ISSN 1980-5411 (On-line version)
Production, 33, e20220074, 2023
DOI: 10.1590/0103-6513.20220074

Thematic Section - Production Engineering leading the Digital Transformation

Industry 4.0 at Brazilian modular consortium: work, process and knowledge in engine supply chain

Jorge Muniz Junior[a], Giovanni Pessin Moschetto[a]*, Daniel Wintersberger[b]

[a]Universidade Estadual Paulista, Guaratinguetá, SP, Brasil

[b]University of Birmingham, Birmingham, United Kingdom

*giovanni.moschetto@unesp.br

Abstract

Paper aims: This paper aims to discuss Industry 4.0 (I4.0) impacts on the Brazilian Modular Consortium (BMC) assembly lines related to work – issues correlated with human resources; production – physical resources used in production process; knowledge – associated with creation and sharing of knowledge.

Originality: Findings explore I4.0 research opportunities related to work and human factors on assembly lines. In lieu of gaps in literature, this research further discusses management challenges to support digital transformation and impacts on workers and organizations.

Research method: A case study on Engine Value Chain (EVC) of BMC, which includes MWM, engine manufacturer; Powertrain, engine assembler at BMC; Volkswagen Truck & Bus, BMC responsible. Semi-structured interviews were conducted with four senior managers responsible for I4.0 implementation. Responses were treated via content analysis.

Main findings: The interviewees highlight work and human factors as important for I4.0 implementation, which include workers tasks, skills, nature of work, human resource development, hiring process and organizations strategies. It was also found that knowledge sharing poses a huge challenge.

Implications for theory and practice: The findings contribute with academic interest on work, production and knowledge impacts on assembly lines, and with practitioners on issues related to I4.0 implementation.

Keywords

Industry 4.0. Brazilian Modular Consortium. Work. Knowledge Management. Production.

How to cite this article: Muniz Junior, J., Moschetto, G. P., & Wintersberger, D. (2023). Industry 4.0 at brazilian modular consortium: work, process and knowledge in engine supply chain. *Production*, *33*, e20220074. https://doi.org/10.1590/0103-6513.20220074

Received: June 5, 2022; Accepted: Feb. 20, 2023.

1. Introduction

The digital transformation of operations management, known variously as Manufacturing of the future (Engineering and Physical Sciences Research Council, 2018), Advanced Manufacturing Technologies (Executive Office of the President of the United States, 2018) and Industry 4.0 (Siemens, 2015; European Parliament, 2016), includes digital technologies such as: Internet of Things (IoT), Advanced Robotics, Additive Manufacturing and Artificial Intelligence. This paper applies the term Industry 4.0 (I4.0) to name this context, which promises customized products produced in smaller lots, and that repetitive manufacturing tasks can be automated very soon (Karre et al., 2017).

New technologies not only transform the means of production and distribution of goods and services, but also have the potential to impact worker skill requirements, process productivity, knowledge sharing, environment, income distribution and social well-being (Organisation for Economic Co-operation and Development, 2017). The Acatech Report (Becker et al., 2017) relates the implementation of I4.0 to social systems, which comprises society, sustainability, regional development, workers, culture, organizational structure, productivity, competitiveness and worker's skills and qualification. Therefore, studying the impacts of I4.0 implementation in Work, Process and Knowledge perspectives are needed.

In view of Work, the IndustriALL Global Union (2017) indicates that I4.0 creates opportunities for different workers, if they have access to (re)education, (re)qualification and specialized training. Socioeconomic aspects, such as the lack of qualified labor and the postponement of retirement due to societal aging affect I4.0 implementation (Shamim et al., 2016; Peruzzini & Pellicciari, 2017). Under I4.0 there is a need for a skilled worker, including soft skills such as creativity, problem solving approach and communication (Kaasinen et al., 2020; Kipper et al., 2020).

It is often disregarded that the successful implementation of a certain technology depends on who applies and uses it, neglecting the role of the worker, who is important in this process (Kipper et al., 2020; Valentina et al., 2021), and should be considered by the managers during the implementation. A labor context in which there is a reduction in wages, job insecurity, job reduction, competition between human productivity and machines needs to be mitigated.

For the Process angle, the new technologies and mass customization context demand that the Human Resource (HR) programs should be updated to support training strategies in order to prepare workers to handle the I4.0 environment (Sima et al., 2020; Wibowo et al., 2020). The complexity of the new tasks requires from workers the skill to solve problems and cope with new technologies (Kaasinen et al., 2020).

Completing the necessity with Knowledge perspective, the promise to automate repetitive manufacturing tasks may lose worker tacit knowledge. Sié & Yakhlef (2009) highlight the importance of knowledge management related to the dialogue about understanding why things happen (socialization), which include the worker's judgment and experiences.

Muniz Junior et al. (2022a) discuss that management challenges to support the implementation of I4.0, which includes training review, performance assessment, staff profile, and organizational flexibility are needed. HR programs need to implement new training strategies in order to prepare workers to apply new technologies (Melo et al., 2022; Ribeiro et al., 2022).

The I4.0 literature analysis indicates that most of the papers are theoretical and technology based. Consequently, there is an opportunity for research on empirical studies related to the impacts of I4.0 on production systems considering Work, Process and Knowledge, as research opportunities:

- How does I4.0 affect workers and processes (Jerman et al., 2020)?
- Which worker's skills should be developed to work in I4.0 (Wibowo et al., 2020; Goswami & Daultani, 2022; Melo et al., 2022)?
- How does knowledge management influence I4.0 (Kipper et al., 2020; Ribeiro et al., 2022)?
- How managers (organization) deal with the implementation of I4.0 (Kipper et al., 2020; Strohmeier, 2020)?

This paper aims to discuss the impact of I4.0 on assembly lines of an Engine supply Chain (ESC) in a managerial perspective related to work – issues correlated with human resources; process – physical resources and technologies used in the production process; knowledge – associated with creation and sharing of knowledge among workers.

The study focuses on a case study based on the ESC of the Brazilian Modular Consortium (BMC), which includes: MWM, engine manufacturer; Powertrain – joint venture of MWM and Cummins – responsible for engine assembly at BMC; Volkswagen Truck & Bus (VWTB), assembler responsible for the BMC. This paper chooses the ESC of the BMC because of its complex and knowledge-intensive nature (Muniz Junior et al., 2010, 2022a), especially considering three firms, three different heads, and three different philosophies of work, reinforcing the multi-firm and multi-cultural aspect of the BMC that provides a fertile setting for this study ensuring representative context-specific cultural and institutional conditions (Rodriguez et al., 2021) that might impact I4.0 implementation. Investigating different social systems adjusting to I4.0 is essential for industrial sectors to function efficiently in this new context.

Brazil remains one of the 10 largest vehicle manufacturers in the world, which produced over 2.0 million in 2021 (Organisation Internationale des Constructeurs d'Automobiles, 2021), showing the significance of the automotive industry in the Brazilian economic sector. Dalenogare et al. (2018) points out some potential difficulties associated with the implementation of new technologies in emerging economies. Particularly, Brazil has aspects related to cultural factors, employment, IT infrastructure, which are constraints to adopt new technologies.

