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A sociotechnical perspective of the Operator 4.0 factory: A literature review and future directions

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Abstract. In this study, I illustrate the sociotechnical perspective of the Operator 4.0 factory, where advanced Industry 4.0 technologies – such as robots, the internet of things, virtual reality - are deployed to collaborate with operators and help them to their activities within manufacturing organisations. There is a lack of studies exploring how Operator 4.0 factory operates through the interplay between technologies and workers. I address this gap by conducting a systematic literature review employing the sociotechnical theory. This theory sees an organisation as a work system, composed of social and technical systems and helps understand how the work system operates. Thus, I portray the novel role of Operator 4.0, the enabling technologies of the Operator 4.0 factory and the challenged to implement them, and the instrumental and workforce benefits. The results show that studies are focused on both systems meaning that operator 4.0 plays a crucial role in this factory in conjunction with Industry 4.0 technologies. Organisations adopting such production systems experience instrumental benefits related to a more efficient production process and better workforce conditions. I conclude by proposing some future research avenues.

Keywords: industry 4.0, operator 4.0, operator 4.0 factory, socially sustainable manufacturing, sociotechnical systems, socio-technical perspective, industry 5.0, quality 4.0

1 Introduction

To face competitors from developing countries, worldwide leading manufacturing nations launched various national industrial plans to innovate the production systems [1]. In 2011, the German government was the first to launch the industrial plan called “Industrie 4.0”, which are then followed by similar initiatives of European, American And Asian countries called Industry 4.0, Smart Manufacturing and Industrial Internet of Things [2]. These industrial plans share the same principles and objectives [2]. They aim at adopting advanced digital technologies – robotics, additive manufacturing, internet of things - which are called Industry 4.0 (I40) [3]. Also, these plans aim to increase the automation of the production system through the deployment of cyber-physical systems [4]. The production process reduces the lead time of operations and increases efficiency because decision making and production activities are automated

[1]. Thus, manufacturing production systems are vertically and horizontally integrated within and across organisations [5].

As a result, such industrial initiatives usher in the Fourth Industrial Revolution that following a technocentric perspective of I40 technologies. Such perspective privileges the role of technology over the workforce and opens for concerns related to labour disruption, reducing the importance of the workforce and maintaining stable carriers [6].

To address these social issues, various studies call for a human perspective of the Fourth industrial revolution, which is named "Operator 4.0", "Operator 4.0 Factory" or "socially sustainable manufacturing" – for some Industry 5.0 [7–10]. For the sake of simplicity, in this paper, I use the term Operator 4.0 (OP40) factory referring to this perspective.

This perspective is characterised by I40 technologies that are deployed to collaborate with the operators 4.0 that has a crucial role in the production system because they manage I40 technologies and are helped by the technologies to their activities [7, 11]. As a result, operators and technologies are integrated into the human cyber-physical systems that increase the automation of the production process and improve workforce conditions [12].

Although some literature reviews summarise the human resources practices to build such operators and build a human cyber-physical system [12, 13], there is a lack of studies exploring how the OP40 factory operates through the interplay between technologies and OP40.

I address this gap by conducting a systematic literature review of the OP40 factory employing the sociotechnical theory [14]. This theory considers the production systems as a work system composed of social and technical systems and allows studying the dynamics between systems and the main characteristics of both systems [15]. In this way, I can explore how the OP40 factory operates, the challenges to adopting I40 technologies in the OP40 factory, and the main characteristics of I40 technologies for the OP40 factory and the role of OP40.

The study addresses the following research question: "What are the sociotechnical characteristics of the Operator 4.0 factory?"

I contribute to the sociotechnical literature presenting a synopsis of the main characteristics of the social and technical system of the OP40 factory. That differs from the traditional technocentric I40 perspective, particularly for a strong emphasis on the social systems. I also illustrate the challenges and benefits of the technical and social system of the OP40 factory after the I40 adoption.

The paper is structured as follows. I present the theoretical background in section 2. The research design is described in section 3. I illustrate the findings in section 4, and I discuss them in section 5. The article concludes in section 6.

2 Theoretical Background

The study is based on two main literature streams: the Operator 4.0 factory and the sociotechnical theory. Such streams are present in this section.

2.1 The origin of the Operator 4.0 factory

The OP40 factory – also called socially sustainable manufacturing - describes the human perspective of the fourth industrial revolution. Such a complex production system sees the human agency, the so-called OP40, cooperating with I40 technologies [8]. The OP40 is defined as a smart and skilled operator who performs not only - 'co-operative work' with robots - but also - 'work aided' by I40 technologies [7].

