the web page.
3. The method is simple to find and use.

4. The method has a minimum condition for use. That is, the authors of the risk assessment tool have defined only a minimum criterion for managers, researchers, production engineers, human resource personnel to access the risk assessment methods.

5. The selected existing risk assessment tool should contain satisfying assessment criteria to relate to the psychosocial impacts of operator 4.0 typologies.

Considering the results of literature review analysis and inclusion criteria, the following are the selected psychosocial risk assessment methods.

1. International Labour Organization (ILO) stress checkpoints[1].

   According to Owen and Dollard (2018), ILO launched this tool in 2012. 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. At each checkpoint, operators can react with 'Yes, No, and Priority'. If any operator responds with a 'Yes' or a 'Priority,' there is a section where they can make comments about that impact. Following the evaluation, managers or human resource personnel meet with representatives from the operators to discuss the assessment's conclusions in order to reduce psychosocial impacts. This tool can help organizational managers, human resource managers, and health and safety practitioners. This tool is free to download from the Apple and Google Play stores as 'ILO Stress Checkpoints'. The tool is in English. There are no restrictions when it comes to using this method (Owen & Dollard, 2018).

2. OiRA tool

   This technique was created by the EU-OSHA for psychosocial risk assessment. This tool is easy to download for free from the OiRA web page for managers based on the industrial sector for assessment in different languages and countries. This application can also assist companies and organizations in developing risk assessment tools specific to the industrial sector. Results of the evaluation were used to improve working conditions (European Commission, 2018).

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[1]Tool can be accessed from http://www.ilo.org/wcmsp5/groups/public/@ed_protect/@protrav/
@safework/documents/instructionalmaterial/wcms_177108.pdf

3. Work Design Questionnaire (WDQ)[2]

> According to Owen and Dollard (2018) this tool is primarily used to assess the effects of work-related characteristics. Morgeson and Humphrey developed the technique in 2006 (Morgeson & Humphrey, 2006). It takes the form of a self-report questionnaire with 77 questions, and the operator can grade each question on a 1-5 scale to indicate whether the operator agrees or disagrees with the proposition. Questionnaires on task characteristics include the autonomy of the operator in the task, superior feedback in the task, task complexity, and knowledge demand in information processing. Social aspects of the 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 worker's equipment. However, managers must satisfy the criteria in order to use this technique 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 can be translated into (Owen & Dollard, 2018).

7.2.2 Design of the theoretical framework

Based on the possible psychosocial impacts (Table 5) linked to the studied situations (Table 4) as a consequence of the analysis of the literature review, a framework for the risk assessment of operator 4.0 typologies was proposed. All tools in the proposed framework are already existing self-report questionnaires that help operators to address psychosocial impacts and their suggestions of those impacts. Hence, the suggested framework links currently available tools to the psychosocial impact assessment of operator 4.0 typologies. Without using sensor-based measurements of operators, all of these tools assist managers, human resource personnel, researchers, and production engineers in addressing the psychosocial effects of operators.

For the design of the theoretical framework, possible psychosocial impacts of operator 4.0 typologies have to be considered. According to the results of the literature review analysis, when *virtual operator*, *healthy operator*, *augmented operator* (in assembly, maintenance, and training operation), and *super-*

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[2] Tool copy can be downloaded for free at https://msu.edu/~morgeson/English_WDQ.pdf

strength operator (in assembly operation) are considered for psychosocial impact assessment, psychosocial impacts related to job control, social support, and equipment-related impacts should be considered. In WDQ, all these assessment criteria are included. Hence WDQ can be used for the psychosocial risk assessment of *virtual operator*, *healthy operator*, *augmented operator*, and *super-strength operator*.

Considering the *collaborative operator* (in assembly operation) for psychosocial impact assessment should consider impacts including implications on job demand, job control, and organizational impacts related to work environment changes. All these impacts are included ILO-based checkpoints of 50 checkpoints. That is, impacts on work environment (checkpoints 21-23), job demands (checkpoints 6-10), job control (checkpoints 11-15), workload, and working time (checkpoints 26-30). Hence *collaborative operator* (in assembly operation) can use ILO stress checkpoints as the psychosocial impact assessment tool. Considering the *social operator* (in training operation) for psychosocial impact assessment, impacts related to social support for operators, data communication between operators, and work-life balance should be considered. Considering the *smarter operator* (in maintenance operation) for psychosocial impacts assessment, 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 operation) and the *smarter operator* (in maintenance operation) are included in the ILO stress checkpoint assessment criteria. That is, impacts related to social support (checkpoints 16-20), data communication (checkpoints 46-50), work life balance (checkpoints 26-30), and job control (checkpoints 11-15). Hence *social operator* and the *smarter operator* can use the ILO stress checkpoint as the psychosocial impact assessment tool.