According to Muniz Junior et al. (2022b), the discussion of Brazilian public actions related to the UN Sustainable Development Goals (SDG) "Decent work and economic growth" (SDG-8) and "Industry, innovation and infrastructure" (SDG-9) needs to be aligned with "Quality Education" (SDG-4) and "Partnerships and Means of Implementation" (SDG-17). Universities and companies are responsible for the development of professionals, however, in Brazil, they work separately and independently. Technological change poses challenges for teaching and its implementation demands an academic and business agenda to prepare professionals, professors and learners to work with these technologies and apply them to generate income and social well-being, highlighting the difficulties in implementing new technologies in emerging economies.

Important factors for the implementation of I4.0 can be favored by knowledge management and HR management (People), which are concerned with leadership, culture, information and communication technology, strategy, organizational infrastructure, processes, motivational incentives, training and personal characteristics. These challenges are imposed for a new manufacture, that is, a new relationship between technology and worker.

The multidisciplinary topics of social systems in production management contribute to the alignment of manufacturing concepts, capabilities and technologies, considering social (human-centered) requirements to better understand how different assembly lines and workers are influenced by digital transformation, which supports discussion about sustainable organizational practices and to guide professional curricula affected by I4.0. Understanding the impacts of I4.0 implementation on Work, Process and Knowledge perspective may contribute to mitigate problems related to employment, work, productivity and organization management, and to identify knowledge management practices for workers training, thus supporting HR strategies.

This paper is structured as follows: Section 2 describes the theoretical background of I4.0, Work, Process and Knowledge in assembly lines; Section 3 presents the applied questionnaire, data collection and data treatment based on content analysis; Section 4 presents the data analysis and discussion; and Section 5 draws conclusions, theoretical and practical implications, and further research.

2. Theoretical background

2.1. Industry 4.0

I4.0 connects suppliers, equipment, plants and organizations digitally in order to create an integrated network and competitive supply chain (Resman et al., 2021). I4.0 enables plants to cope with learning and decision-making in real time, which is supported by dedicated high performance networks (Cyber Physical Systems - CPS) to facilitate instantaneous data communication between machines and processes on the assembly line (Benotsmane et al., 2019). The dynamic integration promoted by CPS can collaborate with planning, analysis, simulation, implementation and maintenance of high-performance manufacturing processes (Lu, 2017). It is expected that collaborative robots will be carrying out simultaneous tasks to reduce human interventions on the processes and increase productivity (Wollschlaeger et al., 2017). I4.0 includes, but are not limited to, a variety of digital technologies shown in Table 1.

Table 1. Industry 4.0 related technologies.

Technologies	Definitions
Additive manufacturing, fast prototyping or 3D impression	Versatile machines for flexible manufacturing systems (FMS), able to transform digital 3D models into physical products using additive manufacturing
Artificial Intelligence	Computer-based algorithms using analytical and statistical methods to support data analysis and automated decision-making
Big Data Analytics	Computer-based predictive analytics, data mining and statistical analysis to treat large and unstructured data sets, generated by sensors
Computer-Aided Design and Manufacturing	Computer-based systems for product design, manufacturing planning and management
Cloud computing	Storage and processing of large data volumes in remote computers
Cyber Physical System	Production system combining several technologies, able to interact with other systems, communication networks and operators
Sensor-based digital automation	Automated systems with embedded sensor technology
Digital Product-Service Systems	Digital services embedded in products, using IoT, sensors, processors and software enabled capabilities
Flexible manufacturing lines	Digital automation of manufacturing processes using sensors that allow Reconfigurable Manufacturing Systems (RMS) able to change production
Integrated engineering system	Integration of IT support systems for information exchange in product development and manufacturing
IoT	High-speed internet-based sensors that allow to remotely control equipment
Manufacturing Execution Systems (MES) and Supervisory control and data acquisition (SCADA)	Real time, remote shop floor monitoring that allow dynamic scheduling
Robotics	Application of programmable, autonomous manufacturing machines
Simulations / analysis of virtual models	Application of analytical methods in engineering projects and systems simulate their properties and outcomes
Virtual Factory	Integrated factory simulation model to support decision making capability

Source: Ribeiro et al. (2022).

2.2. Impacts of Industry 4.0 on Work and Process in assembly lines

The nature of assembly line work has changed significantly. Decisions related to handling equipment, tightening torque and sense of assembly are based on knowledge, memory, experience, ability independent of the instructions and trainings that the operator had, placing a lot of importance on worker creativity, problem-solving skills and tacit knowledge (Kotha, 1995; Muniz Junior et al., 2022a). Despite these contextual developments arguably making assembly lines work more knowledge intensive, there appears to be a dearth of systematic inquiries into workforce skills (Müller, 2019; Novakova, 2020), national education (Hariharasudan & Kot, 2018; Vrchota et al., 2019), training (Goswami & Daultani, 2022), human-machine interaction (Sima et al., 2020), opportunities and limits of technologies and impact on the nature of work and employment (Song et al., 2021).

The need for a skilled workforce (Novakova, 2020), worker acceptance (Müller, 2019) and change management (Goswami & Daultani, 2022) are enablers to I4.0 implementation. In this context, I4.0 requires workers to gain new skills, and cope with challenges of digital transformation. Table 2 shows skills associated with I4.0.

Table 2. Skills associated with Industry 4.0.

Skills	Description	Authors
Creativity	Think and work out different ways of solving certain situations, making connections between seemingly unconnected problems and finding hidden patterns.	Grzybowska & Łupicka (2017), Maisiri et al. (2019)
Entrepreneurial thinking	Identify opportunities and paths to increase customer satisfaction, serve new markets or gain more share in the current market, in addition to having proactiveness and initiative to implement and seek solutions.	Grzybowska & Łupicka (2017), Hernandez-de-Menendez et al. (2020)
Analytical thinking	The logical and structured thinking process for analyzing information and making decisions in a logical and structured way.	Maisiri et al. (2019), Hernandez-de-Menendez et al. (2020)
Problem solving	Interpret reality, generate logical ideas, compare them, select the best option and put it into practice.	Grzybowska & Łupicka (2017), Hernandez-de-Menendez et al. (2020)
Ability to search	Use of reliable sources to conduct research and obtain detailed and in-depth information about a given situation.	Grzybowska & Łupicka (2017), Prifti et al. (2017)
Efficiency orientation	Use available resources in the best possible way, through actions and decisions.	Grzybowska & Łupicka (2017), Spöttl & Windelband (2021)
Conflict resolution	Solving deadlocks, with maturity, empathy, self-control, patience and analytical thinking.	Maisiri et al. (2019), Škrinjarić & Domadenik (2020)
Social skills	Communication with the ability to convey, persuade and influence people to adhere to your ideas, including collaboration and teamwork.	Škrinjarić & Domadenik (2020), Prifti et al. (2017), Ada et al. (2021), Kipper et al. (2021)
Flexibility	Adapt to new situations, new rules and new work environments.	Ada et al. (2021), Kipper et al. (2021), Maisiri & van Dyk (2021)
Emotional intelligence	Remain emotionally stable in the face of challenges.	Maisiri et al. (2019)
Leadership	Ability to lead and motivate a team towards something or achievement of goals.	Ada et al. (2021), Maisiri & van Dyk (2021), Spöttl & Windelband (2021)
Technical skills	Knowledge such as know-how in a certain function and/or IT knowledge (knowledge of programming languages and data protection).	Ada et al. (2021), Kipper et al. (2021), Spöttl & Windelband (2021)

Source: Melo et al. (2022).

