

FINAL SCIENTIFIC REPORT

Project PN-III-P1-1.1-TE-2019-1773

Title: „The fourth industrial revolution: overcoming the challenges of implementing Industry 4.0 technologies at manufacturing companies in Central-Eastern Europe”

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Project website: <https://te2019szasz.github.io/>

1. Proposed objectives

The main objective of the project proposed for financing in the program titled “Research projects for stimulation of young independent teams”, was the exploration of digital technologies in the era of the fourth industrial revolution. To be more specific, the project proposal aimed to explore:

1. The challenges specific to the implementation of these digital technologies, especially at Central and Eastern European companies
2. The impact of these digital technologies on the performance of Central and Eastern European companies

In order to achieve these objectives, the following **research activities** have been proposed:

1. A systematic analysis of the literature to define a research model
2. Conducting a qualitative research based on case studies carried out at Central and Eastern European companies
3. Conducting a quantitative, survey-based research on an international sample of production companies
4. Dissemination of the results at conferences, and by two articles published in leading international scientific journals

In the initial project the following have been set for the **dissemination of the research results**:

- 6 international scientific conference participations, including the most relevant ones for the subject studied: the Annual EurOMA conference (European Operations Management Association), the annual POMS conference (Production and Operations Management Society), and the IWSPE (International Working Seminar on Production Economics)
- 2 publications during the project in leading international scientific journals, including at least one journal from the Q1 zone in the domain

2. The degree of accomplishment of the proposed objectives

Regarding the two main objectives, the degree of accomplishment is as follows:











1. The challenges specific to the implementation of these digital technologies: the project has identified the following challenges specific to the implementation of digital technologies for which the existing literature offers little insight: (1) challenges regarding the cooperation between human resources and new technologies, (2) challenges regarding the interaction between technology and sustainability, to which a new challenge has been added which was initially not included in the project proposal, namely (3) the coronavirus pandemic which has become a global phenomenon only during the first half of 2020.
2. The impact of Industry 4.0 technologies on the performance of production companies was evaluated with the help of a two survey-based studies, the method ensuring a higher level of result generalization.

Regarding the two proposed **research activities**, the **degree of accomplishment** is as follows:

1. The systematic analysis of the specialty literature in order to define a research model:
 - Starting from 337 potentially relevant articles, the systematic analysis of the relevant literature included a total of 52 articles.
 - The results of the systematic analysis of the literature were published within a conference (see C3 below), respectively an article was sent to be published in the scientific journal *International Journal of Production Economics* (Web of Science, Q1; AIS 2021 = 1,597, IF 2021 = 11,251 – cf. JCR 2022). Currently the article is in the first round of revision (see P3 below).
 - Based on these results a research model has been developed which aided the creation of an interview protocol used in the qualitative research based on case studies.
2. Conducting a qualitative research based on case studies at Central and Eastern European companies:
 - Even though the pandemic period has posed major barriers for the accomplishment of case studies, by the end of the project ten Industry 4.0 projects were included in the case studies, originating from five automotive plants operating in Romania (2) and Hungary (3)
 - In order to cover the entire supply chain, the five companies include: (1) an OEM (original equipment manufacturer) from Hungary (12 000 employees), (2) two “tier 1” suppliers (direct suppliers) from Romania (3200 employees) and Hungary (4450 employees), and (3) two “tier 2” suppliers (indirect suppliers) from Romania (200 employees) and Hungary (1335 employees), respectively. These companies are presented in Table 1.
 - In these case studies a total of 21 interviews have been conducted with an average duration of over 1 hour each, along with 7 plant visits at the investigated production facilities.
 - The results of the research based on case studies were presented at 3 international scientific conferences (see C2, C4 and C6 below), and the final manuscript will be

sent to the *International Journal of Operations and Production Management* (Web of Science, Q2; AIS 2021 = 1,373; IF 2021 = 9,360 – cf. JCR 2022)