Based on the findings from the limited literature related to the *analytical operator*, the OiRA tool was suggested as the tool for the psychosocial impact assessment for the *analytical operator* (in assembly operation). Because in the OiRA tool, the risk assessments can be created by managers, human resource personnel, researchers, and production engineers for impact assessment of operators in any language and any sector in a standard manner and that assessment can be updated in the future. Hence this updatable tool is chosen to add the future studied impact for assessment of *analytical operator*. The proposed framework is tabulated in Table 6.

Table 6: The proposed framework for the risk assessment of operator 4.0 typologies in studied operations

Operator 4.0 typology	Proposed psychosocial impact assessment method	Manufacturing operation
Healthy operator		Assembly, Training, and Maintenance operation
Augmented operator		
Virtual operator		
Super strength operator	WDQ	
Analytical operator	OiRA tool	
Collaborative operator		Assembly operation
Smarter operator		Maintenance operation
Social operator	ILO Stress checkpoints	Training operation

8 Discussion

The study began with two study objectives. The first objective (refer to section 1.2) was to determine the possible psychosocial effects of the operator 4.0 typologies. The second objective (refer to section 1.2) was to identify the changes in the operator paradigm as the industry transitions from 4.0 to 5.0. A systematic literature review approach is used in the study to answer the study objectives. This study only used data from published sources, such as conference papers, book chapters, and journal articles, instead of my own empirical data.

The study considered operator 4.0 typologies in assembly, training, and maintenance operations. The available literature shows that the operator 4.0 typology is continually growing in terms of the technologies that will be required to transform an operator 4.0 from a traditional industrial operator. Technology except AR needs further study regarding operator assistance in all manufacturing operations. According to the study findings, the selected published sources discussed the psychosocial impacts of the *augmented operator* in assembly, training, and maintenance operations. That is, from the 25 collected articles, seven papers included the study of AR in assembly operations and two-three papers were included training and maintenance operations. A limited number of studies are available to study the psychosocial impacts of *analytical*, *smarter*, and *social operators* in manufacturing operations (see in Appendix A).

According to study results, only Alexa, Siri, and Hey Google or Google's Assistance are used by *smarter operators* as digital assistance, and operators do not use any industry-specific AI voice digital

assistance (Romero et al, 2016a; Liao et al, 2019; Ekandjo et al, 2021). Study results also show that only public social networks, such as Facebook, Twitter, and LinkedIn are used in the workplace and operators do not use any industry-specific networking platforms (Romero et al, 2016a; Van Zoonen et al, 2017). The selection criteria for operator aiding technology in the manufacturing industry and methods for evaluating an operator to make sure that the helping technology is suitable for each operator are absent from studies on operator 4.0 typologies (Mark et al, 2021).

Studies also shows that operators might be hesitant to accept new technologies in their workplace. For each operator, fear can be induced by many reasons. Operators might be hesitant to accept new technology because of this fear. Operators in collaborative work environments might be afraid of working with cobots because they believe that introducing cobots will transfer their technical expertise to a machine (Di Pasquale et al, 2021). Job insecurity is another factor that makes operators afraid of cobots in the workplace. By implementing cobots, manufacturing companies can decrease the number of human operators in physically demanding operations, which makes the operators worried about losing their jobs. Another concern for *collaborative operators* is their safety in a collaborative workplace. The safety measures (ISO/TS 15066:2016) disable cobots when a human presence is detected. But, operators can be unaware of these security mechanisms and cause trust concerns (Kopp et al, 2021).

Operators' fears about accepting IPA are linked to risk in privacy. Since VA is capturing the user's every word, those data can be accessed by malicious attacks and can misuse the data such as unlocking voice authenticated devices (Bolton et al, 2021). Smart wearables come with a number of difficulties. Battery life of a wearable solution, user convenience, data processing of large amounts of data from various devices, device connectivity problems, and power consumption for underground operators are all technological challenges (since currently available solutions like Wi-Fi, Zigbee, and Bluetooth are limited to short-distance communication with significant delay) (Svertoka et al, 2021). However, a social difficulty with wearables is operator discomfort from long-term use, as well as privacy and security concerns. According to studies, smartwatches such as wearables can be hacked and hand movement information reproduced, and this information can be utilized to retrieve any personal or professional security keys (Kapoor et al, 2020). The exoskeletons provide ergonomically balanced work postures for the operators. However, they are less acceptable for older personnel because they worry that the exoskeleton would make additional weight for them due to its hardware (De Assis Dornelles et al, 2022). The typology of *analytical operator* is not much studied. *Smarter operator and*

social operator is not much investigated from the viewpoint of manufacturing operation, but rather from the standpoint of implementation in the work environment.

