Babeş-Bolyai University

Faculty of Economics and Business Administration

Summary of doctoral thesis

The impact of Industry 4.0 technologies on the human resources of multinational companies in the automotive sector

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Content of the summary of the doctoral thesis

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Abstract

Purpose: The ongoing digital transformation (identified commonly as Industry 4.0) of the manufacturing industry is not just a purely technological process: it has widespread interactions with several organizational aspects of the adopting firm, including its human resource base. Therefore, the purpose of this research is to extend previous research by investigating the role of human resources related to digital manufacturing technology adoption projects during different adoption stages and in relation with different organizational levels.

Methodology: Given the scarcity of results in the literature, this research adopts an exploratory, multiple case study approach. Data collection is carried out through semi-structured interviews with managers, complemented with site visits. Altogether, 10 cases studies from 5 manufacturing plants are investigated in two different countries.

Findings: The results provide a more fine-grained perspective on the interrelationship between human resources and digital technologies. These technologies affect different the identified three main human resource categories (managers, development experts and shop-floor employees), and the effect differs in the three key implementation phases (pre-implementation, during implementation and post-implementation) too. From a practical perspective, I aim to provide a tool for managers responsible for digitalization to identify most important activities, skills, and competencies along the implementation journey to arrive at a successful technology adoption.

Keywords:

digitalization, manufacturing technologies, industry 4.0, human resources, case study

Abbreviations

A – After the I4.0 implementation (post-implementation)
AGV – Automated Guided Vehicle
AI – Artificial Intelligence
B – Before the I4.0 technologies (pre-implementation)
CEF – Connecting Europe Facility
CT – Contingency Theory
D – During the I4.0 implementation (during implementation)
DE – Development Experts
DESI – Digital Economy and Society Index
E – Shop-floor employees
EDI – Electronic Data Interface
EU – European Union
HMI – Human-Machine Interaction
HR – Human Resources
HTO – Human–Technology–Organisation
I4.0 – Industry 4.0
IT – Information Technology
IIoT – Industrial Internet of Things
IoT – Internet of Things
LR – Literature Review
M – Manager
MVP – Minimal Viable Product
OCR – Optical Character Recognition
OEM – Original Equipment Manufacturer
OM – Operations Management
OWI 4.0 – Operator – Workstation Interaction 4.0
PM – Project Manager
QUAL – Qualitative
QUAN – Quantitative
RBV – Resource-Based View
RPA – Robotic Process Automation
SM – Smart Manufacturing
STS – Socio-Technical Systems
TAM – Technology Acceptance Model
TOE – Technology-Organization-Environment
TP – Top Manager
VR – Virtual Reality
WoS – Clarivate Web of Science

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1. Introduction

The ongoing digital transformation of the manufacturing industry, identified commonly under the umbrella term of Industry 4.0 (I4.0), promises to revolutionize the way manufacturing companies operate, enabling them to attain higher performances than ever before (Büchi et al., 2020; Szász et al., 2021). However, this transformation is not just a purely technological process, having widespread interactions with several organizational aspects of the adopting firm (Demeter et al., 2021), including its human resource base (Nayernia et al., 2021). Nevertheless, the human resource implications of implementing I4.0 technologies have received far less attention in literature, most of such articles applying only a narrow focus on either the new skills and competencies required for future manufacturing jobs or on aspects of new employee roles in an I4.0 context (Nayernia et al., 2021).

Successful digital transformation, however, would require a more complex management of human-system interaction, for which the literature offers limited guidance (Neumann et al., 2021). Existing studies in this field usually focus on a narrow aspect of human-technology (HR-I4.0) interaction. Thus, results currently offer only fragmented evidence, leaving the whole I4.0 technology implementation landscape uncovered. Nevertheless, a holistic approach is crucial in the management of the digital transformation process to reveal how different HR activities interact during different implementation stages and across organizational levels to improve the success of I4.0 implementation.

Thus, this research aims to: (1) identify research gaps in the I4.0-HR literature, (2) address these gaps with my case research and finally, (3) provide a holistic picture on how the success of I4.0 technologies can be enhanced by a proper management of human resources, guided by the following general research question **(RQ)**: **what is the role of human resources in the adoption of digital manufacturing technologies?**

2. Industry 4.0 in the countries of the European Union and in Central and Eastern Europe

First, the presence of I4.0 strategies in the European Union (EU) was analysed to find out some insight about the macro-level factors. Specialized I4.0 strategies are very common in the EU; most countries already have dedicated I4.0 strategies (ec.europa.eu, 2017). Central and Eastern European countries, like Hungary, Slovakia, Czechia, and Poland already have an I4.0 strategy (ec.europa.eu, 2017). In Romania, there are some national initiatives for industry digitalization, but the country does not have an I4.0 strategy. Therefore, in Romania, the I4.0 intentions can certainly be developed for most of the companies. Although many Romanian companies already use some I4.0 technologies (zf.ro, 2022), unfortunately Romanian firms in general lag behind the EU average in terms of digitalization, based on the DESI (Digital Economy and Society Index) (digital-agenda-data.eu, 2022). Due to this fact, the research could be relevant for the Romanian scientific community and for the entrepreneurial era too. One of Romania's neighbouring countries, Hungary has a focused Industry 4.0 strategy since 2016 (i40platform.hu, 2016). The Hungarian I4.0 strategy also noticed the human resources factor as a bottleneck for digitalization and as an area for urgent development.

3. Digitalization and Industry 4.0 in the automotive industry

Historically, the evolution of the manufacturing industry can be divided into four stages, the last decade being the era of I4.0 (Kagermann et al., 2013; Marnewick and Marnewick, 2020). Nowadays the industry has reached its fourth phase, I4.0. This contemporary stage is not just about automation and the use of advanced industrial technologies (Olsen & Tomlin, 2020); its distinctive feature is related to interconnected, complex production systems, where all actors – humans and machines – share data with each other and form a cyber-physical system together (Lee et al., 2015; Fatorachian & Kazemi, 2018). The backbone of this interconnected system is provided by the Internet of Things (IoT) which creates a digital network that connects machines, processes, and human actors (Fatorachian & Kazemi, 2018; Olsen & Tomlin, 2020). This transformation in the automotive industry started somewhere at the beginning of 2000, ahead of other industries. Today the cars are almost fully personalized, the production in most cases is automatized, the humans and the robots have been working together for a lot of years. Nowadays three megatrends are dominating the I4.0 in the automotive sector. These are cloud computing, cybersecurity, and big data analytics (automotiveworld.com, 2015).

4. Literature review on the role of human resources in Industry 4.0

To map current knowledge and gaps in the literature, a systematic literature review was conducted (Durach et al., 2017; Tranfield et al., 2003; Seuring & Gold, 2012). The search was made in the Clarivate Web of Science (WoS) database (which is the largest and the most recognized scientific database) on December 20, 2021. To generate a relevant initial pool of sample, several inclusion criteria have been established (Table 1).