OP40 factory shares the most important I40 technologies of the fourth industrial revolution. They are the internet of things, cloud manufacturing, and additive manufacturing deployed fairly towards workers and features that enable cooperation [16, 17]. The internet of things is a network based on IT infrastructure where technologies and physical products are equipped with sensors – Barcode, RFDI and wireless sensors - to collect and communicate in real-time data among technologies and humans [2, 18].

Cloud Manufacturing is a virtual network in which actors of a supply chain share resources on-demand on a platform through the internet [19]. Additive manufacturing refers to a set of technologies - including 3d printings - which allows the fast prototyping, production and customization of high-quality products [20]. Such technologies are integrated with OP40s forming the human-cyber physical systems that allow automation of the production process and improve workforce conditions. Thus, I40 production systems are vertically and horizontally integrates [5]. The vertical integration is internal to the organisation and represents the integration of several units. Horizontal integration refers to the digital information sharing that facilitates collaboration among partners within a supply chain and customers [5].

2.2 The sociotechnical theory

The term "sociotechnical" was coined in the 1950s by Trist and Emery of the Tavistock Institute [21]. The sociotechnical theory considers the organisation as a working system composed of social and technical systems. The former includes the workers, their roles, and the organisational rules. The latter includes the technologies for accomplishing organisational tasks [15]. Such systems effectively operate when they are jointly optimised, i.e. when workers effectively use the technologies. To this end, the organisation follows the tenet of "minimal critical specifications" – opposed to the mechanistic Fordist perspective – claiming that workers need essential training to work with technologies and in the production system that leaves them autonomy to fulfil tasks. This joint optimisation delivers benefits in both systems. In technical systems, the improvements concern instrumental benefits, including better performance and achieving economic objectives. In contrast, the improvements in the social system concern humanist objective, including enhanced job satisfaction and a higher quality of work-life balance [15]. Figure 1 summarises the elements of the sociotechnical theory.

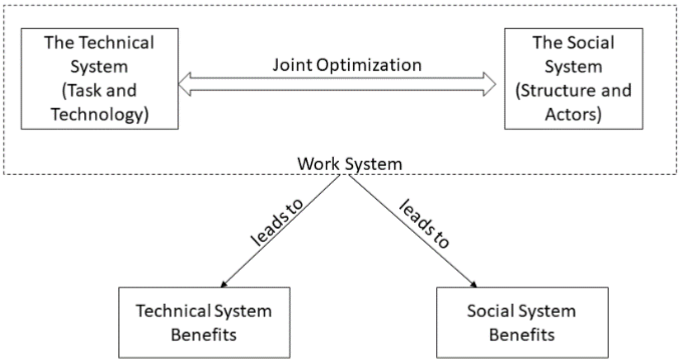

Figure 1 The sociotechnical framework (based on Sarker et al. 2013)

3 Research Design

I conducted a systematic literature review to summarise the sociotechnical perspective of the OP40 factory in January 2021, using the Scopus database, Google Scholar, and Science Direct. To this end, I employed the following research query: "Operator 4.0" OR "Socially sustainable factory", which are the core keywords of the OP40 factory [8]. I refined the research by selecting articles in English. Although some scholars recommend excluding conference proceedings from a literature review, the present study included them to extract insights relating to this emerging research area [22]. Table 1 illustrates the literature research.

Item	Description
Source	Scopus, Google Scholar and Science Direct
Query	"Operator 4.0" OR "Socially sustainable factory" Refined by: LANGUAGES: (ENGLISH)
Hits	60
Papers retained after: - Title -Full- text selection -Backward and forward search	 32 23 25

Table 1 Details of the literature search

The query released 60 articles. I removed all the papers with incomplete bibliographic data points, duplicates, and an abstract in English and the remaining text in a different language. I included in the review both conceptual and empirical papers.

The data analysis aimed to detect the sociotechnical perspective of the OP40 factory. I used as a sensitive device the sociotechnical framework in Figure 1 in order to summarise:

- the main characteristics of the social and technical systems of the OP40 factory.

- the challenges facing organisations to operate the social and technical systems of OP40 factory.
- the benefits of the social and technical systems of OP40 factory after I40 adoption.