2.3. Impacts of Industry 4.0 on Knowledge Management in assembly lines

Traditionally, production systems vary in terms of variety and volume of output (i.e. assembly lines, manufacturing cells and continuous process), which influences aspects related to Work, Process and Knowledge. We still need to understand the impact of I4.0 on these different production systems and aspects to create strategies of worker tacit knowledge management. Knowledge sharing remains a critical activity for the organizations, since the overall effectiveness and efficiency depend on how well the current know-how and best practices can be shared and transferred among members in organizations (Hong et al., 2011). Knowledge sharing concerns how to transfer expertise and knowledge from the knowledge bearers to novices (Kuo & Young, 2008). It is a process where people share task relevant ideas, information and suggestions (Cyril Eze et al., 2013) among individuals, groups, teams, departments and organizations (Ipe, 2003).

However, despite the growing recognition of the factors that enable knowledge sharing in organizations (Tohidinia & Mosakhani, 2010; Wang & Noe, 2010), our understanding about the unique challenges encountered by workers in the I4.0 context is rather limited. Important factors for the implementation of I4.0 supported by Knowledge Management include: support and managerial leadership (Archanjo de Souza et al., 2020; Maisiri & van Dyk, 2021; Spöttl & Windelband, 2021), culture, information technology, strategy and purpose, measurement, organizational infrastructure, processes and activities, motivational incentives, resources, training, Human Resources Management (HRM) practices and personal characteristics (Muniz Junior et al., 2021, 2022a).

3. Methodology

This study applies a qualitative approach allowing to understand the meanings that people build about their context (Bernardes et al., 2019), in this case discussing the impacts of I4.0 on ESC of BMC in a managerial perspective. It was opted for a theory building from cases (Eisenhardt, 1989) that is appropriate in situations where there's either no theory or a problematic one, such as the issue related to the impact of I4.0 implementation in Work, Process and Knowledge perspectives.

The methodological strategy adopted considers three main steps as described below:

- Theoretical background based on the guidelines to the literature review for empirical papers (Nakano & Muniz Junior, 2018).
- Fieldwork design, which defines the study context related to ESC of BMC, the data collection, interviewees selection and the data treatment.
- Fieldwork research performing interviews, data analysis and discussion.

The theoretical background includes discussion of Work, Process and Knowledge related to implementation of I4.0 and it is based on the preferred reporting items for systematic reviews and meta-analyses (PRISMA, Moher et al., 2010). The documents were selected in Web of Science and Scopus databases following identification, selection/exclusion and eligibility steps (see Table 3).

Table 3. Step-by-step literature review methodology (adapted from Moher et al., 2010).

Steps	Web of Science	Scopus
Research topics (Identification)	"industr* 4.0" OR "manufactur* of the future" or "future manufactur*" OR "advanced manufactur* technolog*" OR "smart* factor*" OR "digitalizat*" OR "smart* manufactur*" AND Human* OR Competenc* OR Skill OR Social* OR Qualific* OR Job* OR Employ* OR Work* AND automot* OR vehicl*	
Documents results	453	897
Type of document (1st exclusion criteria)	Article AND Review Article	Final AND Article AND Review
Documents results	258	304
Categories (2nd exclusion criteria)	Engineering Manufacturing OR Management OR Engineering Industrial OR Business OR Operations Research Management Science OR Industrial Relations Labor OR Social Science Interdisciplinary OR Education Educational Research OR Social Issues	Engineering OR Business, Management and Accounting OR Social Science
Documents results	93	265
Language (3rd exclusion criteria)	English	English
Documents results	91	242
Eligibility by title and abstract (4th exclusion criteria)	33	50 (15 duplicate)
Total of literature review documents	68	

3.1. Study context

The Brazilian Modular Consortium (BMC) opened in 1996 and was presented as an original production model in vehicle assembly based on the relationship among the assembler (VWTB) and its component suppliers (Modules), which are involved in a joint enterprise to establish a "modular system" of production. In this system, the Modules perform the assembly of their components on the BMC, being a revolutionary change in the notion of the supply chain as the Modules are brought inside the factory as assembly (Abreu et al., 2000). As such, few of the production workers are employed by the assembler, whose main role in the process is to coordinate production and to market the assembled vehicles.

The BMC works with eight Modules, which interact directly on the assembly line, sharing physical space, responsibilities, and quality control. The BMC belongs to VWTB, responsible for project development, industrial engineering and indirect activities, in addition to owning the assembly line assets, but it does not participate with any directly employed staff. The responsibility of each Module is the management of direct activities required for the delivery and assembly of their components into the final product (Muniz Junior et al., 2022a).

The fieldwork research was conducted in the ESC at BMC: MWM engine manufacturer; Module Powertrain, which is responsible for engine assembly at BMC; VWTB, assembler responsible for the BMC.

3.2. Data collection and interviewees selection

A semi-structured questionnaire was applied for interviewing ESC managers (Table 4), in order to understand their experiences leading to I.4 implementation on their assembly lines. The questionnaire was based on research opportunities composed by two question sets related to Organization (O) and Employee (E):

(O1) What do you see as challenges and opportunities for your organization' digital transformation / I4.0?

(O2) In what way and to what extent are workers involved in the I4.0 implementation within your organization?

(O3) Do they participate in higher level decision making regarding technological change and investments? If so, how?

(O4) Do you see any change of organization structure(s) as the result of digital transformation?

(E1) In what ways will I4.0 affect workers and their tasks?

(E2) Do you feel that it will increase or decrease the levels of worker decision making and autonomy? How?

(E3) To what extent do you feel that current worker skills and qualifications are consistent with the changing workplace?

(E4) Which potential challenges (if any) do you see in the future in terms of worker skills?

Table 4. Interviewee's profile.

Organization	Function	Code	Professional background
MWM	Quality, Manufacturing and Lean Manager	GQML	Degree in Mechanical and Production Engineering, Master's in Automotive Engineering and MBA. 21 years of professional experience, all of that at MWM.
Powertrain	Industrial Manager	GI	Degree in Business Administration and Post Degree in Industrial Management. 30 years of professional experience, considering 25 years at Powertrain.
VWTB	Industrial Engineering and Maintenance Senior Manager	GEEIM	Master's Degree in Engineering and MBA. 31 years of professional experience, considering 26 years at VWTB.
VWTB	Organization and Human Resources Senior Manager	GEORH	Degree in Business Administration and Post Degree in HR and Business Management. 21 years of professional experience, all of that at VWTB.