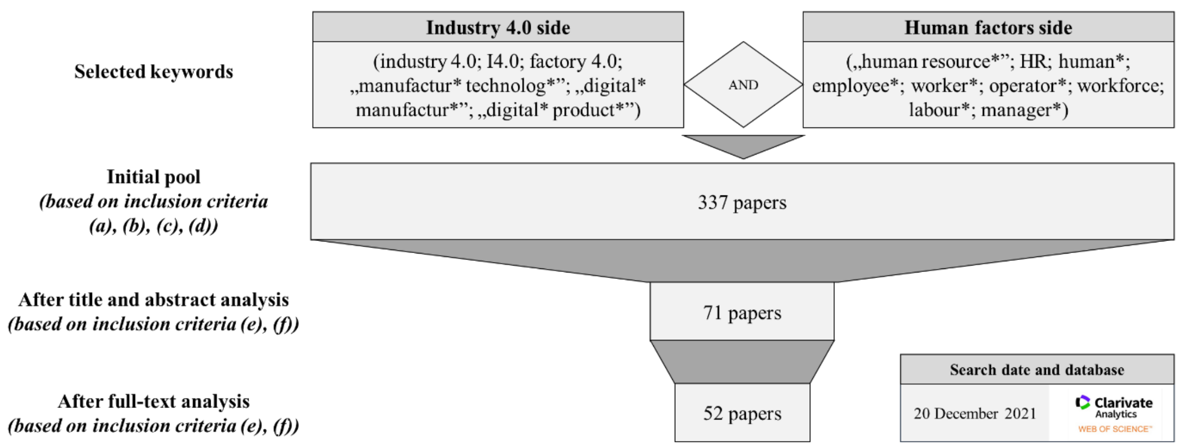
Table 1: Inclusion criteria

Inclusion criteria	Detailed argument
(a) Papers written in English.	English is the dominant research language in business and economics research; the use of English ensures the accessibility and comparability of the results.
(b) Papers published in or after 2012	The concept of I4.0 appeared in 2012 (Kagermann et al., 2013; Liao et al., 2017). Although some constituent technologies appeared earlier, 2012 can be considered as the seminal point of the I4.0 literature stream.
(c) Type of publication: scientific article, review or early access paper	This review focuses only on high quality, peer-reviewed scientific papers, where a rigorous review process ensures the reliability of the results. Other publication types, such as conference papers or book chapters are excluded.
(d) Based on its topic, the journal I in Business, Business Finance, Operations Research and Management Science, and/or Economics domains in Web of Science	This review focuses exclusively on the managerial and economic implications of I4.0 technologies in the human resource management domain. Purely technical discussions of the technology-human interaction are excluded.
(e) The paper focuses on manufacturing industries	Some papers use the I4.0 concept in a non-manufacturing context, which are filtered out.
(f) The paper focuses on the interplay between HR and at least one type of I4.0 technologies	Topical restriction through search keywords to identify results relevant to my research question.

Source: own construction

As an operationalization of the last inclusion criterion (f), several keywords have been defined to discover potentially relevant articles. Keywords were defined in relation with the two main domains of investigation, i.e. I4.0 and human resources. The keyword-based search resulted in a total of 337 articles. First, I have read the title and the abstract of each article to determine if they are potentially relevant or not. After evaluating the titles and abstracts for relevance, I have arrived at a total of 71 papers. As a last step, I have conducted a full-text analysis of the 71 papers to determine whether they truly contain relevant information to my topic, reaching thereby a final sample of 52 relevant papers (Figure 1).

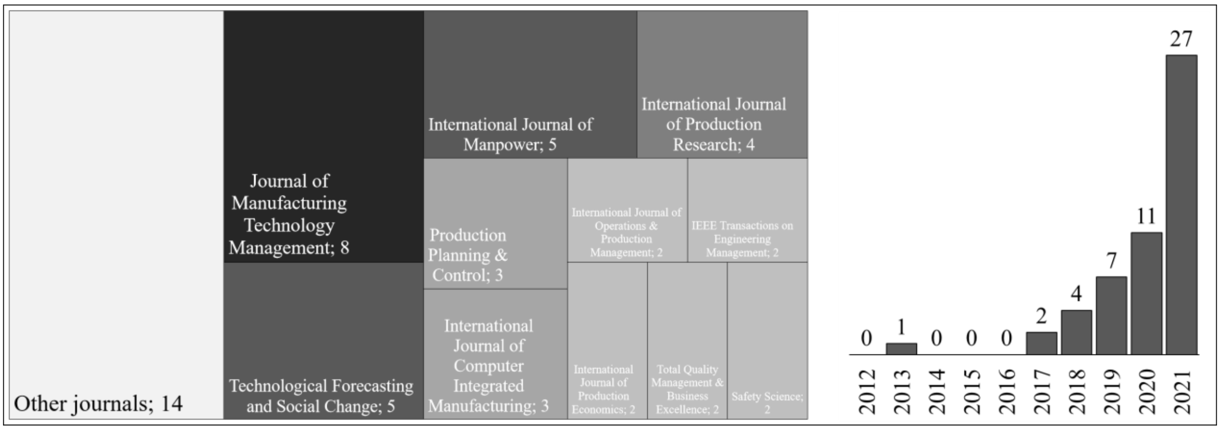
Figure 1: The article selection process



Source: own construction

While technological aspects of I4.0 (e.g., constituent technologies, synergies between different technologies, implementation drivers and barriers, performance implications, etc.) have been present in literature for almost a decade, human resource implications are still an emerging aspect in this stream (Neumann et al., 2021). This is supported by the fact that almost 52% of the relevant articles in my sample appeared in 2021; and 87% of all relevant papers are no older than 5 years (Figure 2). Thus, these results indicate that scientific discussion about the interplay between I4.0 and human resources has started only recently, leaving much room for advancing the understanding of the topic.

Figure 2: Sample characteristics based on publication year and the publishing journals

