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Human-Centred Dissemination of Data, Information and Knowledge in Industry 4.0

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Abstract

The manufacturing industry faces immense challenges for maintaining and increasing their productivity and flexibility. In this context, it is important for companies to ensure that their employees have the relevant data, information and knowledge necessary to make well-informed decisions. Due to recent development with Industry 4.0 enabling technologies that create new possibilities, the amount of available data, information and knowledge increase rapidly, but the insights into how to utilize it to its full potential are still lacking. In this paper, a human-centred perspective has been applied, aiming at improving how to cognitively support humans at work with new Industry 4.0 enabling technologies. Heavy emphasis is placed on people's requirements and preferences of data, information and knowledge for enhancing their performance and satisfaction at work. This paper examines the relationship between existing literature on dissemination of data, information and knowledge within the manufacturing industry with state-of-the-art research on Industry 4.0. The outcome of the research recognizes the increased importance of utilizing data, information and knowledge for people at work, facilitated by exploiting the new possibilities from Industry 4.0. To accomplish this, it is concluded that there exists an urgency to design: both a holistic framework for identifying and accommodating individuals' needs and expectations of relevant data, information and knowledge; and demonstrators and concepts to simplify the implementation of Industry 4.0 enabling technologies that support the aforementioned dissemination of data, information and knowledge.

Keywords: data; information; knowledge; Industry 4.0

1. Introduction

As the manufacturing industry has moved from cost-efficient mass production towards mass customization with a larger variety of products [1,2], complexity has increased for manufacturing systems in general [3] and assembly work in particular [4]. If this increased complexity, that requires flexibility [1,5], is properly managed, the manufacturer will gain a competitive advantage because of better capabilities to meet individual customers' demands [3,6].

In this manufacturing context with increased complexity, two visions appear. First, the incoming technology-driven paradigm shift of Industry 4.0 [7,8] will increase digitization, automation, and communication [9]. This will lead to greater integration of data and information vertically within the organization and horizontally throughout the supply chain, as well as digitally end-to-end across a product's value chain [10,11]. Second, that in such future production systems, the human operators remain as invaluable resources [12] because of their abilities to coordinate and solve problems [13], to make decisions [14], to manage increased complexity [3], and to flexibly adapt to challenging work environments [15].

These two visions converge, as Industry 4.0 enabling technologies create opportunities to cognitively support human operators, the Operator 4.0 [16,17]. Operator 4.0 needs different types of support in three different phases, whether it is during a learning phase with new work tasks, a more steady-state operational phase, or a disruptive phase with unexpected problems occurring [16]. However, the design and subsequent implementation of such cognitive support systems remain a

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difficult challenge for many manufacturing companies [18,19,20]. Many problems with implementing automation arise from designers or managers having different expectations than operators [21]. Hence, companies must strive to develop their organizational capabilities to more effectively identify and support Operator 4.0's needs for relevant data, information and knowledge [22].

Therefore, this paper aims to propose future research directions on the design of effective cognitive support for Operator 4.0 in an Industry 4.0 context.

The paper is structured as follows, first, a keyword analysis on Industry 4.0 literature is presented followed by a keyword analysis on literature on dissemination of data, information and knowledge in the manufacturing industry. To further study the intersection between Industry 4.0 and dissemination of data, information and knowledge, a structured literature review is presented, followed by a discussion of the results from the three analyses. Finally, the paper is concluded with the identification of directions for future research on how dissemination of data, information and knowledge in Industry 4.0 contexts should be designed and managed.

2. Industry 4.0

Industry 4.0 is becoming increasingly more well-researched, attracting attention from both practitioners and researchers [23,24]. As a genre, Industry 4.0 is quite broad [10]. By analyzing the keywords, the literature search aims to identify where research attention has focused so far. A search on Scopus database for titles, abstracts and keywords containing *Industry 4.0* or *Industrie 4.0*, as visualized in Fig. 1, resulted in 4565 documents, all between the years 2012 and 2019. The keywords that appear in more than 1% of the documents are listed in Table 1.

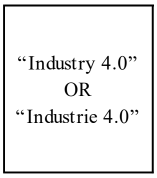

Fig. 1. Search string for literature search on Industry 4.0

While the keywords from Table 1 are not case sensitive, there are some similar spellings that constitute as thematic duplicates but are kept for methodological rigour. As expected, *Industry 4.0* and *Industrie 4.0* were among the most popular keywords. The various keywords relating to both *Internet of Things* and *Cyber-Physical Systems* appear regularly with many hits, forming a bedrock of published research focus. Follow suit, popular keywords include both general themes such as *digitalization*, *automation*, and *simulation*, as well as more specific technologies such as *big data*, *augmented reality*, *cloud computing*, *machine learning*, *digital twins*, and *additive manufacturing*.