Table 1. Production companies included in the survey-based research

Firm code and basic information		
	Firm code: 1 OEM (HU)	
	Year of foundation: 1993 Number of employees: 12,000 Turnover (million EUR): 7,300	
	Firm code: 3 Tier 1 (RO)	
	Year of foundation: 2013 Number of employees: 3,200 Turnover (million EUR): 465	
	Firm code: 5 Tier 2 (RO)	
	Year of foundation: 2004 Number of employees: 200 Turnover (million EUR): 11	
	Firm code: 2 Tier 1 (HU)	
	Year of foundation: 1990 Number of employees: 4,450 Turnover (million EUR): 921	
	Firm code: 4 Tier 2 (HU)	
	Year of foundation: 1992 Number of employees: 1,335 Turnover (million EUR): 190	

3. Conducting a quantitative, survey-based research on an international sample of production companies
 - Because of the pandemic, the adherence to the international research project conducted by Global Manufacturing Research Group (GMRG) was not achieved, as it was launched on a global level way too late in 2022
 - Therefore, the risk management method proposed in the submitted project was been activated, meaning the usage of different databases containing information from international survey-based researches, namely:
 - International Manufacturing Strategy Survey (IMSS) – www.manufacturingstrategy.net
 - Continuous Innovation Network (CINet) - <https://www.continuous-innovation.net/>
 - The research samples are presented in Table 2.
 - The results of the data analysis originating from the two organizations were disseminated through two participations at international conferences (see C1 and C5 below), respectively through an article published in the *International Journal of Production Economics* (Web of Science, Q1; AIS 2021 = 1,597, IF 2021 = 11,251 – cf. JCR 2022) (see P1 below).

- Another article sent to be published in the *Journal of Manufacturing Technology Management* (Web of Science, Q3; AIS 2021 = 0,823, IF 2021 = 8,144 – cf. JCR 2022) is currently in the second round of reviews (see P4 below).

Table 2. Examples of company samples used during the survey-based research (IMSS sample – left, CINet sample – right)

Country	Frequency (number of firms)	Relative frequency (%)
Belgium	10	7,04%
Brazil	7	4,93%
Finland	3	2,11%
Netherlands	5	3,52%
India	20	14,08%
Japan	17	11,97%
Canada	1	0,70%
China	27	19,01%
Hungary	7	4,93%
Malaysia	1	0,70%
Germany	1	0,70%
Norway	1	0,70%
Italy	5	3,52%
Portugal	4	2,82%
Romania	2	1,41%
Spain	3	2,11%
Switzerland	2	1,41%
Sweden	11	7,75%
Taiwan	3	2,11%
USA	12	8,45%
Total	142	100,00%

Country	Frequency	Pct.
Pakistan	41	21.6%
Hungary	40	21.1%
Spain	37	19.5%
Italy	32	16.8%
Brazil	9	4.7%
Switzerland	9	4.7%
Canada	7	3.7%
Sweden	7	3.7%
Denmark	7	3.7%
Austria	1	0.5%
Total	190	100.0%

- The dissemination of results at conferences, and by two articles published in leading international scientific journals
 - The results of the dissemination are presented in the next section
 - Given the fact that the period of this research project (2020-2022) was profoundly marked by the impact of **COVID-19**, a new topic has been added to the project to complement the ones included in the original proposal, which was tied to digital technologies as well, more precisely to the impact of the pandemic on online retail. The results of this research were published in the *Journal of Retailing and Consumer Services* (Web of Science, Q2; AIS 2021 = 1,330, IF 2021 = 10,972 – cf. JCR 2022) (see P2 below).

Concerning the proposed **dissemination** of project results, the **degree of accomplishment** is as follows:

Articles published:

- **(P1)** Szász, L., Csíki, O., & Rácz, B. G. (2021). Sustainability management in the global automotive industry: a theoretical model and survey study. *International Journal of*

Production Economics, Vol. 235, 108085. (**Web of Science, Q1; AIS 2021 = 1,597, IF 2021 = 11,251 – cf. JCR 2022**)