In order to perform the interviews, a one-hour virtual meeting via Google Meeting with each of the interviewees was scheduled and the questionnaire was made available in advance, so they could prepare themselves. The first five minutes of the meeting were used to present the study and then the eight questions performed. The interviews were audio recorded and transcribed by the plugin installed in the meeting platform.

One of the article's author has professional relation with the BMC and interviewees, which promoted reliability during the interviews as well as in the content analysis. Therefore, this fact assured the criteria of reliability (replicability) and validity (accuracy) to perform this qualitative research (Bernardes et al., 2019).

3.3. Data treatment

The transcribed text from each of the interviews were complemented with the audio record and after that organized by question. The complete answers (Meaning units) were analyzed by the Content Analysis technique (Graneheim & Lundman, 2004) (Table 5), which is a systematic and replicable technique for compressing many words of text into fewer content categories based on explicit rules of coding qualitative approach (Stemler, 2000).

Table 5. Example of content analysis (adapted from Graneheim & Lundman, 2004).

Meaning unit	Condensed meaning unit	Code
The challenge is really the human resource, as the technology is already available. There are several suppliers to offer the technologies and, if you have the resources and want to implement them, you will have no difficulties. (GEEIM)	The challenge is really the human resource, as the technology is already available.	Human Resource

4. Data analysis

In this section, the analyzed findings after the data treatment are presented and organized by the Work, Process and Knowledge perspectives.

4.1. Work perspective

The interviewees highlight the importance of work and human factors for the implementation of I4.0. Current literature highlights the importance of studies on HR actions for the implementation of I4.0 (Sima et al., 2020; Wibowo et al., 2020).

> *... the challenge is really the human resource...* [GEEIM].

For the interviewees, the transformation to I4.0 will affect workers and their tasks. They indicate the workers responsibility to adapt to this transformation, but it is important that the organization supports them. The workers' preparation maximizes the opportunities brought by I4.0.

> *... workers will have to adapt to the new technologies and methods that will emerge with the implementation of I4.0... both workers and organizations must prepare to be open and absorb the necessary knowledge and skills as much as possible. When workers see which the trends and the organization are makes it all clearer, there will be good results* [GI].

The ESC organizations are undergoing structural changes due to the transformation to I4.0 and they have required new workers skills, for example decision-making based on big data and knowledge of software to work with I4.0 technologies. Interviewees believe in the need of reviewing job descriptions.

> *We have an example in the Engineering Department, when a new job position for a chassis engineer was opened, an analysis was performed to justify whether we really needed this field of expertise or rather a worker with knowledge in software* [GEORH].

The current skills and qualifications of workers are not consistent with the needs generated by the implementation of I4.0, however the use of new technologies will determine which skills they should develop. They must be ready for changes in their workplace and being prepared means a competitive advantage.

> *I think their skills and qualifications are not consistent, because many people don't understand and are not part of I4.0. We created an e-learning training on I4.0 that everyone did, especially the blue-collar workers, because in the beginning there were a lot of questions saying that I4.0 would replace workers, so we broke that paradigm* [GQML].

> *... workers are qualifying and preparing themselves, day after day, for the changes that have been happening...* [GEEIM].

People are important to contribute to the I4.0 implementation. Together with the elimination of routine tasks, the demand for innovation capacity will increase, in addition to the challenge in knowledge sharing, as eliminated tasks can take knowledge with them.

> *Technology itself gives you an opportunity, but if you don't have the human capital working in the right way to use it, it won't work...* [GI].

> *... it will require a lot of more creation, as workers will stop doing routine work...* [GEORH].

Interviewees believe that the decision-making level of workers will change with the implementation of I4.0, requiring greater analytical skills to assess the information available on each situation. Consequently, the level of workers' autonomy tends to increase.

> ... *workers must be prepared for decision-making at each hierarchical level, as the tendency is to perform even more assertive decisions with the implementation of these technologies, thus more information available...* [GI].

Interviewees highlight that for white collar workers, knowledge in software, programming, applied mathematics and statistics, as well as soft skills, should be encouraged to be developed.

> ... *these changes demand professionals more focused on analysis and decision making, aligning the knowledge and skills necessary for I4.0. So, it's not just the technical development, the worker must be prepared and have a more analytical view of things* [GI].

> *For the white-collar worker, for example, how it will be for a financial analyst? This job will be increasingly automated, demanding soft skills development* [GEQRH].

> *Potential challenge is knowledge in programming, software, statistics and applied mathematics* [GQML].

Engineers are involved in the development and implementation of new I4.0 technologies, through technical knowledge and participation in the implementation process. GEORH added that they are the source of I4.0 initiative within the organization.

> ... *the engineer level is totally* [involved]... *they bring information through the technique, state opinions and participate actively in the decision-making process...* [GEEIM].

The involvement of blue collars workers in I4.0 technologies implementation is low and on demand. When it happens, the workers provide information as technology users. In this direction, they do not participate in the decision-making process.

> ... *workers on the shop floor, it's almost nothing (no involvement), they are users* (of the technology) *and are involved to collect information for the development... Decision-making is very low on the shop floor* [GQML].

> *It is not the blue-collar workers who decide and study what to implement...* [GEEIM].

However, for the successful I4.0 implementation, the engine manufacturer reinforces the necessity of workers' involvement and transparency in communication while implementing new technologies (Müller, 2019).

> *When the workers are part of the discussion, they will be even more excited. For example, in the implementation of the autonomous line feeding robot, blue collar workers were involved, because they looked at it and thought that they would lose their jobs. So it's a concern that you must involve them when you use technology to replace tasks, and it must be very transparent, showing what is the objective and what is the expected result... we seek to involve them to guarantee the user experience, because they will end up using it* [GQML].

4.2. Process perspective

The ESC interviewees indicate benefits of I4.0 as mass customization, through assembly of a higher variety of products in smaller lots, operation complexity reduction and gains in efficiency and quality. These benefits impact organizational competitiveness (Novakova, 2020).

> ... *I4.0 provides* [contributes to] *mass customization to manufacturing...* [GEEIM].

> ... *the main competitive advantages are gains in productivity, quality, cost reduction...* [GI].

... virtual reality has completely changed the Pilot Plant... where previously analyzes of mountability, accessibility and ergonomics of a new product were carried out only in physical vehicles [prototypes], *today everything is virtual. The virtual analyzes are much better than the physical ones...* [GEEIM].

The interviewees GEORH and GQML indicate the importance of disseminating I4.0 across the organization and prioritizing it in corporate strategies, which includes considering investments that contemplate I4.0 and not compete with ongoing initiatives, situation presented by Dalenogare et al. (2018) when referring to the challenges to implement I4.0 in the economies of emerging countries, especially due to level of investments.

... if we need to do a heavy I4.0 investment in the assembly line, it will compete with the importance of continuing investing in the current product line... so, how do you compete with it in order to gain priority in the company's investment plan? [GEORH].

The challenge is to disseminate "what is I4.0". *So, it must be within a corporate strategy as it is being developed to bring competitiveness* [GQML].

It is also mentioned the benefit of sharing data from the vehicle assembly until its operations, via IoT, throughout its life cycle for the development of new products.