The study proposed a theoretical framework for the psychosocial risk assessment of operator 4.0 typologies only considering single operator 4.0 typology. But studies show that all operator 4.0 typologies are not always single but can be mixed. A hybrid form of operator 4.0 typology was mentioned by Romero et al (2016a) and Romero et al (2018). They mentioned a hybrid form as smart exoskeleton, in which body sensors in exoskeleton helps to assess the risk of musculoskeletal disorder of operator. They also mentioned adaptive cobots as another hybrid form of operator 4.0 typology, those adaptive cobots can adjust assistance to operators by measuring the parameters of the operator using body sensors such as pulse sensors (Romero et al, 2018). The *analytical operator* can be mixed with the *collaborative operator*, *smarter operator*, and *healthy operator* (Romero et al, 2016a). Considering the risk assessment method for hybrid operator 4.0 typologies, any operator 4.0 typology mixed with *augmented operators*, *virtual operators*, *super-strength operators*, and the *healthy operator* can use WDQ as the risk assessment. Because among the proposed methods, only WDQ can assess the equipment-related impacts. OiRA tool is proposed for *analytical operators*. If any other operator 4.0 typology is mixed with the *analytical operator*, that can use the proposed methodology of that mixed operator 4.0 typology (refer Table 6) or can use OiRA tool by updating the assessment criteria of OiRA tool based on the mixed operator 4.0 typology.

Operator 5.0, which is the study's second goal (refer to section 1.2), is still in its early phases of development. Romero and Stahre (2021) termed operator 5.0 as "Resilient Operator 5.0" and defined as, "*a smart and skilled operator that uses human creativity, ingenuity, and innovation empowered by information and technology as a way of overcoming obstacles in the path to create new, frugal solutions for guaranteeing manufacturing operations sustainable continuity and workforce wellbeing in light of difficult and/or unexpected conditions*" (Romero & Stahre, 2021, p. 1090). Operator 5.0 means an operator with the ability to resist unexpected events in operations, according to the definition of operator 5.0. The need for resilience operators was created as a result of the Covid-19 pandemic's consequences on the manufacturing industry. The key goal was to keep the production line going in the case of unexpected events. The purpose of operator 5.0 is to establish a sustained, resilient, and human-centered operator paradigm. One of the examples of operator 5.0, in a collaborative work setting, cobots move away from just following a program and instead analyze operator intent by utilizing machine learning, vision cameras, and deep learning to understand human operator behaviors. This environment brings up new career options as Chief Robotics Officer (CRO). CRO

encourages autonomy in decision-making and task distribution in collaborative settings (Romero & Stahre, 2021; Mourtzis et al, 2022).

Sustainability: Implementation of operator 4.0 typologies helps to support the sustainable industrial development goals in the workplace (goal 5 regarding gender equality, goal 9 regarding industry, innovation, and infrastructure, and goal 12 regarding sustainable consumption and production) mentioned in the 2030 agenda for sustainable development (EU, 2021a; EU, 2021b; EU, 2021c). One of the targets of goal 9 is to promote sustainable industrialization. The social sustainability of operators can be achieved by ensuring their health and safety workplace. Considering operator 4.0 typologies, implementation of the *healthy operator* can ensure the sustainability of operators by real-time monitoring of operators including posture movement and biometrics data by smart wearable solutions. Also, the implementation of cobots can improve the sustainability of operators. This since *collaborative operators* are not subjected to repetitious and physically demanding tasks and help to maintain the operator's health by providing an ergonomically (physical) balanced work environment and reducing accidents in the work environment. Considering goal 5, the target is to promote gender equality and empower women in the work environment. This goal can be achieved by the implementation of a *super-strength operator*. The exoskeleton provides physical support for operators in manufacturing operations. Hence women can perform physically challenging tasks by wearing exoskeletons. Considering goal 12, targets include sustainable consumption of resources and waste reduction. Sustainable consumption of resources can be achieved by implementing AR, VR, social networks, smartwatches, and IPA technologies of operator 4.0. All these technologies transform paper instruction into digital instruction and thus reduce the resource consumption for paper making. Regarding waste reduction, virtual training can achieve a waste reduction compared to physical training. Implementing big data analytics for the analysis of operations helps to forecast operations and can predict machine breakdown and helps to avoid fault products.