- **(P2)** Szász, L., Bálint, C., Csíki, O., Nagy, B. Z., Rácz, B. G., Csala, D., & Harris, L. C. (2022). The impact of COVID-19 on the evolution of online retail: The pandemic as a window of opportunity. *Journal of Retailing and Consumer Services*, Vol. 69, 103089. (**Web of Science, Q2; AIS 2021 = 1,330, IF 2021 = 10,972 – cf. JCR 2022**)

Articles currently under review:

- **(P3)** Csíki, O., Szász, L., & Rácz, B. G. (2022). A systematic literature review on the interplay between Industry 4.0 technologies and human resources. *International Journal of Production Economics* (first round of review) (**Web of Science, Q1; AIS 2021 = 1,597, IF 2021 = 11,251 – cf. JCR 2022**)
- **(P4)** Szász, L., Demeter, K., Csíki, O., & Horváth, R. (2022). Technology, lean, quality and human resource practices in manufacturing: does firm size matter? *Journal of Manufacturing Technology Management* (second round of review) (**Web of Science, Q3; AIS 2021 = 0,823, IF 2021 = 8,144 – cf. JCR 2022**)

Presentations at international scientific conferences:

- **(C1)** Demeter, K., Szász, L., & Rácz, B. G. (2021). *Manufacturing technologies in the Industry 4.0 era: technology bundles and performance implications*, 28th EurOMA Conference “Managing the “new normal”: The future of Operations and Supply Chain Management in unprecedented times”, July 5-7, 2021, online, University of Sussex.
- **(C2)** Csíki, O., & Szász, L. (2021). *The impact of industry 4.0 technologies on the human resources of multinational companies in the automotive sector*, 5th International Conference on Economics and Business Management, Nov 12, 2021, Babeş-Bolyai University, Cluj-Napoca, Romania.
- **(C3)** Csíki, O., Szász, L., & Rácz, B. G. (2022). *A systematic literature review on the interplay between Industry 4.0 technologies and human resources*, 22nd International Working Seminar on Production Economics, Feb 21-25, 2022, Innsbruck, Austria.
- **(C4)** Csíki, O., Szász, L., Rácz, B. G., & Benedek, B. (2022). *The role of human resources in the implementation of digital technologies: case study in the automotive sector*, 29th EurOMA Conference, July 1-6, 2022, Berlin, Germany.
- **(C5)** Demeter, K., & Szász, L. (2022). *The impact of incremental and radical innovation on business process improvement and performance*, 29th EurOMA Conference, July 1-6, 2022, Berlin, Germany.
- **(C6)** Szász, L., Csíki, O., Rácz, B. G., Demeter, K. & Losonci, D. (2022). *The role of human resources in an Industry 4.0 context: a case study based investigation*, 6th World Conference on Production and Operations Management, August 23-25, 2022, Nara, Japan.

3. Summary of the results and indicators

At the end of the research project, the results look like as follows (indicating the codes of the conferences and publications in which the results are described):

- Concerning the project's **scientific objectives**, the two main objectives were **fulfilled**: (1) the challenges of the Industry 4.0 technologies' implementation were identified (P3, P4, C2, C3, C4, C6), and (2) the impact of these technologies on the production companies has been analyzed (P1, C1, C5). In the process, (3) the investigation of the impact of COVID-19 on the digital and online technologies has been added to these thematic objectives (P2).
- In concordance with the **main activities** described in the project proposal, these were **fulfilled** during the project: (1) a systematic analysis of the literature has been developed (P3, C3), (2) a qualitative research based on case studies with 10 analyzed technologies at 5 production companies in the automotive industry has been conducted (C2, C4, C6), and multiple survey-based studies were carried out (P1, P4, C1, C5), exceeding the initial objectives described in the project proposal.
- The **dissemination of results** was **fulfilled** by publishing two articles in Web of Science journals, and altogether 6 participations at conferences, as projected in the project proposal. The results of the dissemination can be synthesized as follows:
 - 2 articles published in journals indexed by the Web of Science (both Q1 based on impact factor, respectively Q1 and Q2 based on AIS)
 - 2 articles being under review at journals indexed by the Web of Science (both Q1 based on impact factor, respectively Q1 and Q3 based on AIS)
 - 6 participations at international scientific conferences in the domain

These results are summarized in Table 3.