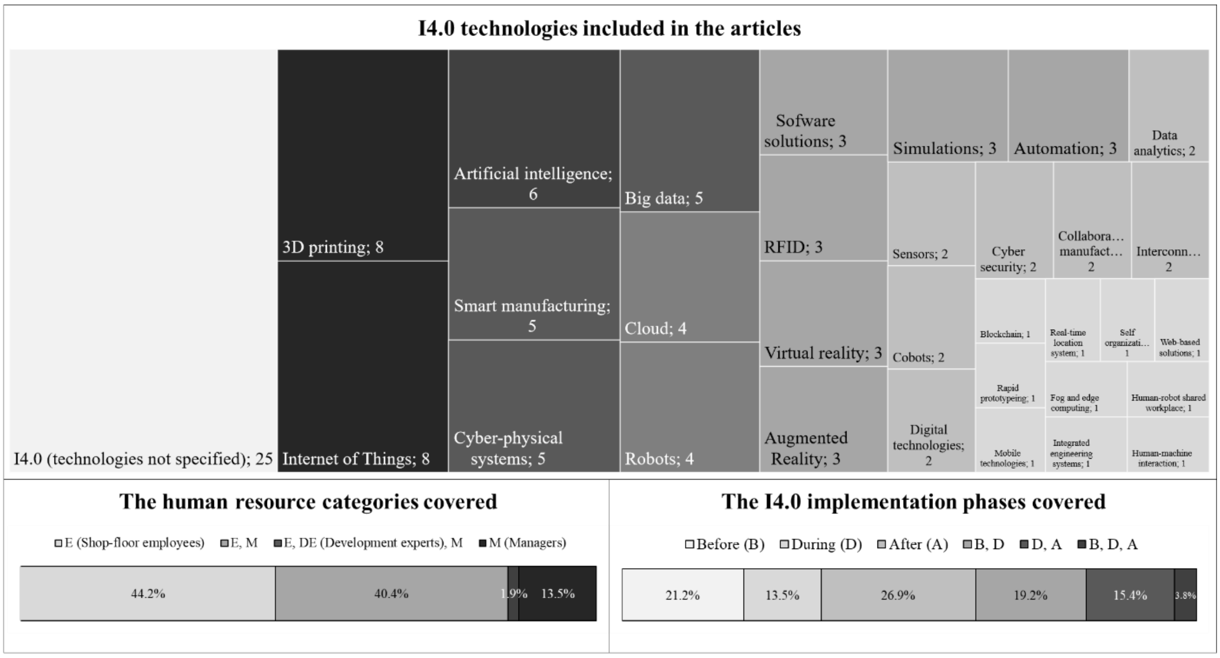


Source: own construction

The umbrella term I4.0 covers many different technologies (Culot et al., 2020). In my sample of articles 31 different technologies can be distinguished (Figure 3). These technologies might have different effects on human resources: the large number of different technologies predicts a diversity of the effects of I4.0 on human resources. It is also noticeable, that many articles do not specify the I4.0 technologies studied, using only the term “Industry 4.0” in a generic way. Employees play a defining role in the implementation of I4.0 technologies, thus it is not surprising that 86.5% of the articles reviewed include employee-related issues in their topics (Figure 3). 21.2% of the articles take only pre-implementation phase into consideration, another 13.5% focus exclusively on the implementation phase, while 26.9% highlight the post-implementation phase. Some articles cover more than one phase.

Existing studies generally focus on one specific organizational level and a single implementation phase. While focal employee groups are clearly defined in these papers, implementation phases are less frequently specified. Thus, in the following I will offer a summary of the literature grouped by the organizational levels they focus on.

Figure 3: Thematic aspects covered



Source: own construction

Managerial questions in the most cases are investigated in the context of the pre-implementation stage. This is explained by the fact that managers are the ones who make the decisions on the implementation of I4.0, thus playing the most defining role in the phase before implementation. Managers with a strong operational presence and early-adopter profile will foster quick I4.0 implementation (Moeuf et al., 2020). As in project management in general, in I4.0 implementation the support and commitment of top management is similarly crucial (e.g., Ukobitz, 2021). In addition, following a conscious planning process also can be considered as an important aspect (e.g., Horváth and Szabó, 2019). The willingness of leaders to introduce the new I4.0 technologies can be considered as one of the most important factors, without their commitment the I4.0 implementation probably will not even start.

During the transformation process, managers should have the necessary competences for achieving success, such as design thinking, research orientation or entrepreneurial intelligence. Based on these competences, continuous support from management, or securing the support from external partners should be present along the implementation. New technologies often require some adjustments in the organization and in the business model (e.g., Schneider, 2018), therefore organizational changes are continuously on the managers to-do list during implementation. Another important aspect, namely workers' resistance, represents a major challenge for managers during I4.0 adoption. Therefore, the top management should correctly inform the employees about the upcoming changes.

Last, the literature does little to address the role of managers after the implementation phase, though their role might similarly be crucial in enhancing the performance benefits achievable by the use of I4.0.

Development experts is a rarely mentioned category, many researchers focusing only on shop-floor employees and/or the managerial level. Selvarajoo et al. (2021) mentions the lack of expertise as a major challenge for implementation, which can be tackled by involving external experts, such as design engineers or technical engineers. Demeter et al. (2020) also highlights the role of the digital experts, as the ambassadors of change. Knowledge management can become a challenging aspect when external development experts are involved in a business unit’s I4.0 project.

Turning to the **shop-floor employee** side, much of the research focuses on the post-implementation stage, the first two phases receiving somewhat less attention. In general, the most common topics are the existing skills and competences (e.g., Stentoft et al., 2021; Ukobitz, 2021); new skills and competences (e.g., Agarwal et al., 2021; Vereycken et al., 2021) and, as a consequence of the new skills required, the way of acquiring them by training and education (e.g., Agarwal et al., 2021; Ozkan-Ozen and Kazancoglu, 2021). Before the implementation, having the right willingness and motivation can be a challenge for employees, but without them the effectiveness of I4.0 adoption can be hurt. Based on the literature, common understanding and vision among employees (Agarwal et al., 2021) can be considered as “step zero”. To enhance employee motivation to work with the I4.0 solutions, their involvement already in the development, and later in the implementation phase, could be a viable solution (Vereycken et al., 2021).

During the implementation phase, literature focuses mostly on the topic of employee trainings (e.g., Moeuf et al., 2020), as they can represent an effective solution for the emerging need for new skills and knowledge, and are also crucial in the employee relocation process when machines take over human roles, and employees need to take more complex, non-automated jobs.

In the after-phase, one of the main challenges is related to changes in job characteristics, among which the increase in job complexity can be frequently expected (Vereycken et al., 2021; Ozkan-Ozen and Kazancoglu, 2021). Job flexibility, increased creativity and improved transparency are also features that become more prevalent after I4.0 implementation. However, increased expectations from employees can also lead to work overload and technostress (Malik et al., 2021). Undoubtedly, digitalization changes the landscape of existing jobs: it can create new jobs too, while in some repetitive and manual jobs, it replaces the human workforce. According to many researchers, this replacement effect will represent an important shift in a digitalized context (e.g., Ito et al., 2021; Malik et al., 2021). Regardless of the implementation phase, fear of change (Ito et al., 2021), increased human-machine interaction (Ozkan-Ozen and Kazancoglu, 2021) and job loss fear (Malik et al., 2021) can continuously cause resistance among employees.

As shown before, current **literature offers several fragmented insights** into the human-related implications of I4.0 implementation, but **there are several missing pieces** too, such as the role of managers after the I4.0 implementation, or several aspects of employee implications in the before and during stages that would need a more in-depth investigation. Furthermore, a holistic approach is missing, that would involve the joint investigation of several implementation phases on more organizational levels in an interconnected manner. Therefore, in this research I aim to offer a more holistic approach to discover the full shift of human resource roles because of I4.0 implementation.