Hence, the research focus of this technology-driven transformation of the manufacturing industry has mainly focused on the development of technological capabilities.

Table 1. List of keywords that appear in more than 1% of documents from Scopus search on *Industry 4.0* or *Industrie 4.0*.

Keywords	No. of documents
Industry 4.0	1878
Internet of Things	261
Industrie 4.0	242
Cyber-Physical Systems	180
Big Data	164
Smart Factory	155
Smart Manufacturing	143
IoT	137
Manufacturing	82
Augmented Reality	78
Digitalization	77
Cloud Computing	67
Industrial Internet of Things	67
Automation	63
Simulation	58
Internet of Things (IoT)	57
Machine Learning	52
Digital Transformation	51
Industrial Internet	51
Digital Twin	50
Security	50
Additive Manufacturing	46

Unsurprisingly, none of these most popular keywords related to Industry 4.0 is specifically concerning operators or humans at work in the manufacturing industry. Nevertheless, Industry 4.0 enabling technologies have the possibilities to cognitively support Operator 4.0 [25], which is important as the role of operators becomes more creative [26]. Human-centred research within Industry 4.0 related to cognitive support mainly focus on ergonomic user interfaces, intelligent assistance systems, virtual training, IT-based knowledge systems, and Manufacturing Execution Systems [27]. These research foci tend to emphasize the interaction between humans and automation. However, the data, information and knowledge that constitute the cognitive support originate from various sources, of which there is a lack of published research found in this Industry 4.0 keyword analysis.

3. Dissemination of Data, Information and Knowledge

The data, information and knowledge that are important for Operator 4.0 originate from various sources and need to be disseminated through various means of sharing and transferring to be able to support humans at work. By analyzing the keywords, the literature search aims to identify where research attention has focused so far. A Scopus search for titles, abstracts and keywords containing *dissemination*, *transfer* or *sharing* of *data*, *information* or *knowledge* in *manufacturing*, as clarified in Fig. 2, resulted in 3548 documents from the years 2012 to 2019, the same years Industry 4.0 existed in the previous literature search. The keywords that appear in more than 1% of the documents are listed in Table 2.

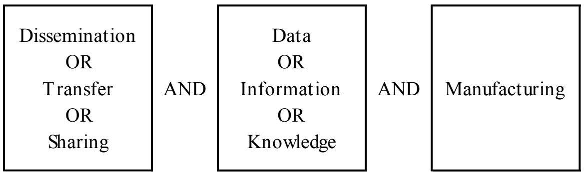

Fig. 2. Search string for literature search on dissemination of data, information and knowledge.

Table 2. List of keywords that appear in more than 1% of documents from Scopus search on *dissemination*, *transfer* or *sharing* of *data*, *information* or *knowledge* in *manufacturing*.

Keywords	No. of documents
Knowledge Management	91
Knowledge Sharing	86
Knowledge Transfer	79
Information Sharing	78
Additive Manufacturing	70
Cloud Manufacturing	70
Manufacturing	70
Innovation	63
Industry 4.0	48
Technology Transfer	48
Heat Transfer	47
Supply Chain Management	46
Supply Chain	35

Same as for Table 1, the keywords in Table 2 contain some thematic duplicates. The discipline of *Knowledge Management* appears as the most popular keyword. Further, as expected, popular keywords contain variants of the search string. Also here, *Industry 4.0* appears, signifying the important role it has for managing data, information and knowledge in the manufacturing industry, as well as more technology-focused keywords, e.g. *additive manufacturing*, *cloud manufacturing*, *heat transfer*. In relation to the end-to-end integration of Industry 4.0, the *supply chain* and its *management* also appear above the 1% barrier.

Similar to the Industry 4.0 keywords in Table 1, none of the keywords listed in Table 2 is specifically concerning operators or humans at work. However, the top keywords that regard *management*, *sharing* and *transfer* of *knowledge* implicitly include humans. Knowledge requires a higher level of understanding [28], which is dependent on the commitment and beliefs of individual humans [29]. Knowledge builds on information but mixed with experiences, values, and insights derived from minds at work [30]. While knowledge builds on information, information builds upon data endowed with purpose and relevance [28]. This spectrum, from data that is discrete facts about events [30] via information to knowledge, encompasses concepts which can be shared and transferred through proper dissemination based on the needs of individuals [31]. In this keyword analysis with documents from 2012 to 2019, dissemination of data, information and knowledge have received attention from researchers and in a certain extent been linked to Industry 4.0, but from a more technological and managerial perspective rather than focusing on the humans working in these socio-technical systems.