This study does not use any simulation tools or the collection of empirical data. The study of the psychosocial impacts of operator 4.0 typologies and suggestion of a risk assessment method for operator 4.0 typologies are based on reviewing documents such as published research articles, conference papers, conference proceedings, and white papers related to the study objectives. To create the suggested framework, possible and expected scenarios of operator 4.0 typologies were prepared based on the collected papers. Then theoretical framework was proposed by relating the psychosocial impacts of operator 4.0 typologies to an already existing psychosocial risk assessment method developed by other researchers and organizations. Operator 4.0 typologies are connected with VPD.

VR can use the combination of interactive virtual reality with simulations of real-world situations for decision-making. Such as in product design operators can create 3D virtual models of desired products using 3D models in CAD software tools and VR, and operators can use those simulation tools to check the impacts in the virtual model by variation in design layouts and specifications (Romero et al, 2016a).

In terms of the operator 4.0 typology's present use cases, AR, VR, exoskeletons, social networks, and wearables are all in use. The following are a few of them. The most common application of AR is to project instructions or provide remote assistance to operators. Instead of sending on-site technicians, Howden Compressors organization with PTC organization deployed remote help with augmented reality for the operators to facilitate troubleshooting with shared photos and videos during the Covid-19 pandemic. The transportation company DB Schenker implemented exoskeletons provided by the Ottobock organization in logistics to help operators in lifting operations. Grupo Bimbo with Parsable organization used a software-as-a-service (SaaS) platform to aid shop floor operators in incident investigation. GAP organization with ProGlove was employed in the form of a scanning glove by wearables to ensure operators micro ergonomics in their hands during operations (World Economic Forum, 2022).

9 Conclusion

A systematic literate review approach is used to study the possible psychosocial impacts related to the operator 4.0 typologies. Only the first objective of the study's two objectives (refer section 1.1) is being studied. Major possible psychosocial impacts related to operator 4.0 typologies are, impacts connected to the nature of the work, the impacts related to the social and organizational context of work, and impacts related to individual factors. The framework is proposed by connecting already existing self-report questionnaire psychosocial impact assessment to psychosocial impact assessment of operator 4.0 typologies based on the studied scenarios and possible psychosocial effects of operator 4.0 typologies, rather than any method based on sensors. *Healthy operators* can employ sensor-based impact evaluation. The study did not take wearable solutions-based tools in the designed framework of psychosocial impact assessment, due to the discomfort that sensor-based measurement causes for operators, the stress that continuous monitoring causes for operators, and the privacy risks associated with wearable measurement (data can be hacked). Using the self-report questionnaires operators can submit their views and opinions concerning the psychosocial effects which they experienced in the work environment. The suggested framework of psychosocial risk assessment can be used by managers, production engineers, human resource personnel, and researchers. They can use this

proposed tool to survey the operators. For evaluation, the manager, human resource personnel, production engineers, researchers, and representatives from operators can discuss the study conclusion and possible action plan to reduce the impacts.

Study findings show that all operator 4.0 typologies are not studied in assembly, training, and maintenance operations. Augmented reality is the most studied technology in the manufacturing process. There are insufficient resources to investigate the second objective. Operator 4.0 aimed to create a socially sustainable and human-centric technology for operators in the industry. Operator 5.0, provides resilience capabilities to the operator 4.0 abilities. Taking into account the findings of the review, equipment related impacts can be minimized by user convenient design of equipment. The reluctance of operators necessitates the awareness program for operators regarding the operator 4.0 typologies.