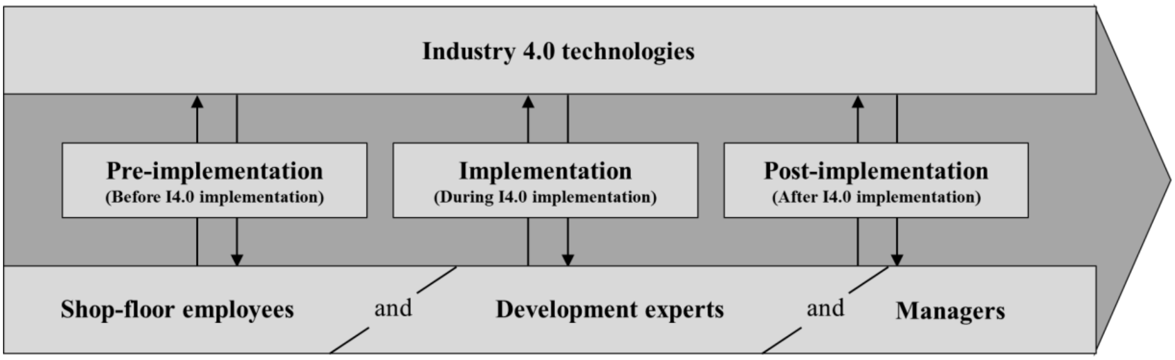
5. Conceptual framework development

The purpose of this research is to extend previous research by investigating the role of human resources related to projects of digital manufacturing technology adoption during (a) different adoption stages and (b) in relation with different organizational levels – two decisive aspects that have been overlooked by previous studies. Within the role of human resources, I specifically focus on the (i) activities performed by human resources and the (ii) required skills and competencies to perform those activities.

(a) More specifically, I rely on previous technology adoption studies to map activities, and required skills and competencies, along all three main phases of technology adoption, i.e., pre-implementation, implementation, and post-implementation phase (Cardoso et al., 2012; Stornelli et al., 2021). The pre-implementation phase contains all steps until a final implementation decision is made and implementation is initiated in practice, which marks the start of the second phase involving set-up and installation steps. The post-implementation phase also represents a relevant phase as further adaptation is expected during the steps of post-installation (i.e., actual use) of a digital technology.

(b) Furthermore, studies investigating success factors and barriers of I4.0 adoption argue that human resource implications have to be considered on all organizational levels, from shop-floor employees to top management (Horváth and Szabó, 2019). Three main groups can be distinguished as relevant human resource categories involved in a digital manufacturing technology implementation, namely shop-floor employees (the ones that work directly with the technology), development experts (engineers, trainers with relevant technological knowledge) and managers (overseeing and setting broader objectives for technology implementation projects) (Demeter et al., 2021; Horváth and Szabó, 2019) (Figure 4).

Figure 4. Conceptual framework of the interplay between I4.0 and human resources



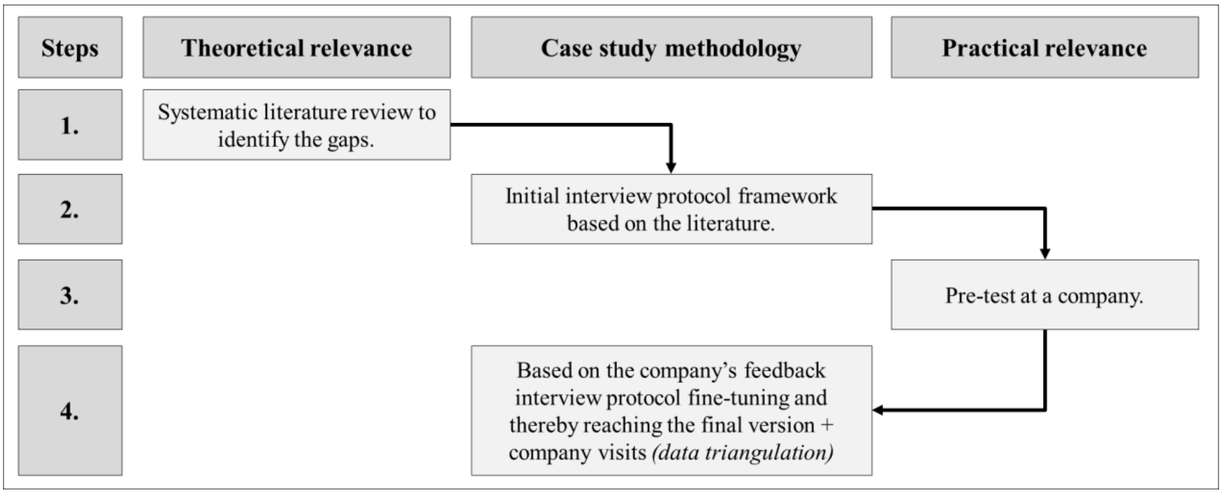
Source: own construction

6. Data and methodology

Given the scarcity of results in the literature on how human-system interactions should be managed during different phases of adopting digital manufacturing technologies and on various organizational levels, this research adopts an exploratory, multiple case study approach. Data collection is primarily carried out through semi-structured interviews with managers, complemented with site visits. For the semi-structured interviews, I have applied a customized interview protocol, which was developed in several steps (Figure 5).

The created interview protocol enables me to assess multiple dimensions and their interdependencies in a holistic manner. The interview protocol is based on a 3x3 matrix basis, including, on one hand, the human resources dimensions (managers, development experts and shop-floor employees), and on the other hand, the I4.0 implementation phases (before, during and after the implementation). Thus, altogether 9 main categories can be distinguished. The questions were then fitted into one of the squares, while some of them were relevant for more categories simultaneously.

Figure 5: The steps of interview framework creation



Source: own construction

The case research only focuses on manufacturing firms that have already used at least two I4.0 technologies. I only focused on the automotive industry; thus, only automotive companies were targeted in my research. I tried to include not just OEMs, because there are some differences in the supply chain, which should enrich my results. I wanted to exclude the small firms; the case study firms should have at least 50 employees. This criterion was introduced due to the fact that the technologies are more meaningful in case of larger firms. In total, 5 production plants are being involved, (3 form Hungary and 2 from Romania), all of them are subsidiaries of automotive multinational companies (Table 2).

Table 2: Case study companies

Firm code	Type	Year of foundation	Number of employees	Turnover (million EUR)	Country
1	OEM	1993	12,000	7,300	Hungary
2	Tier 1 supplier	1990	4,450	921	Hungary
3	Tier 1 supplier	2013	3,200	465	Romania
4	Tier 2 supplier	1992	1,335	190	Hungary
5	Tier 2 supplier	2004	200	11	Romania

Source: own construction

In total 12 interviewees participated in the research; Table 3 describes the interviewees involved.