4. Dissemination of Data, Information and Knowledge in Industry 4.0

Despite the importance of humans in the future manufacturing industry [3,12,13,14,15], i.e. Operator 4.0 in Industry 4.0 [16,17,25,26], most research focuses on technological solutions, as found in the two keyword analyses above, when it is more important to originate from the information needs of individuals [31].

To further study human-centred dissemination of data, information and knowledge in an Industry 4.0 context, a systematic literature review was conducted. The Scopus database rendered 178 documents when searching for titles, abstracts and keywords containing *dissemination*, *transfer* or *sharing* of *data*, *information* and *knowledge* in *Industry 4.0*, as clarified in Fig. 3. In turn, the abstracts of the 178 documents were systematically reviewed in accordance with the exclusion criteria listed in Fig. 3. Only those articles with full text where included. The most common exclusion criteria were articles that focused on IT or system architecture without including human aspects, security and privacy of data, machine-machine communication and articles that study other contexts than manufacturing. The search was performed without any limitations to the publication year but all articles that were included in the analysis were published between 2015 and 2019. After the exclusions, the 178 documents were narrowed down to 15 articles, listed and summarized in Table 3.

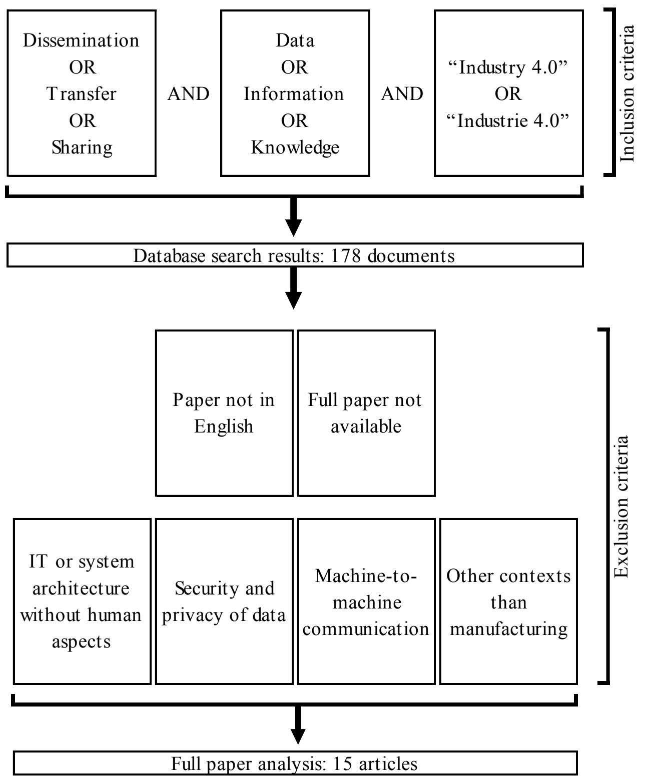

Fig. 3. Overview of the systematic literature review process.

Table 3. List of articles that were reviewed, including summary and content theme.