A total of 32 papers were selected for the final review. The selected papers were then thoroughly read, and I reached a group of 23 papers that illustrate the sociotechnical perspective of the OP40 factory. I concluded the review by conducting a backward references search to reinforce the result of the literature review [14]. The final query produced 25 papers which I used to identify the sociotechnical perspective of the OP40 factory.

4 Findings

In this section, I report the findings of the literature review. Firstly, I present the descriptive statistics of the literature review. Then, I illustrate in-depth the technical and social systems of the OP40 factory.

4.1 Descriptive Statistics

Figure 2 depict the publication trend of the literature review. The trendline depicts a growing publication trend and has the maximum number of publications (13) in 2020. In 2021, there is only one publication as I finished the literature review in January 2021. The literature comprises 16 articles from journals and the remaining nine from conference proceedings or book chapters.

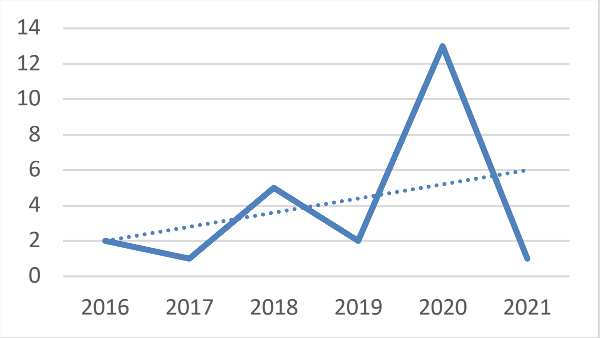

Figure 2 Publication Trend of the Operator 4.0 factory

The most used article keywords are Operator 4.0 and Industry 4.0, with 16 and 14 occurrences, respectively. Then, I found human cyber-physical systems and socially sustainable manufacturing with three occurrences. These results confirm that studies of OP40 factory are oriented toward the inclusion of the workforce in I40 applications.

Figure 3 depicts the top contributing authors with more than two contributions. The most prolific author is David Romero (Tecnológico de Monterrey, Mexico) with seven articles, followed by Åsa Fast-Berglund (Chalmers University of Technology, Sweden) and Thorsten Wuest (West Virginia University, USA) with five and four contributions, respectively.

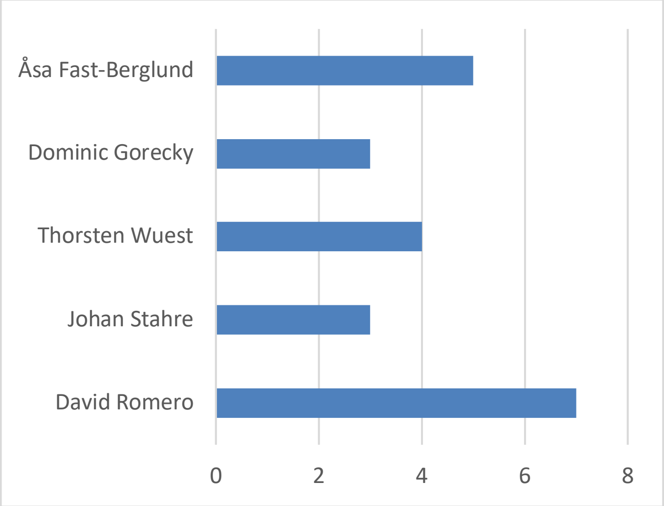

Figure 3 Top contributing authors (>two papers)

4.2 The technical systems of Operator 4.0 factory

The technical system of the OP40 factory is built upon the well-known I40 technologies deployed with features that allow cooperation with OP40s. Romero et al. propose a list of I40 technologies for the OP40 factory [7, 23, 24]:

- The exoskeleton is a wearable mobile machine facilitating limb movement with increased strength and endurance through electric engines.
- Cobots are robots designed to collaborate with human agencies in safety. Cobots can conduct strenuous, repetitive, and non-ergonomic operations.
- Augmented and virtual reality technologies enrich or simulate the real-world factory environment with digital information and media overlaid in real-time in her field of view by head-gear [25].
- Enterprise social networks, incorporated in mobile devices, allow communicating among OP40s and share real-time information about production status and knowledge about operations.
- Intelligent personal assistance, a software agent or artificial intelligence, facilitates the interaction with the human-machine interface of I40 technologies, computers, and information systems.
- Big Data analytics is a set of technologies that analyse unstructured or semi-structured data extracted from I40 technologies to discover valuable information about the production process.