... we have a great expertise for tailor made and now we can, with I4.0, finally have mass customization... the truck is a big IoT and carries a lot of information [during its life cycle]. *This information can be stored and used for the maintenance contract, traceability and development...* [GEORH].

The I4.0 initiatives at BMC are planned and implemented as they become necessary, especially aiming for cost optimization. Now, the engine manufacturer has the most I4.0 initiatives in place. The main reasons for this maturity are establishment of a specific I4.0 management committee, definition of a technological roadmap, use of pilot projects following the proof-of-concept strategy and integration of I4.0 implementation with Lean Manufacturing. It is possible to infer that organizations with more manufacturing activities are more mature in I4.0.

We started in 2018 creating an I4.0 committee to map the technologies and initiatives that the departments were doing. Then we prepared a Roadmap, defined key enabling technologies and started developing (implementing) *them. We always apply proof of concept strategy to start testing the technology and see if it works in the industry environment, then generating scalability until it becomes systemic* [GQML].

Among the consequences of implementing I4.0, GEEIM and GEORH highlight the reduction of manual and repetitive tasks through routine tasks automation (e.g.: robot process automation - RPA) (Sima et al., 2020; Novakova, 2020).

... there are a lot of people doing conference control activities that could be easily automated, so we are working on it to have more robots in the administrative areas, freeing up resources to work with I4.0 technology. [GEORH].

... since some operations and jobs are impacted, affecting workers, such as collaborative robots, requiring them to learn acting and working with a collaborative robot, so they will receive a differentiated training. [GEEIM].

Interviewees say that there is a change in organizations' objectives for the transformation to I4.0, but consequently and not on purpose, they are still focusing on increasing the organization's revenue and competitiveness. GQML added that objectives should not focus exclusively on I4.0 technologies, but also across the organization.

It always focuses more on technology, but it is also necessary to focus on the organization culture and structure [GQML].

4.3. Knowledge perspective

There is consensus among interviewees in the ESC on the need for greater knowledge about I4.0, through elementary knowledge, continuous learning and attention to new technologies. The interviewees GEEIM and GI indicate that new projects have allowed the implementation of new technologies.

... a big I4.0 dilemma is what is Buzzword and what is I4.0? [GEORH].

... you must have the team engaged, all the time looking at new trends and taking advantage of new products implementation and assembly line changes, in order to fit them [new technologies] ... [GEEIM].

In the sphere of blue-collar workers, there is also a concern with knowledge in software, but it is knowledge sharing that poses a greater challenge.

Another challenge is the issue of tacit knowledge, for example, a worker who knows a lot about engines and who works with it his whole life. He is already at an age that will not be willing to modernize himself, but a new worker is coming and how are we going to share this knowledge? [GQML].

Regarding lessons learned from I4.0 implementation, interviewees summarized the importance of workers skills development, workers involvement in implementing a new technology, attention to knowledge sharing and mechanisms for retaining qualified workers.

... a digitization project did not deliver concrete results, only promises. I think the reason was lack of soft skills [GEORH].

... an online system for the process sheets was developed by a worker, but it did not go through a robust implementation process. When that worker left the organization, the know-how of this software was lost [GI].

A not-so-successful was the implementation of an autonomous mobile robot for line feeding, which at first gave a lot of failures and blue collar workers did not believe in the functionality of it, in addition to being jealous, because the robot was doing their job. It was thought even to cancel this initiative due to rejection and a lot of failures, but we persisted. To meet this challenge, we involved more blue-collar workers [GQML].

5. Discussion

Recently, the European Commission has begun to call Industry 5.0, where "[...] the wellbeing of the worker is placed at the center of the production process and uses new technologies to provide prosperity beyond jobs and growth, while respecting the production limits of the planet [...]" (European Commission, 2021).

Work and human factors are relevant to implement I4.0 (Müller, 2019; Wibowo et al., 2020). Digital transformation promotes human-machine interaction, and workers need to develop skills in order to meet this demand (Sima et al., 2020). The interviewees also highlight human factors as important to I4.0, which include workers tasks, skills and qualifications, nature of work, HR development, hiring process and organizations strategies. It is also found that knowledge sharing poses a huge challenge.

The findings indicate that I4.0 will affect workers and reduce their tasks. There is an organization's concern about a lack of qualified workers to work with I4.0. Benotsmane et al. (2019) emphasizes the demand of a skilled labor force for programming and operation of intelligent devices in I4.0, registering that there will be replacement of workers by intelligent devices, and there will be reduction of manual and repetitive tasks through automation of routine tasks (Trotta & Garengo, 2018; Sima et al., 2020).

The necessary worker skills and qualification to act with I4.0 came out of the research. They should develop technical skills, software knowledge, programming, applied mathematics, statistics, and soft skills, such as innovation and creativity, openness to learning, acceptance and ability to adapt to changes. The findings are consistent with the literature review (Jerman et al., 2020; Novakova, 2020).

The nature of work of white- and blue-collar workers differ in the I4.0 implementation. White collar workers contribute with technical knowledge and participate more in I4.0 implementation than the blue-collar workers, who provide information to the implementation as technology users (e.g.: MES). Despite the importance of the workers' participation to the success of I4.0 implementation (Kipper et al., 2020; Valentina et al., 2021), there are few participations at BMC. The workers are still engaged in the continuous improvement at the assembly lines after technology implementation.

An adequate number of skilled workers must be hired (Benotsmane et al. 2019) and workers with less qualification are exposed to employment risks (Novakova, 2020). The interviewees state that workers need an appropriate skill development program, so they can contribute ideally to the organization in the transformation to I4.0. According to the research, organizations and workers have the responsibility to adapt to this transformation, because their current skills and qualifications are not consistent with the needs of I4.0.

Sima et al. (2020) also describes the importance of updating the hiring process, as job descriptions should reproduce new demands for creativity and multidisciplinary skills. Therefore, additionally to skills and qualification programs, interviewees point out that the organization should update its hiring process, especially job descriptions, as well as promote mechanisms for retaining skilled workers, such as attractive levels of income and additional allowances, as mentioned by Benotsmane et al. (2019).

Regardless of the multi-firm and multi-cultural aspect of the BMC, there is a convergence of the interview's results between the studied organizations.

6. Conclusion

Assembly lines are sociotechnical systems, which involve ongoing interactions between workers and technology, and they are rapidly transforming virtually all areas of Work, Process and Knowledge. The digital transformation is impacting the way human work is organized and performed. Not surprisingly, I4.0 based technologies studies are much more relevant than I4.0 based human studies, which is an important topic still underrepresented in the literature.

This paper explores work and human factors of digital transformation through discussion supported by relevant theoretical and senior managers perspective, who have been leading I4.0 application projects at ESC of BMC. There are reasonable I4.0 initiatives at ESC. This paper conducts a comprehensive discussion, and presents an overview of content, scope, and findings related to:

- Work, considering social (human-centered) requirements as HRM, including workers tasks, skills and qualification, HR development, hiring process and organizations strategies;
- Process, considering new technologies that contribute to mass customization and efficiency, such as MES and RPA, and reinforces the flexibility of BMC, through its reconfigurable and changeable manufacturing systems alignment;
- Knowledge, considering the risk of knowledge loss/retention related to layoffs and retirement scenarios.