Authors	Year	Type	Ref.	Summary	Content
Gorecky et al.	2017	Journal article	[15]	Presents a virtual training system by using available digital tools such as Nintendo Wii and Microsoft Kinect. Also, discusses automatic training content generation by merging heterogeneous enterprise data.	Technological solution or the use of it **and** Learning and training
Kaasinen et al.	2019	Journal article	[17]	Discusses expectations and concerns with using Operator 4.0 solutions. They also have a short discussion about knowledge sharing.	Challenges and issues within Industry 4.0
Li et al.	2018	Conference article	[22]	Discusses the importance of considering organizational aspects when implementing emerging technologies to support operators in SMEs.	Organizational aspects of Industry 4.0
Kinkel et al.	2017	Conference article	[32]	Presents a framework for identifying and preventing critical competencies and discuss how knowledge can be shared both in face-to-face meetings and via social media.	Technological solution or the use of it **and** Learning and training
Aromaa et al.	2018	Conference article	[33]	Demonstrates different concepts (social media platform, AR, training platform, etc.) to engage workers.	Technological solution or the use of it
Alexopoulos et al.	2016	Journal article	[34]	Presents an architecture for context-aware manufacturing information system with the purpose of providing the proper information to the right person at the right time.	Technological solution or the use of it
Scheuermann et al.	2016	Conference article	[35]	Presents a technological solution with AR to identify a scene and attach annotations to objects in the virtual representation to share information between experts in maintenance.	Technological solution or the use of it
Mourtzis et al.	2018	Conference article	[36]	Presents a visualization of step-by-step instructions from CAM using AR.	Technological solution or the use of it
Scheuermann et al.	2015	Conference article	[37]	Information sharing within incident localization and assistant system by using smart-glove, smart-phone and Bluetooth.	Technological solution or the use of it
Thoben et al.	2017	Journal article	[38]	Discusses research issues related to Industry 4.0 and highlights issues about visualization of data and the different requirements of visualisation from different stakeholders.	Challenges and issues within Industry 4.0
Marinagi et al.	2018	Conference article	[39]	Discusses challenges with the use of intelligent agent technology, data mining and big data, cloud computing, internet of things, RFID technology, and industry 4.0, to implement information sharing in supply chains.	Challenges and issues within Industry 4.0
Haghi et al.	2018	Conference article	[40]	Presents that the most common challenge for SMEs is the lack of having a central unified source of data and for larger enterprises, the challenge is to identify all relevant data for predictive work.	Challenges and issues within Industry 4.0
Bauer et al.	2018	Conference article	[41]	Describes how digitalization will affect humans and organizations in the future.	Organizational aspects of Industry 4.0
Johansson et al.	2018	Conference article	[42]	Describes an industrial demonstrator of an assembly station focusing on a flexible information system where the assembly information can be altered based on the workers experience level and preferences.	Learning and training
Posselt et al.	2016	Conference article	[43]	Describes how learning can be improved by providing several human senses with feedback from the learning situation.	Learning and training

Summaries of the 15 articles, based on a review in full, are presented in the fifth column of Table 3. A thematic analysis of the content of the 15 articles, by reviewing and summarizing its contents, four content groups appeared, presented in the fifth column of Table 3. The 15 articles could be separated into four thematic groups, with implication for the design of dissemination of data, information and knowledge, based on their content:

- technological solutions or the use of them
- issues or challenges with Industry 4.0 and Operator 4.0
- the organizational aspects of Industry 4.0
- learning or training

4.1. Technological solutions or the use of them

These articles focus on how new technologies can be used to improve the information dissemination to ensure that the relevant information is presented to the right person at the right time. Different platforms or systems architectures can be used to store and share information such as social media platforms [32,33], training platforms [33] and a context-aware information system architecture [34]. To present and collect the information several Industry 4.0 enabling technologies can be used. The most common technologies in this review are

Augmented Reality (AR) which can be used in maintenance [35], for visualizing instructions [36], and to increase the worker engagement by providing context-related information [33]. Other technologies described are smart gloves and smartphones which can both collects and presents data in maintenance [37] and commercial off-the-shelf digital merchandise such as Nintendo Wii and Microsoft Kinect which can be used to create virtual training systems [15].

4.2. Challenges and issues with Industry 4.0 and Operator 4.0

The new technologies and solutions generated by the implementation of Industry 4.0 provide humans with easy access to data, information, and knowledge [17]. However, the implementation also brings challenges to organizations. Most of the identified challenges are related to technological systems, e.g. standards and interfaces [38], data security [17,38], data mining and big data [39], and cloud computing [39]. The size of the company also affects the challenges that derive from the implementation, for SMEs the main challenge is to have a central source of data while for the larger enterprises the identification of the relevant data is the most common challenge [40]. Challenges related to the humans in the systems concerns visualization of information [38], and negative influences and stress which can be caused by comparing the individual workers [17].

4.3. Organizational aspects of Industry 4.0

The transformation towards Industry 4.0 leads to changes within all dimensions of work which includes new challenges for the organization, qualification, employment and leadership [41]. Li et al. [22] highlight the difficulties in implementing Industry 4.0 enabling technologies in SMEs, however, the companies were able to improve their dissemination of data, information and knowledge using their existing technologies in a structured way.

4.4. Learning and training

The implementation of Industry 4.0 enabling technologies improves the prerequisites for efficient learning and training for humans in manufacturing systems. Technologies such as Nintendo Wii and Microsoft Kinect can be used to create a virtual training system for manual assembly, in which the trainee can use voice commands, movements and gestures, and receive haptic feedback, for example, from collisions in the virtual system [15]. Another way to improve learning is by using demonstrators or learning factories to test and validate information systems [42] as well as improving the learning process by providing feedback to several of the human senses [43].