The studies of the literature explore only the vertical integration of the OP40 factory. Various studies explore how to develop a technical system that allows integration with the social system [26]. To this end, I40 technologies are designed to improve operations down the production process and support human capabilities and safety [27]. In order to support human capabilities, I40 technologies are means to improve ergonomics of operations and workstations, and such technologies are used to acquire and monitor personal data (i.e. heart activity, body temperature, steps) of OP40 to detect physical and mental stress conditions OP40 [28, 29]. To develop such technical systems, the organisations encounter various challenges. The I40 adoption has a high cost that requires developing a clear financial plan for the organisation [30]. The integration of the I40 technologies is often difficult because they are managed by proprietary software that does not allow integration with I40 technologies of different vendors [31]. There are also difficulties analysing data retrieved by such technologies and developing a common platform to integrate the I40 technologies [31].

I40 adoption in an OP40 factory delivers various instrumental benefits [32]. The adoption of robotics and cobot allows a more efficient production process because these technologies perform operational tasks in less time than humans. The adoption of virtual reality helps workers conduct operations efficiently and avoid potential production mistakes [33]. Similarly, OP40, equipped with an exoskeleton, conducts hard muscular activities smoothly and efficiently and with moderate effort. The analysis of big data, retrieved from I40 technologies along the assembly line, prevents potential mechanical issues and maintains a constant production line [12].

4.3 The social systems of Operator 4.0 factory

OP40 describes the manufacturing worker operating in I40 organisations [34]. This role is the progression of the traditional manufacturing workers conducting operations employing mechanical technologies. The literature distinguishes three types of traditional manufacturing workers. Operator 1.0 conducted manual operations supported by mechanical and machine tools. Operator 2.0 was in charge of assisting work with computer tools like computerised numerical control machines and IS. Operator 3.0 conducted tasks by cooperating with robots, other pieces of machinery, and computer tools [74].

In contrast, OP40 operates in an I40 assembly line, and she or he is in charge of managing, collaborating, and supervising these advanced technologies [7]. More specifically, the extant literature proposes seven typologies for OP40 [7]:

- The super-strength operator describes an OP40 who conducts manual tasks—such as handling heavy products—equipped with a smart exoskeleton.
- The smarter operator is an OP40 that uses an intelligent personal assistant to manage I40 technologies because it mediates the interaction with the I40 technology interfaces and OP40.
- Virtual and augmented operators are OP40s that conduct manual, mental, and maintenance tasks with augmented reality or virtual reality that offers visual guidance for their tasks.

- The collaborative operator is in charge of working with I40 technologies down the assembly line—such as cobots of robots.
- The analytical operator is the OP40 that examines big data from I40 technologies. This operator is in charge of predicting and preventing potential critical events along the assembly line, such as the breaks of machinery pieces or lack of lubrication of the conveyor belt.

The extant literature illustrates that traditional requalifying workers for this novel role are challenging because traditional manufacturing workers only possess operational competencies to assemble products and not competencies for managing the maintenance of complex I40 technologies [35]. To address this issue, OP40s are continuously trained with refresh courses, training on the job, and mentorship both during and afterwards the I40 adoption process [30]. Finally, the literature reports that I40 adoption is a means to improve workforce conditions [8, 36]. Manufacturing workers experience physical workload and cognitive load due to their operational activities [37]. Big data analysis helps predict relevant and critical events along the assembly line, like the lack of lubrication or conveyor belt breaks. Thus, OP40 can better forecast potential machinery mishaps to maintain constant production and avoid illness in a more stimulating workplace [38]. Manual activities like handling heavy products and repetitive assembly movements increase the physical workload. I40 adoption can solve such issues by automating hard muscular and non-ergonomic body movements through cobots to avoid strain and injury. Also, the monitoring of physical data can prevent possible physical workload [39]. Still, the exoskeleton adoption mitigates physical efforts during several manual tasks, and therefore, it can reduce work fatigue and increase operator productivity [40].

In addition, the manufacturing workers suffer from mental load owing to conducting assembly activities and supervising technologies. Also, the workers experience issues in recollecting products and material in managing different computer systems [33].

Virtual and augmented reality adoption alleviates these issues by supporting real-time operator training, maintenance, and complex activities with a digital assistance system, thus reducing human errors [40]. Also, these technologies embedded features (like chat) allows communication among OP40s. These features enable knowledge sharing that sustain a high level of knowledge operations within the organisation [41, 42].

Similarly, the adoption of enterprise social networks accelerates the idea creation to innovate products and processes. Also, it facilitates the problem-solving of OP40 by interconnecting operators with the organisation's punctual information [43].