This research reinforces the importance of human capital for the implementation of I4.0 and points out that the success for the implementation of new technologies in the ESC of the BMC implicates involving workers throughout the process.

6.1. Practical and theoretical implications

For most practitioners, the digital transformation and its implications on human operations processes remain a black box. A better understanding of Work, Process and Knowledge integration approach supports HRM and contributes to the promotion of a favorable context for creation and sharing of knowledge by workers in I4.0, fostering continuous improvement, and broadening the field of vision of practitioners for decision-making, seeking competitiveness.

The findings contribute with the academic interest on I4.0 impacts on Work, Process and Knowledge, and with elements for reflection about the importance of Work, Process and Knowledge on the shop floor. In this sense, the scenario of economic activity reduction and layoffs in the industry highlight the importance of knowledge sharing, influencing remaining workers and future hiring, when restarting the sector's stability.

6.2. Further research

Once the impacts of the implementation of I4.0 in the automotive industry have been discussed in the managerial context, an opportunity opens up, following the method defined in this paper, to discuss the impacts also from the worker's perspective, with a possible extension of interviews with workers' representatives. Following the same strategy, the possibility of expanding the sample internationally is also an opportunity, in a discussion that involves organizational culture.

The Knowledge Management (KM) appears implicit in the interviews and indicates a demand to further research related to capture, share and reuse tacit worker knowledge during implementation of I4.0. The discussion on KM in I4.0 implementation is recent (Cassia et al., 2020; Manesh et al., 2020; Ribeiro et al., 2022), and its influence on the digital transformation of production systems, HRM and creation of favorable contexts for knowledge sharing is still few explored (Muniz Junior et al., 2021, 2022a).

The education of I4.0 is a challenge which enables its implementation (Hariharasudan & Kot, 2018). The new Brazilian engineering guidelines concern with I4.0 implementation, and the academic curricula are being revised to qualify new workers. The complexity associated with existing methods remains an inhibitor for digital transformation (Erol et al., 2016). I4.0 learning models proposed by Hecklau et al. (2016), Prinz et al. (2016), Baena et al. (2017) and Uhlemann et al. (2017) are highlighted as pioneers, but these methods still require strong empirical validation of existing models, which represent a research opportunity.

Acknowledgements

The authors gratefully acknowledge the following Brazilian research funding agencies for their support: grant #2021/10944-2, Sao Paulo Research Foundation (FAPESP); #88887.310463/2018-00 (CAPES-PrInt), and Coordination of Superior Level Staff Improvement (CAPES).

References

Abreu, A. R. D. P., Beynon, H., & Ramalho, J. R. (2000). 'The Dream Factory': VW's Modular Production System in Resende, Brazil. *Work, Employment and Society*, *14*(2), 265-282. http://dx.doi.org/10.1177/09500170022118400.

Ada, N., Ilic, D., & Sagnak, M. (2021). A framework for new workforce skills in the era of industry 4.0. International Journal of Mathematical. *Engineering and Management Sciences*, *6*(3), 771.

Archanjo de Souza, D. S. D. O., Pedro Salgado, A. M., Marins, F. A. S., & Muniz, J. (2020). The influence of leaders' characteristics on the relationship between leadership and knowledge management. *Knowledge Management Research and Practice*, *18*(4), 462-473. http://dx.doi.org/10.1080/14778238.2020.1730716.

Baena, F., Guarin, A., Mora, J., Sauza, J., & Retat, S. (2017). Learning factory: the path to industry 4.0. *Procedia Manufacturing*, *9*, 73-80. http://dx.doi.org/10.1016/j.promfg.2017.04.022.

Becker, T., Blocher, A., Bücker, I., Drewel, M., Faath, A., Harland, T., & Zeller, V. (2017). *Industrie 4.0 Maturity Index. Managing the Digital Transformation of Companies*. Herbert Utz Verlag.

Benotsmane, R., Kovács, G., & Dudás, L. (2019). Economic, social impacts and operation of smart factories in Industry 4.0 focusing on simulation and artificial intelligence of collaborating robots. *Social Sciences*, *8*(5), 143. http://dx.doi.org/10.3390/socsci8050143.

Bernardes, E., Muniz Junior, J., & Nakano, D. (2019). *Pesquisa qualitativa em engenharia de produção e gestão de operações*. São Paulo: Atlas.

Cassia, A. R., Costa, I., da Silva, V. H. C., & de Oliveira Neto, G. C. (2020). Systematic literature review for the development of a conceptual model on the relationship between knowledge sharing, information technology infrastructure and innovative capability. *Technology Analysis and Strategic Management*, *32*(7), 801-821. http://dx.doi.org/10.1080/09537325.2020.1714026.

Cyril Eze, U., Guan Gan Goh, G., Yih Goh, C., & Ling Tan, T. (2013). Perspectives of SMEs on knowledge sharing. *Vine*, *43*(2), 210-236. http://dx.doi.org/10.1108/03055721311329963.

Dalenogare, L. S., Benitez, G. B., Ayala, N. F., & Frank, A. G. (2018). The expected contribution of Industry 4.0 technologies for industrial performance. *International Journal of Production Economics*, *204*, 383-394. http://dx.doi.org/10.1016/j.ijpe.2018.08.019.

Eisenhardt, K. M. (1989). Building theories from case study research. *Academy of Management Review*, *14*(4), 532-550. http://dx.doi.org/10.2307/258557.

Engineering and Physical Sciences Research Council – EPSRC. (2018). *Manufacturing the future: standard research proposals*. EPSRC. Retrieved in 2019, November 28, from https://www.ukri.org/opportunity/manufacturing-the-future/

Erol, S., Jäger, A., Hold, P., Ott, K., & Sihn, W. (2016). Tangible Industry 4.0: a scenario-based approach to learning for the future of production. *Procedia CIRP*, *54*, 13-18. http://dx.doi.org/10.1016/j.procir.2016.03.162.

European Commission. (2021). *Industry 5.0*. Retrieved in 2021, November 12, from: https://ec.europa.eu/info/research-and-innovation/research-area/industrial-research-and-innovation/industry-50_en

European Parliament. (2016). *Industry 4.0. Directorate General for Internal Policies, Policy Department A: Economic and Scientific Policy*. Study for the ITRE committee. Retrieved in 2019, November 28, from http://www.europarl.europa.eu/RegData/etudes/STUD/2016/570007/IPOL_STU(2016)570007_EN.pdf

Executive Office of the President of the United States. (2018). *Strategy for American Leadership in Advanced Manufacturing* (35 p.). Washington: National Science and Technology Council. Retrieved in 2019, November 28, from https://trumpwhitehouse.archives.gov/wp-content/uploads/2018/10/Advanced-Manufacturing-Strategic-Plan-2018.pdf

Goswami, M., & Daultani, Y. (2022). Make-in-India and industry 4.0: Technology readiness of select firms, barriers and socio-technical implications. *The TQM Journal*, *34*(6), 1485-1505. http://dx.doi.org/10.1108/TQM-06-2021-0179.