5. Discussion

The results from the keyword analysis of "Industry 4.0" focused mainly on the development of technological capabilities and none of the most used keywords are specifically concerning the humans working in the manufacturing system. When looking at the results from the keyword analysis for the dissemination of data, information and knowledge in manufacturing we can see that similar to the Industry 4.0 analysis, there are no keywords specifically focusing on humans in manufacturing. However, several keywords related to the knowledge management field are implicitly concerning humans since knowledge is dependent on the commitment and beliefs of the human [29]. This gap in the literature needs to be addressed in future research since the human will continue to remain invaluable research in the manufacturing industry [12].

Another interesting finding is that Industry 4.0, and other keywords related to the concept, are used in the research about dissemination of data, information and knowledge, which indicates the importance of Industry 4.0 enabling technologies in the work towards better dissemination of data, information and knowledge. However, the dissemination of data, information and knowledge is not a topic of focus in the research domain of Industry 4.0. Based on these findings it is clear that there is a need to further explore the existing literature in the intersection between Industry 4.0, and data, information and knowledge dissemination from a human-centred perspective.

The four content themes, derived from the 15 reviewed articles, focus on various aspects of dissemination of data, information and knowledge in an Industry 4.0 context.

The new *technological solutions* for information dissemination, as identified in the systematic review, support operators cognitively in different ways [15,32,33,34,35,36,37], which is important for operators' performance as work tasks become more creative [26] and will require other types of cognitive support [25] in different situations [16]. Hence, this array of various cognitive support systems adds flexibility that can help reduce complexity for operators [1,3] but implementing such support tools remain challenging [19,20]. Consequently, formalized guidance would improve companies' preparedness to implement and embrace complexity-reducing cognitive support systems for operators.

All the new possibilities with Industry 4.0 enabling technologies also brings new *challenges* for the organizations. From the reviewed literature in Table 3, it can be seen that most of the discussed challenges are related to technological problems, which is in line with the findings in the keyword analyses. However, there is also an emphasis on challenges connected to the identification of the relevant data [40] and how to visualize it [38] which requires a more human-centred approach to understand the needs the individual stakeholders in the systems has on the information and its visualization.

While *organizational aspects* are important for implementation of Industry 4.0 enabling technologies in general [10,11], it is especially important when a human-centred focus is applied [22,41]. If organizationally considered, implementation of cognitive support systems should effectively reduce complexity, helping operators to solve problems [13] and make decisions [14]. In this context, organizational challenges include difficulties in understanding individuals' different needs [31] and expectations [21] on information content and presentation. Hence, the dissemination of data, information and knowledge needs to be supported by an organizational reconciliation and accommodation of the aforementioned individual needs and expectations.

Another highlighted area in the literature about dissemination of data, information, and knowledge in Industry 4.0 is the use of different digital tools to provide better *learning and training* opportunities for humans in manufacturing. The training can be both in a virtual environment [15] as well as in a so-called learning factory where different sensors and actuators are used to provide feedback to the trainee [43]. The use of learning factories and demonstrators is also a useful tool to test and verify how different technologies can be used [42] and how to address the aforementioned challenges.

6. Conclusion

Based on the two keyword analyses and the systematic literature review, two research directions for studying how to design the dissemination of data, information and knowledge in Industry 4.0 contexts have been identified.

First, the design of strategic frameworks for identifying and supporting individuals' needs of relevant data, information and knowledge that also incorporates the possibilities of Industry 4.0. Together, shorter feedback loops with data, information and knowledge at the right place and right time have many advantages for Operator 4.0. This can be challenging to design due to the difficulties in accurately identifying the many information needs of individuals and how to reconcile different preferences.

Second, designing and implementing organizational changes and new supportive technologies can be difficult. Hence, new solutions for the human-centred dissemination of data, information and knowledge need to be thoroughly tested, which can be conducted both conceptually in a learning factory environment, as well as empirically in cases at companies, which depends on the level of technological and organizational readiness.

These two research directions go hand-in-hand and contain challenges for both academia and industry. The design of a holistic framework needs to be based on industrial practice, at the same time implementation of new technologies need to have its foundation in purposeful design. In this context, the interplay between theory and practice need to consider the relationship between organizational and technological aspects of human-centred dissemination of data, information and knowledge in Industry 4.0.

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