Table 3: Data about the specific interviews

Firm code	Number of interviews	Interviewees	Duration	Number of company visits	Year
1	2	(1) Project manager; (2) I4.0 project manager	(1) 0h 39m; (2) 1h 10m	1	2022
2	2	(1) Lead engineer; (2) I4.0 project manager	(1) 1h 16m, (2) 1 h 0m	0	2022
3	2	(1) HR manager; (2) I4.0 project manager	(1) 0h 42m, (2) 0h 28m	1	2023
4	2	(1) Site leader; (2) I4.0 project manager	(1) 0h 58; (2) 1h 40m	1	2022
5	4	(1) CEO; (2-3) I4.0 project managers; (4) Team member	(1) 0h 35m; (2-3-4) 1h 02m	1	2022

Source: own construction

The projects presented at firm 1 and 2 and one project at firm 5 are more like incremental innovation, those at firm 3 and 4 and the second project at firm 5 can be thought as radical innovation (Table 4). In general, the projects analysed were closed from 6 months up to 18 months ago, thus the projects were not too old, but also not too young too; thus, the interviewees were able to make the conclusions about the post-implementation phase too.

Table 4: The technologies analysed

Firm code	Type	Country	Technologies analysed
1	OEM	Hungary	Internal software for the reworks
			Data processing software
2	Tier 1 supplier	Hungary	Automated business reports
			Digitization of production monitoring
3	Tier 1 supplier	Romania	Supply chain information flow
			AGVs (Autonomous Guided Vehicles)
4	Tier 2 supplier	Hungary	Intralogistics automation
			AGVs (Autonomous Guided Vehicles)
5	Tier 2 supplier	Romania	RPA (Robotic Process Automation)
			Digital tool for troubleshooting the production equipment's failures (maintenance)

Source: own construction

These technologies are not homogenous; they differ from each other in a lot of dimensions. This could be a limitation of the research since I cannot focus on a particular type of I4.0 technology. But since all the mentioned technologies are new, they have one common characteristic: to implement them, the people form the organization should be ready and willing to work with something new for them. Thus, this is not technology-focused research; it is focused only on the HR aspects of the adoption of the new digital technologies.

Fortunately, all interviewees agreed to make audio records. Thus, the transcripts were made based on the audio file, by a special interview transcription software, but the rough output was verified and corrected by me. The final transcripts from the 5 companies were analysed in a specialized qualitative research software, in NVivo. With the help of this tool, I have coded the relevant phrases from the transcripts (in total 172 pages). The relevant phrases were triple coded, which means that one code refers to the organizational level, one code for the implementation phase and one describes the phrase (e.g., is a particular skill, or activity).

7. Case analysis results

7.1. Code frequencies

Altogether 437 phrases were coded, belonging to a total of 155 distinguishable code categories. Of the 155 different code categories 117 can be linked to the pre-implementation phase, 88 to the during phase and 58 to the post-implementation phase. Because one code can be attributed to more than one implementation stages and/or organizational levels at the same time, the sum of the codes is not equal with the total number of codes. From the 155 different code categories, 129 can be linked to the managers, 64 to development experts and 27 to shop-floor employees (Table 5).

Table 5: Code frequencies

Organizational levels	Code type / Total	Before	During	After	Total*
Managers	Activities	73	51	38	104
	Skills and competences	23	17	4	25
	Total of managers	**96**	**68**	**42**	**129**
Development experts	Activities	23	18	16	38
	Skills and competences	23	15	7	26
	Total of development experts	**46**	**33**	**23**	**64**
Shop-floor employees	Activities	6	3	4	10
	Skills and competences	8	7	10	17
	Total of shop-floor employees	**14**	**10**	**14**	**27**
	Total*	**117**	**88**	**58**	**155**

**Total is not the sum of the categories, since one code category can be used in more organizational levels and implementation phases.*

Source: own construction

7.2. The I4.0 activities identified

Based on the interviews, I have identified 113 activities. Since the interviewees highlighted that I4.0 project implementation is very similar to other projects, when I have grouped the 113 activities, I have used an Operations Management framework (Slack et al., 2007). Finally, I have made 18 main activity categories (Table 6). It is important to highlight that these categories fit well in the chosen Operation Management framework, every element has at least one identified activity from the interviews.

Table 6: The main I4.0 activity categories identified

Activity categories	Number of cases	Firm 5	Firm 4	Firm 3	Firm 2	Firm 1	Managers	Development experts	Shop-floor employees
Cooperation with other organizations, departments, experts and robots	5	1	1	1	1	1	High	Medium	Low
Data management	3	1	1	1	0	0	Medium	High	Low
Ensure the necessary material and immaterial resources	4	1	1	1	0	1	High	Low	Low
Failure prevention	2	1	0	0	1	0	High	Medium	Low
Goal setting	5	1	1	1	1	1	High	Low	Low
I4.0 technology integration	4	1	1	1	1	0	High	Medium	Low
Job design and work organization	5	1	1	1	1	1	High	Low	Low
Knowledge sharing and knowledge enhancement	5	1	1	1	1	1	High	Medium	Low
Meet stakeholder requirements	5	1	1	1	1	1	High	Medium	Low
New idea generation	4	1	1	0	1	1	High	Low	Low
Operations improvement	2	0	1	1	0	0	High	Low	Low
Post-implementation control	1	0	1	0	0	0	High	Low	Low
Presenting the project and reporting	5	1	1	1	1	1	High	Low	Low
Project planning	5	1	1	1	1	1	High	Low	Low
Regular project control	5	1	1	1	1	1	High	Low	Low
Savings and profit calculation	2	0	1	0	1	0	High	Medium	Low
Step-by-step implementation	5	1	1	1	1	1	High	Medium	Low
Team coordination	5	1	1	1	1	1	High	Low	Low

Source: own construction based on Slack et al. (2007)

The three main organizational levels have different duties; therefore, the dominant activity types differ too. General project management activities are predominant when companies try to implement an I4.0 solution. In the before phase, in the case of **managers,** the most frequently mentioned activity categories are linked to the planning process and meeting the stakeholders' requirements (e.g., top-management, users, employees) (Table 7). During the implementation, the step-by-step implementation, regular project control and making the financial calculations will become the most relevant activities. Since I4.0 solution often generates a lot of data, data management and ensuring data security will be on the top of the managers to-do list. Similarly, managing the changes on the job and within the organization will also have a priority among the tasks, since based on the interview's relocation and new carrier path planification will become an urgent task. After the scale-up phase, managers should be able to cope with a larger and more complex system.