The adoption of intelligent personal assistance provides vocal instruction to OP40 supporting their activities. The personal analytics of OP40, extracted from wearable trackers, can be exploited to plan their work to reduce their physical and cognitive workload.

5 Discussion & future avenues

In this study, I illustrate a sociotechnical perspective of the OP40 factory. Such a factory is designed to allow cooperation between technologies and workers, and therefore, it avoids job disruption from I40 technologies and automation. The study results show that the literature is focused on technical and social systems, and the development of the OP40 factory leads to benefits for workers and organisations.

To advance the studies of OP40 factory, it is crucial to debate the determinants of the adoption that push organisations to adopt the OP40 factory rather than the technocentric (and traditional) perspective of the fourth industrial revolution. Although it is clear that the OP40 factory is more valuable for workers, why is it more economically viable for the organisations rather than the technocentric perspective of the fourth industrial revolution? How do OP40s help to achieve superior organisational performance?

Furthermore, a future research line is to conduct further literature related to the OP40 factory in conjunction with Industry 5.0. The latter is a novel concept that the European commission stressed at the beginning of 2021 and embraced the OP40 factory concept.

With regards to the technical systems, I40 technologies such as the internet of things and cloud manufacturing are not reported in the literature. Thus, future studies should focus on exploring how to implement such technologies in the OP40 factory. Still, researchers should study the privacy implications related to personal data usage of OP40 because these novel technologies extend the control of management over OP40s related to personal information (like hearth status). Another important future avenue for OP40 factory is to investigate how such a production system can mitigate the environmental impacts of manufacturers in terms of energy usage and natural resources usage.

The literature also reports vertical integration of OP40 factory without exploring the horizontal indentations of these perdition systems. Further studies should fill these gap, illustrating a sociotechnical perspective of such integrations. Similarly, I found that most of the OP40 factory studies are conceptual and very few studies. Thus, future research should use qualitative and quantitative methods in order to investigate the maturity of the OP40 factory, the enabling I40 technologies in use and whether organisations develop the various type of OP40s.

With regards to the social systems, the literature describes the role of OP40, the challenges to develop such operators and the humanistic benefits. Further studies should continue investigating this evidence, focusing on the competencies that OP40 needs to operate in complex production systems and activities to maintain a high knowledge level of operations of OP40. Also, further studies should explore when replying to workers is more fruitful to hire new ones. This action contradicts the OP40 factory vision because traditional manufacturing workers can be excluded from the job market. Thus, it is important to explore such actions (like training courses or knowledge management) that avoid this circumstance. Another interesting future avenue that can help to explore the social system of OP40 is to investigate the OP40 factory from a worker perspective, which lacks in literature since most of the studies are based on the management perspective.

The study has implications for practitioners. Practitioners can use this study as a guide to address workforce issues through the adoption of I40 technologies. They can also use the study to explore how the workforce role changes in the OP40 factory and how operators contribute to a more efficient production process. I40 technologies should be designed with an easy-to-use human-computer interface to allow the interplay between the workforce and technologies. It is very important that workers conduct various training courses during the I40 adoption to learn how to use such complex technologies. Such courses should be coupled with mentorship and training on the job to increase the acceptance rate of these technologies. Plus, the management needs to organise refresh courses for workers afterwards the I40 adoption periodically in order to maintain a high level of digital competencies for workers.

Policymakers should encourage the development of the OP40 factory rather than the technocentric I40 factory. They can provide additional funds to organisations that want to adopt I40 technologies to improve workforce conditions and stable employment after I40 adoption.

6 Conclusion

The study is motivated by a lack of studies that explore how the OP40 factory operates. I address this gap by conducting an extensive literature review of the OP40 factory employing the sociotechnical theory. The literature reveals I40 technologies used in the OP40 factory, the role of OP40 and the challenges facing organisations to operate the social and technical systems of the OP40 factory. The benefits of I40 adoption on the technical systems are a more efficient and optimised production process. The benefits of the social systems of the OP40 factory after I40 adoption include better workforce conditions and an enriched role of the OP40 down the assembly line.

The study has a certain limitation because it is based on a systematic literature review on Scopus, Google Scholar, and Science Direct, analysing only English articles. Future studies should address this study limitation by conducting a systematic literature review in different databases — like EBSCO and Web of Science—analysing papers in various languages. Scholars can also extend the keyword search by adding “future of work” to detect further articles related to the topic.

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