Graneheim, U. H., & Lundman, B. (2004). Qualitative content analysis in nursing research: concepts, procedures and measures to achieve trustworthiness. *Nurse Education Today*, *24*(2), 105-112. http://dx.doi.org/10.1016/j.nedt.2003.10.001. PMid:14769454.

Grzybowska, K., & Łupicka, A. (2017). Key competencies for Industry 4.0. *Economics & Management Innovations*, *1*(1), 250-253. http://dx.doi.org/10.26480/icemi.01.2017.250.253.

Hariharasudan, A., & Kot, S. (2018). A scoping review on Digital English and Education 4.0 for Industry 4.0. *Social Sciences*, *7*(11), 227. http://dx.doi.org/10.3390/socsci7110227.

Hecklau, F., Galeitzke, M., Flachs, S., & Kohl, H. (2016). Holistic approach for human resource management in Industry 4.0. *Procedia CIRP*, *54*, 1-6. http://dx.doi.org/10.1016/j.procir.2016.05.102.

Hernandez-de-Menendez, M., Morales-Menendez, R., Escobar, C. A., & McGovern, M. (2020). Competencies for industry 4.0. *International Journal on Interactive Design and Manufacturing*, *14*(4), 1511-1524. http://dx.doi.org/10.1007/s12008-020-00716-2.

Hong, D., Suh, E., & Koo, C. (2011). Developing strategies for overcoming barriers to knowledge sharing based on conversational knowledge management: a case study of a financial company. *Expert Systems with Applications*, *38*(12), 14417-14427. http://dx.doi.org/10.1016/j.eswa.2011.04.072.

IndustriALL Global Union. (2017). *The challenge of industry 4.0 and the demand for new answers*. IndustriALL Global Union. Retrieved in 2021, November 12, from http://www.industriall-union.org/sites/default/files/uploads/documents/2017/SWITZERLAND/Industry4point0Conf/industry_4_en_web.pdf

Ipe, M. (2003). Knowledge sharing in organizations: a conceptual framework. *Human Resource Development Review*, *2*(4), 337-359. http://dx.doi.org/10.1177/1534484303257985.

Jerman, A., Pejić Bach, M., & Aleksić, A. (2020). Transformation towards smart factory system: Examining new job profiles and competencies. *Systems Research and Behavioral Science*, *37*(2), 388-402. http://dx.doi.org/10.1002/sres.2657.

Kaasinen, E., Schmalfuß, F., Özturk, C., Aromaa, S., Boubekeur, M., Heilala, J., Heikkilä, P., Kuula, T., Liinasuo, M., Mach, S., Mehta, R., Petäjä, E., & Walter, T. (2020). Empowering and engaging industrial workers with Operator 4.0 solutions. *Computers & Industrial Engineering*, *139*, 105678. http://dx.doi.org/10.1016/j.cie.2019.01.052.

Karre, H., Hammer, M., Kleindienst, M., & Ramsauer, C. (2017). Transition towards an Industry 4.0 state of the LeanLab at Graz University of Technology. *Procedia Manufacturing*, *9*, 206-213. http://dx.doi.org/10.1016/j.promfg.2017.04.006.

Kipper, L. M., Furstenau, L. B., Hoppe, D., Frozza, R., & Iepsen, S. (2020). Scopus scientific mapping production in industry 4.0 (2011-2018): a bibliometric analysis. *International Journal of Production Research*, *58*(6), 1605-1627. http://dx.doi.org/10.1080/00207543.2019.1671625.

Kipper, L. M., Iepsen, S., Dal Forno, A. J., Frozza, R., Furstenau, L., Agnes, J., & Cossul, D. (2021). Scientific mapping to identify competencies required by industry 4.0. *Technology in Society*, *64*, 101454. http://dx.doi.org/10.1016/j.techsoc.2020.101454.

Kotha, S. (1995). Mass customization: implementing the emerging paradigm for competitive advantage. *Strategic Management Journal*, *16*(S1), 21-42. http://dx.doi.org/10.1002/smj.4250160916.

Kuo, F. Y., & Young, M. L. (2008). Predicting knowledge sharing practices through intention: a test of competing models. *Computers in Human Behavior*, *24*(6), 2697-2722. http://dx.doi.org/10.1016/j.chb.2008.03.015.

Lu, Y. (2017). Industry 4.0: a survey on technologies, applications and open research issues. *Journal of Industrial Information Integration*, *6*, 1-10. http://dx.doi.org/10.1016/j.jii.2017.04.005.

Maisiri, W., Darwish, H., & Van Dyk, L. (2019). An investigation of industry 4.0 skills requirements. *South African Journal of Industrial Engineering*, *30*(3), 90-105. http://dx.doi.org/10.7166/30-3-2230.

Maisiri, W., & van Dyk, L. (2021). Industry 4.0 skills: a perspective of the South African manufacturing industry. *SA Journal of Human Resource Management*, *19*, 1416. http://dx.doi.org/10.4102/sajhrm.v19i0.1416.

Manesh, M. F., Pellegrini, M. M., Marzi, G., & Dabic, M. (2020). Knowledge management in the fourth industrial revolution: mapping the literature and scoping future avenues. *IEEE Transactions on Engineering Management*, *68*(1), 289-300. http://dx.doi.org/10.1109/TEM.2019.2963489.

Melo, J. C., Rays Filho, I., Guerra, B. F., & Muniz Junior, J. (2022). Preparação dos trabalhadores para a I4.0: revisão sistemática da literatura. *Exacta*, 1-22. https://doi.org/10.5585/exactaep.2022.21905.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & PRISMA Group (2010). Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *International Journal of Surgery*, *8*(5), 336-341. http://dx.doi.org/10.1016/j.ijsu.2010.02.007. PMid:20171303.

Müller, J. M. (2019). Assessing the barriers to Industry 4.0 implementation from a workers' perspective. *IFAC-PapersOnLine*, *52*(13), 2189-2194. http://dx.doi.org/10.1016/j.ifacol.2019.11.530.

Muniz Junior, J. Ribeiro, V. B., & Pradhan, N. (2021). Knowledge-based assessment applied to lean brazilian toyota plants: employees' perceptions. *International Journal of Knowledge Management*, *17*(2), 1-22. http://dx.doi.org/10.4018/IJKM.2021040101.

Muniz Junior, J., Batista Junior, E. D., & Loureiro, G. (2010). Knowledge-based integrated Production Management Model applied to automotive companies. *International Journal of Knowledge Management Studies*, *4*(3), 301-318.

Muniz Junior, J., Wintersberger, D., & Hong, J. L. (2022a). Worker and manager judgments about factors that facilitate knowledge-sharing: insights from a Brazilian automotive assembly line. *Knowledge and Process Management*, *29*(2), 132-146. http://dx.doi.org/10.1002/kpm.1693.