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Appendix A: Studies selected for systematic literature review

No	Authors	Technology 4.0	Manufacturing activity
1	Baumgartner et al (2022)	Collaborative robots	Manufacturing industry*
2	Bortolini et al (2020)	Augmented reality and smart wearable sensors	Assembly
3	Chacón et al (2020)	Automation,and cyber-physical system	NA
4	Christensen et al (2019)	Digitalization technologies	NA
5	Danielsson et al (2020)	Augmented reality	Assembly
6	De Assis Dornelles et al (2021)	IPA, social networking sites, and data analytics	Assembly, training, and maintenance
7	De Simone et al (2022)	Human robot collaboration	Manufacturing industry*
8	Di Pasquale et al (2021)	Augmented and virtual operator, Collaborative operator, Healthy and super-strength operator	Assembly, and training
9	Drouot et al (2020)	AR	Assembly
10	Ekandjo et al (2021)	IPA	Work practices
11	Enrique et al (2021)	AR,VR, and collaborative robots	Assembly, and training
12	Hariharan et al (2020)	AR	Maintenance
13	Kaasinen et al (2022)	wearables, industrial social networks, voice assistance	Training
14	Kadir et al (2018)	Human robot collaboration	Assembly
15	Kumar and Lee (2022)	Human machine interface	Maintenance
16	Liao et al (2019)	IPA, IoT	NA
17	Maurice et al (2018)	exoskeleton	Assembly
18	Miller et al (2019)	AR	Industry task performance*
19	Nazareno and Schiff (2021)	Artificial intelligence	Industry task performance*
20	Perez Luque et al (2020)	Exoskeleton	Assembly
21	Reiman et al (2021)	Big data	Manufacturing industry*
22	Romero et al (2018)	Healthy operator	Assembly
23	Storm et al (2022)	Human robot collaboration	Assembly
24	Van Zoonen et al (2017)	Social media	Workplace
25	Wesslén (2018)	Exoskeleton	Assembly

NA : not mentioned any specific manufacturing operation, *: study conducted on operators' performance in manufacturing industry, not specified manufacturing operation.

[3] and [4] is excluded for further analysis, since could not find specific industry 4.0 technology related to operator 4.0 typology.

Appendix B: Article categories, step 1

Category	Article number
Discomfort	[20]; [8]; [5]; [11]
limited range of motion	[20]; [12]
Musculoskeletal disorder	[2]; [17]; [7]
Problem solving	[13]
Risk in privacy	[17]; [16]; [13]
Physical workload	[20]; [22]; [25]; [17]
Cognitive Workload	[22]; [8]; [3]; [6]; [15]; [21]
Job control	[5]; [10]; [17]
Communication and social reation	[10]; [24]; [13]
Isolation	[23]; [18]; [11]
Health issues	[6]; [14]; [9]
Participation in decision making	[1]; [6]; [10]; [8]
Job insecurity	[1]; [17]; [4]; [8]
Career opportunities	[7]; [14]; [10]
Work cycles	[7]; [8]
Discrimination in workplace	[6]
Uncertainity in task	[16]
Work-life balance	[24]
Work engagement	[24]
Information overload	[15]
Mental stress and fear	[4]; [19]; [13]; [6]; [7]; [17]; [1]; [14]; [8]
Work flow	[14]

Appendix C: Article categories, step 2

Category	Article number
Job content/ demand (Uncertainty in the task, Work cycles, Physical workload, Cognitive workload, Information overload, Work flow)	[16]; [8]; [7]; [22]; [20]; [25]; [17]; [8]; [6]; [15]; [14]; [21]
Operator control over task (Job control, Participation in decision making, Problem-solving of operator, Work engagement)	[17]; [5]; [10]; [8]; [1]; [6]; [24]; [13]
Equipment related impacts (Discomfort, Musculoskeletal disorder, Health issues)	[20]; [8]; [5]; [11]; [2]; [17]; [7]; [6]; [14]; [9]; [12]
Workplace culture and relationship (Communication and Social relation, Isolation, Discrimination in workplace)	[10]; [24]; [6]; [23]; [13]; [18]; [11]
Workplace stress/ anxiety(Mental stress and fear, Worklife balance, Information overload, risk in privacy)	[19]; [13]; [6]; [7]; [17]; [1]; [14]; [8]; [15]; [24]; [16]
Career development (Job insecurity, Career opportunities)	[1]; [17]; [8]; [7]; [14]; [10]

Appendix D: Categories of refined articles, step 2

Category	Article number
Impact related to nature of work (Job content/ demand, Operator control over the task, Equipment related impacts)	[16]; [8]; [7]; [22]; [20]; [25]; [17]; [22]; [15]; [14]; [5]; [10]; [1]; [6]; [24]; [9]; [2]; [9]; [12]; [21]
Impacts related to social and organisational context of work (Workplace culture and relationship, and career development)	[10]; [24]; [13]; [23]; [18]; [11]; [6]; [1]; [17]; [8]; [7]; [14]
Individual factors (Workplace stress/ anxiety)	[19]; [13]; [6]; [7]; [17]; [1]; [14]; [8]; [15]; [24]; [16]