Table 7: The main I4.0 activity categories identified in case of managers

Activity categories	Number of cases	Sample companies					Implementation phases		
		Firm 5	Firm 4	Firm 3	Firm 2	Firm 1	Before*	During*	After*
Job design and work organization	5	1	1	1	1	1	12	12	15
I4.0 technology integration	4	1	1	1	1	0	20	3	3
Meet stakeholder requirements	5	1	1	1	1	1	12	3	0
Goal setting	5	1	1	1	1	1	14	0	0
Failure prevention	1	0	0	0	1	0	1	0	1
New idea generation	3	1	1	0	0	1	7	3	3
Operations improvement	2	0	1	1	0	0	2	3	3
Step-by-step implementation	4	0	1	1	1	1	2	5	3
Savings and profit calculation	2	0	1	0	1	0	1	1	0
Data management	2	1	0	1	0	0	0	1	3
Presenting the project and reporting	5	1	1	1	1	1	3	2	13
Post-implementation control	1	0	1	0	0	0	0	3	5
Regular project control	5	1	1	1	1	1	14	13	3
Project planning	5	1	1	1	1	1	10	2	1
Cooperation with other organizations, departments, experts and robots	5	1	1	1	1	1	42	20	5
Team coordination	5	1	1	1	1	1	9	4	5
Knowledge sharing and knowledge enhancement	5	1	1	1	1	1	18	7	9
Ensure the necessary material and immaterial resources	4	1	1	1	0	1	9	1	3

*Number of phrases coded

Source: own construction

The **development experts** are mostly a neglected category in the literature, but their special knowledge and network can be a game changer in the I4.0 deployment (Table 8). For example, at firm 4 there is an "expert network" for project troubleshooting. Therefore, for a successful implementation in the before phase, development experts should cooperate with other plants, departments, and experts to come up with the most relevant innovative ideas. During the implementation they should have some regular project control tasks, in addition cooperation and knowledge sharing, and enhancement will be crucial too. After the implementation, the development experts will be responsible for failure prevention activities and data management activities.

Table 8: The main I4.0 activity categories identified in case of development experts

Activity categories	Number of cases	Sample companies					Implementation phases		
		Firm 5	Firm 4	Firm 3	Firm 2	Firm 1	Before*	During*	After*
I4.0 technology integration	3	0	1	1	1	0	2	0	1
Meet stakeholder requirements	4	1	0	1	1	1	3	2	0
Goal setting	1	0	0	0	1	0	2	0	0
Failure prevention	2	1	0	0	1	0	0	0	2
New idea generation	2	0	0	0	1	1	5	0	0
Operations improvement	1	0	0	1	0	0	1	1	1
Step-by-step implementation	2	1	0	0	0	1	3	2	1
Savings and profit calculation	1	0	0	0	1	0	0	0	1
Data management	3	1	1	1	0	0	1	2	5
Presenting the project and reporting	1	0	0	0	1	0	0	1	1
Regular project control	4	1	1	0	1	1	1	4	1
Cooperation with other organizations, departments, experts and robots	5	1	1	1	1	1	12	13	3
Team coordination	1	1	0	0	0	0	0	1	0
Knowledge sharing and knowledge enhancement	5	1	1	1	1	1	8	12	10

**Number of phrases coded*

Source: own construction

Turning to the **shop-floor employees**, in the before phase, they should be involved in the planning process, since the companies mentioned that they can generate valuable ideas too (Table 9). During the implementation, the shop-floor employees must enhance their knowledge in order to be able to work with the new digital technologies. Based on the case studies, after the I4.0 implementation, traditional operators will become "operator 4.0" (e.g., Romero et al., 2016), where problem-solving activities and system supervising activities will be dominant.

Table 9: The main I4.0 activity categories identified in case of shop-floor employees

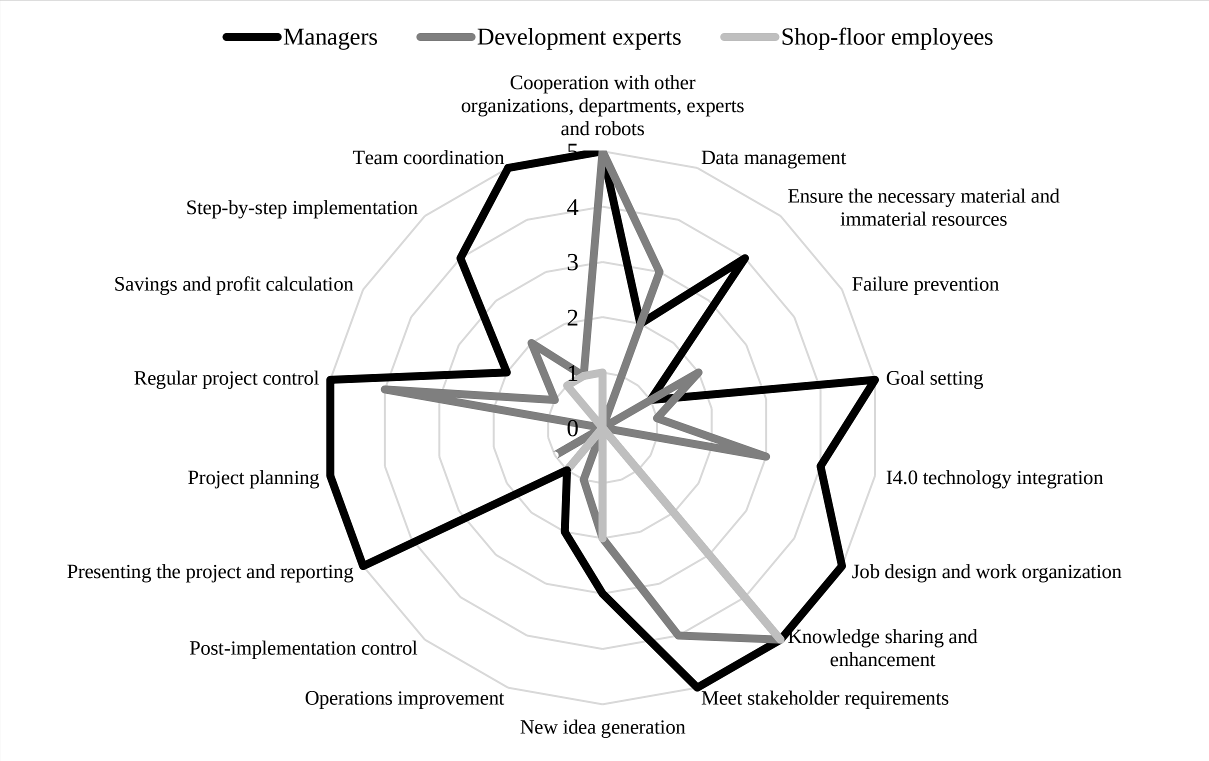
Activity categories	Number of cases	Sample companies					Implementation phases		
		Firm 5	Firm 4	Firm 3	Firm 2	Firm 1	Before*	During*	After*
New idea generation	2	0	1	0	0	1	2	0	0
Step-by-step implementation	1	0	0	0	0	1	1	1	0
Post-implementation control	1	0	1	0	0	0	0	0	1
Cooperation with other organizations, departments, experts, and robots	1	0	0	0	0	1	0	0	1
Team coordination	1	0	0	0	0	1	2	0	0
Knowledge sharing and knowledge enhancement	5	1	1	0	0	1	2	3	4

**Number of phrases coded*

Source: own construction

If we take a look at the major category codes, knowledge sharing and enhancement is the single one which is a highly relevant task for every organizational level (Figure 6). This means that the I4.0 has one similar effect on every organizational level, and mainly requires from them to enhance and share their knowledge and acquire new skills.