Muniz Junior, J., Valentim, M. L. P., Wintersberger, D., Ramirez, P., & Zhang, Y. (2022b). The relationship between Industry 4.0 with official Brazilian actions and the 2030 Agenda. In B. M. Fernandes (Org.), *Building territories based on GDS leaving no one behind*. São Paulo: UNESP.

Nakano, D., & Muniz Junior, J. (2018). Writing the literature review for empirical papers. *Production*, *28*(0), 28. http://dx.doi.org/10.1590/0103-6513.20170086.

Novakova, L. (2020). The impact of technology development on the future of the labour market in the Slovak Republic. *Technology in Society*, *62*, 101256. http://dx.doi.org/10.1016/j.techsoc.2020.101256.

Organisation for Economic Co-operation and Development – OECD. (2017). *Digital economy outlook*. Retrieved in 2021, August 12, from https://www.oecd-ilibrary.org/sites/6f9d3f23-pt/index.html?itemId=/content/component/6f9d3f23-pt

Organisation Internationale des Constructeurs d'Automobiles – OICA. (2021). *Production statistics*. Retrieved in 2022, June 3, from https://www.oica.net/category/production-statistics/2021-statistics/

Peruzzini, M., & Pellicciari, M. (2017). A framework to design a human-centred adaptive manufacturing system for aging workers. *Advanced Engineering Informatics*, *33*, 330-349. http://dx.doi.org/10.1016/j.aei.2017.02.003.

Prifti, L., Knigge, M., Kienegger, H., & Krcmar, H. (2017). A competency model for "Industrie 4.0" employees. In J. M. Leimeister & W. Brenner (Eds.), *Proceedings der 13 Internationalen Tagung Wirtschafts informatik*. St. Gallen: Wirtschafts informatik.

Prinz, C., Morlock, F., Freith, S., Kreggenfeld, N., Kreimeier, D., & Kuhlenkötter, B. (2016). Learning factory modules for smart factories in industrie 4.0. *Procedia CIRP*, *54*, 113-118. http://dx.doi.org/10.1016/j.procir.2016.05.105.

Resman, M., Turk, M., & Herakovič, N. (2021). Methodology for planning smart factory. *Procedia CIRP*, *97*, 401-406. http://dx.doi.org/10.1016/j.procir.2020.05.258.

Ribeiro, V. B., Nakano, D., Muniz Junior, J., & Oliveira, R. B. D. (2022). Knowledge management and Industry 4.0: a critical analysis and future agenda. *Gestão & Produção*, *29*, 29. http://dx.doi.org/10.1590/1806-9649-2022v29e5222.

Rodriguez, I. A., Muniz Junior, J., & Munyon, T. P. (2021). Exploring the Relationship Between Organizational Politic and Knowledge Sharing in Brazilian Modular Consortium. *International Journal of Knowledge Management*, *17*(4), 76-92. http://dx.doi.org/10.4018/IJKM.2021100104.

Shamim, S., Cang, S., Yu, H., & Li, Y. (2016). Management approaches for Industry 4.0: a human resource management perspective. In *Proceedings of the 2016 IEEE Congress on Evolutionary Computation (CEC)* (pp. 5309-5316). USA: IEEE.

Sié, L., & Yakhlef, A. (2009). Passion and expertise knowledge transfer. *Journal of Knowledge Management*, *13*(4), 175-186. http://dx.doi.org/10.1108/13673270910971914.

Siemens. (2015). *On the Way to Industrie 4.0: The Digital Enterprise. Presentation*. Retrieved in 2019, November 28, from https://assets.new.siemens.com/siemens/assets/api/uuid:558e2625-d63c-4567-9bb0-1553ae567ff2/presentation-e.pdf

Sima, V., Gheorghe, I. G., Subić, J., & Nancu, D. (2020). Influences of the industry 4.0 revolution on the human capital development and consumer behavior: a systematic review. *Sustainability*, *12*(10), 4035. http://dx.doi.org/10.3390/su12104035.

Škrinjarić, B., & Domadenik, P. (2020). Examining the role of key competences in firm performance. *International Journal of Manpower*, *41*(4), 391-416. http://dx.doi.org/10.1108/IJM-10-2018-0349.

Song, S., Shi, X., Song, G., & Huq, F. A. (2021). Linking digitalization and human capital to shape supply chain integration in omni-channel retailing. *Industrial Management & Data Systems*, *121*(11), 2298-2317. http://dx.doi.org/10.1108/IMDS-09-2020-0526.

Spöttl, G., & Windelband, L. (2021). The 4th industrial revolution–its impact on vocational skills. *Journal of Education and Work*, *34*(1), 29-52. http://dx.doi.org/10.1080/13639080.2020.1858230.

Stemler, S. (2000). An overview of content analysis. *Practical Assessment, Research & Evaluation*, *7*(1), 17.

Strohmeier, S. (2020). Smart HRM–a Delphi study on the application and consequences of the Internet of Things in Human Resource Management. *International Journal of Human Resource Management*, *31*(18), 2289-2318. http://dx.doi.org/10.1080/09585192.2018.1443963.

Tohidinia, Z., & Mosakhani, M. (2010). Knowledge sharing behaviour and its predictors. *Industrial Management & Data Systems*, *110*(4), 611-631. http://dx.doi.org/10.1108/02635571011039052.

Trotta, D., & Garengo, P. (2018, March). Industry 4.0 key research topics: a bibliometric review. In *Proceedings of the 2018 7th International Conference on Industrial Technology and Management (ICITM)* (pp. 113-117). USA: IEEE.

Uhlemann, T. H. J., Schock, C., Lehmann, C., Freiberger, S., & Steinhilper, R. (2017). The digital twin: demonstrating the potential of real time data acquisition in production systems. *Procedia Manufacturing*, *9*, 113-120. http://dx.doi.org/10.1016/j.promfg.2017.04.043.

Valentina, D. P., Valentina, D. S., Salvatore, M., & Stefano, R. (2021). Smart operators: How Industry 4.0 is affecting the worker's performance in manufacturing contexts. *Procedia Computer Science*, *180*, 958-967. http://dx.doi.org/10.1016/j.procs.2021.01.347.

Vrchota, J., Mařiková, M., Řehoř, P., Rolínek, L., & Toušek, R. (2019). Human resources readiness for industry 4.0. *Journal of Open Innovation: Technology, Market, and Complexity*, *6*(1), 3. http://dx.doi.org/10.3390/joitmc6010003.

Wang, S., & Noe, R. A. (2010). Knowledge sharing: a review and directions for future research. *Human Resource Management Review*, *20*(2), 115-131. http://dx.doi.org/10.1016/j.hrmr.2009.10.001.

Wibowo, E. B., Legionosuko, T., Mahroza, J., & Chandra Jaya, Y. (2020). Industry 4.0: challenges and opportunities in competency development for defense apparatus' human resources. *International Journal of Advanced Science and Technology*, *29*(7), 45-60.

Wollschlaeger, M., Sauter, T., & Jasperneite, J. (2017). The future of industrial communication: automation networks in the era of the internet of things and industry 4.0. *IEEE Industrial Electronics Magazine*, *11*(1), 17-27. http://dx.doi.org/10.1109/MIE.2017.2649104.