Figure 6: The main I4.0 activities identified summarized by organizational levels



Source: own construction

7.3. The I4.0 skills and competences identified

The activities identified require a diverse skillset. Based on the 5 cases, I have identified 42 different skills and competences, which are required if a company wants to implement an I4.0 technology. The 42 skills and competencies were grouped into 9 main categories (Table 10). These skills have different importance for the different organizational levels (e.g., digital skills are very important for development experts, but less important for managers).

Table 10: The main I4.0 skill and competence categories identified

Main skill categories	Number of cases	Firm 5	Firm 4	Firm 3	Firm 2	Firm 1	Managers	Development experts	Shop-floor employees
Adaptation skills	3	1	0	0	1	1	Medium	Low	Medium
Cognitive skills	5	1	1	1	1	1	Medium	Medium	Low
Digital skills	5	1	1	1	1	1	Low	Medium	Medium
Innovativeness, openness to the new	5	1	1	1	1	1	Medium	High	High
Knowledge about the production	3	1	1	0	0	1	Medium	High	Medium
Learning and developing	3	1	0	1	1	0	Low	High	Medium
Managerial, business skills	5	1	1	1	1	1	High	Low	Low
Soft skills	4	1	0	1	1	1	High	High	Medium
Specialized knowledge	5	1	1	1	1	1	High	Medium	Low

Source: own construction

Innovativeness, openness to the new was mentioned by all case study companies, this skillset being especially a priority for I4.0 **managers** (Table 11). This skillset has the most important role before the I4.0 implementation, but it is also relevant during the implementation. This can be explained by the activities: in the before phase, there are many new impulses and new solutions, which require an innovative and open-minded attitude from managers. During the implementation, further new issues can emerge, thus this skill category remains an important one. After the implementation, basically only the maintenance of the implemented I4.0 solution is the dominant activity, which is not a very innovative process, thus innovativeness and openness to the new become less relevant skills for managers.

Table 11: The main I4.0 skill and competency categories identified for managers

Main skill categories	Number of cases	Sample companies					Implementation phases		
		Firm 5	Firm 4	Firm 3	Firm 2	Firm 1	Before*	During*	After*
Adaptation skills	1	0	0	0	1	0	3	3	0
Cognitive skills	3	0	1	1	1	0	3	1	1
Digital skills	1	0	0	0	0	1	3	2	0
Innovativeness, openness to the new	5	1	1	1	1	1	6	4	1
Knowledge about the production	2	0	1	0	0	1	4	2	0
Managerial, business skills	3	0	0	1	1	1	9	9	2
Soft skills	2	0	0	1	1	0	2	1	0
Specialized knowledge	3	0	1	1	0	1	7	2	0

**Number of phrases coded.*

Source: own construction

All the nine skill categories were mentioned in the case of **development experts** (Table 12). Thus, development experts must acquire the most diverse skillset since they have the most encompassing tasks. All the companies mentioned that digital skills are necessary for development experts. This skillset is mainly useful before and during the implementation. Four of the five companies mentioned at least one code related to: cognitive skills; innovativeness, openness to the new; and specialized knowledge. All of them are necessary along the whole implementation journey, but predominantly in the pre-implementation and post-implementation phases. Further categories were mentioned by three case companies: learning and developing; managerial, business skills; and soft skills. Surprisingly, managerial and business skills are required for development experts too. Given that they are responsible for the proper functioning of the I4.0 technology, e.g., decision-making skills, creating a vision for the future and problem-solving skills are useful for a development expert too.

Table 12: The main I4.0 skill and competency categories identified for development experts

Main skill categories	Number of cases	Sample companies					Implementation phases		
		Firm 5	Firm 4	Firm 3	Firm 2	Firm 1	Before*	During*	After*
Adaptation skills	1	1	0	0	0	0	1	0	0
Cognitive skills	4	1	1	0	1	1	5	2	1
Digital skills	5	1	1	1	1	1	5	3	0
Innovativeness, openness to the new	4	1	0	1	1	1	6	1	1
Knowledge about the production	2	1	1	0	0	0	2	1	0
Learning and developing skills	3	1	0	1	1	0	4	4	1
Managerial, business skills	3	1	0	1	1	0	2	2	2
Soft skills	3	0	0	1	1	1	6	2	0
Specialized knowledge	4	1	1	1	1	0	10	9	2

**Number of phrases coded.*

Source: own construction

In the case of **shop-floor employees,** the innovativeness, openness group was mentioned by four different companies (Table 13). Blayone and VanOostveen (2021) and Stentoft et al. (2021) also claim that the right skills and competences should be complemented by the willingness of shop-floor employees to use new digital technologies. This skillset is already highlighted in the pre-implementation phase, but the importance increases along the journey and is the highest after the implementation, because without these skills the shop-floor employees will not use the I4.0 solution or will use it in an inappropriate way - none of these situations being ideal. Even though it is possible that an employee's job is replaced by a machine, in most cases it did not involve layoffs, only relocations to other jobs with labour shortages. These relocations often entail the (re)training of the employees. Basically, the elementary digital skills are required, many employees being sent to trainings to acquire these skills.

Table 13: The I4.0 skill and competency main categories identified for shop-floor employees

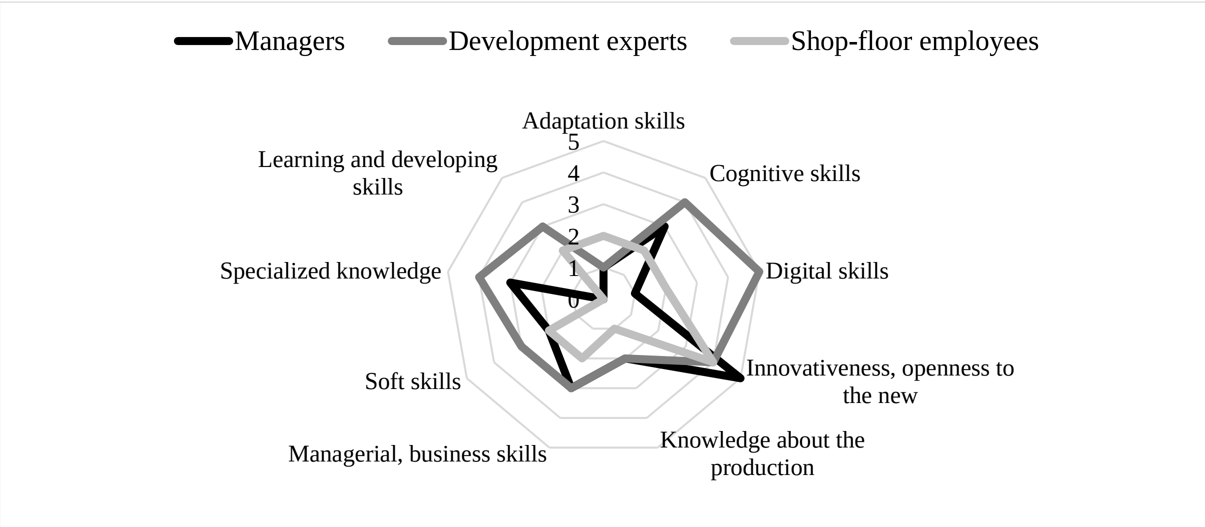
Main skill categories	**Number of cases**	**Sample companies**					**Implementation phases**		
		Firm 5	**Firm 4**	**Firm 3**	**Firm 2**	**Firm 1**	**Before***	**During***	**After***
Adaptation skills	2	1	0	0	0	1	1	0	1
Cognitive skills	2	1	0	0	0	1	1	0	3
Digital skills	2	0	0	1	0	1	0	1	2
Innovativeness, openness to the new	4	1	1	0	1	1	3	5	7
Knowledge about the production	1	0	1	0	0	0	1	0	0
Learning and developing skills	2	0	0	1	1	0	1	2	2
Managerial, business skills	2	0	1	0	1	0	1	1	1
Soft skills	2	1	0	0	0	1	3	1	1

**Number of phrases coded*

Source: own construction

Since this study applies a holistic approach, I can compare the managers, the development experts, and the shop-floor employee's skills (Figure 7). Innovativeness, openness to the new is the only one category, which was mentioned frequently in every organizational level, but the remaining ones has different importance.

Figure 7: The comparison of the different organizational levels' skill and competency profile



Source: own construction

7.4. I4.0 implementation roadmap

Based on the case analysis, a holistic picture can be offered about the skills and activities by implementation phases and organizational groups – I named it the I4.0 implementation roadmap (Figure 8). In this roadmap the main actions and necessary knowledge, skills, and abilities are synthetized, with the intention of assisting practitioners in the I4.0 implementation process and enhancing the previous findings by providing a more thorough understanding of the effects of I4.0 technologies on human resources. The adoption of I4.0 has an impact on managers, development experts (typically from diverse fields), and shop-floor employees too. The requirement for a holistic strategy in relation to the HR aspects of the adoption of an I4.0 solution is supported by the fact that in many circumstances, different organizational levels must collaborate to solve the puzzle.

Figure 8: The summary from the I4.0 implementation roadmap

(b) Organizational levels / *(a) Implementation stages*		**Before**	**During**	**After**
Managers	**Key activities**	Goal setting; Meet stakeholders' requirements; I4.0 technology integration; Project planning.	Step-by-step implementation; Regular project control; Saving and profit calculations; Operations improvement.	Data management; Job design and work organization; Presenting the project and reporting.
	Key skills and abilities	Special knowledge; Soft skills; Knowledge about the production.	Adaptability; Managerial, business skills; Digital skills	Cognitive skills; Managerial, business skills
Development experts	**Key activities**	New idea generation; Cooperation with other organizations, departments, experts and robots.	Regular project control; Cooperation with other organizations, departments, experts and robots; Knowledge sharing and enhancement.	Failure prevention; Data management; Knowledge sharing and enhancement.
	Key skills and abilities	Adaptability; Soft skills; Innovativeness, openness to the new; Knowledge about the production.	Learning and developing skills; Special knowledge; Digital skills.	Managerial, business skills; Cognitive skills; Innovativeness, openness to the new.
Shop-floor employees	**Key activities**	New idea generation.	Knowledge sharing and enhancement; Step-by-step implementation; Cooperation with other organizations, departments, experts and robots .	Knowledge sharing and enhancement; Team coordination; Cooperation with other organizations, departments, experts and robots.
	Key skills and abilities	Knowledge about the production; Soft skills; Adaptability.	Learning and developing skills; Innovativeness, openness to the new, Digital skills.	Cognitive skills; Digital skills; Adaptability.

Source: own construction

8. Discussion

This study offers a more nuanced perspective on the interplay between human resources and the adoption of digital manufacturing technology in a context of multiphase technology implementation, expanding upon the restricted focus of previous human-related studies in the I4.0 literature stream.

One of the most important findings is that from the identified skills every organizational level should have innovativeness and openness to the new to reach a successful I4.0 implementation. Thus, managers should focus on activities of generation of new ideas (e.g., maintaining a system, which support the innovative ideas; managing the flow of the innovative ideas; supporting the new ideas; rewarding the innovative ideas etc.) in the before and during phase.

One of the biggest issues could be finding the appropriate development experts for an I4.0 implementation. Going forward, the success of I4.0 technology implementation could be based on the development expert’s expertise, because without this the project can be started, but cannot be ended with success. This research showed that this organizational level should be put in the focus of the I4.0 adoption, even if the importance of managers is unquestionable.

Shop-floor employees should be involved even before I4.0 implementation. Based on the interviews, this can help also to tackle the biggest I4.0 barrier, the resistance and fear of change. Early shop-floor involvement also could help with the generation of new ideas. These results can contribute to the literature, since, based on the interviews, shop-floor employees have a significant activity in the before phase too.

Regarding the implementation phases, this research pointed out that the before phase is the most important one, basically this predefines the whole I4.0 implementation. Here the managers and the development experts have the most significant role, but the shop-floor employees cannot be left out from this phase, as my research underlined before.

9. Practical relevance

From a practical perspective, the results are intended to offer managers responsible for I4.0 an implementation tool to help them to identify the most crucial tasks, abilities, and knowledge needed along the way to an effective digital technology adoption in manufacturing firms. But besides the I4.0 roadmap, based on the research, 10 practical pieces of advice can be formulated as well, which are easy to use for a successful I4.0 implementation (Figure 9).

Figure 9: Summary of the key practical takeaways for I4.0 implementation

Step 0		Why Industry 4.0?		
Technical side		Align the I4.0 technologies!		
Human side	Innovation	If you want innovation, create a system which maintains it and leave time for it!		
	Connections	Create knowledge: connect people who can contribute!	Create the linkage between development and production areas!	
	I4.0 competencies	Build up your own I4.0 competencies!		
	People of I4.0	Find people who are truly interested!	Sometimes you should be a nutcracker!	Prepare for the retraining and relocations!
	I4.0 users	Involve, ask the users if you don't know what they want!		

Source: own construction

10. Future research and limitations

Promising further research direction can emerge from this study. Based on the interviews, the shop-floor employees have a less important role in the I4.0 adoption, thus further studies can examine why is this. This question also points out one of the limitations: I have made the interviews just with managers, which means that their role and their activities could be overrepresented, because everybody knows best their work, thus they can talk about that in detail. Another limitation is the small number of firms and the narrow regional focus (just 2Eastern-European countries). In further studies I can add more companies, or even could make interviews with development experts and shop-floor employees too. These technologies analysed differ from each other in a lot of dimensions. This also could be a limitation of the research: I was not able to focus on a particular type of I4.0 technology. The nature of this study is qualitative; thus, the results are not generalizable, which is also a limitation.

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