Table 3. The publications of the project indicating the contributions to the accomplishment of the proposed objectives

Publication (code)	Contribution to scientific objectives	Details of objective fulfillment	Type of research activity	Publication type
P1	(2) Impact on performance	Impact on sustainability	Quantitative (survey)	Article Q1
P2	<i>New objective related to COVID-19</i>	Impact of the pandemic on the online commerce technology	Quantitative (secondary data)	Article Q1 (IF), Q2 (AIS)
P3	(1) Implementation challenges	Challenges related to human resources	Systematic literature analysis	Article Q1 (not yet published)
P4	(2) Impact on performance	Impact on operational performance (cost, differentiation)	Quantitative (survey)	Article Q1 (IF), Q3 (AIS) (not yet published)
C1	(2) Impact on performance	Impact on operational performance (cost, differentiation)	Quantitative (survey)	International conference
C2	(1) Implementation challenges	Organizational and human resources related challenges	Qualitative (case studies)	International conference
C3	(1) Implementation challenges	Challenges related to human resources	Systematic literature analysis	International conference
C4	(1) Implementation challenges	Organizational and human resources related challenges	Qualitative (case studies)	International conference
C5	(2) Impact on performance	Impact on innovative performance	Quantitative (survey)	International conference
C6	(1) Implementation challenges	Challenges related to human resources	Qualitative (case studies)	International conference

4. The estimated impact of the results obtained, with emphasis the most significant result obtained

Digitalization represents a trend which is more and more prevalent in all economic sectors, having the potential to transform the way in which companies operate on a daily basis. This trend also includes the **fourth industrial revolution (Industry 4.0)** which refers to a diverse set of technologies and digital solutions which include intelligent products and processes that create together a context in which all company-level actors (human and technological) are connected and share information among them. The current project has identified challenges specific to the implementation of these technologies, and has tried to quantify their impact on company performance, two subjects that have not yet been explored in detail neither on a global scale, nor in the context of Central and Eastern European companies.

Even though in the first phase of the project we focused on creating a regional impact, the results have proven to have a **globally relevant scientific impact**, as it is shown in the publications that were published as part of this project. The challenges related to the implementation of Industry 4.0 technologies seem to be similar at all production companies, regardless of their geographic location, the most important challenge being tied to the cooperation between humans and robots, or in a larger sense, to the interplay between digitalization on human resources working in these companies.

Thus, **the most significant result** of this project is related to the investigation of *interaction between Industry 4.0 technologies and human resources* in production companies. We identify the following novel contributions brought to this domain by our project:

- Based on the literature analysis a **research framework** and a **managerial tool** has been developed in order to help the identification of challenges related to the implementation of Industry 4.0 technologies for human resources in a holistic approach. The tool includes all three phases of implementation (pre-implementation, implementation, post-implementation), and the three relevant categories of human resources (managers, digital experts, shop-floor employees), thus creating a useful framework for the complex identification of all the challenges related to an Industry 4.0 implementation project. The **scientific impact** of this tool refers to the development of a structured framework to identify all the challenges related to human resources and the **practical impact** of the development of this tool consists of offering a useful methodology for production company managers which aids them in preparing the whole company for a more efficient implementation process.
- The case studies relied on this research framework to identify **new and practical solutions** which can help in effectively tackling the challenges and barriers which can appear during an Industry 4.0 implementation project. Besides the obvious **practical impact** of identifying these solutions, the results have an important **scientific impact** as well, representing the first research of this type in the context of Central and Eastern European production companies.

In addition to these contributions related to identification and overcoming of the challenges related to the implementation of digital technologies, we note the fact that the quantitative, survey-based

studies conducted on an international sample of manufacturing plants bring a significant contribution on a regional level as well as on a global level. The establishment of a connection between Industry 4.0 technologies, and their impact on performance represents a new element in the literature. Given the fact that many production companies struggling with achieving the performance improvement promised by these technologies, our results related to various performance domains (i.e.: sustainability performance; operational performance – cost, quality, flexibility, delivery; financial performance – sales, profitability) can represent a useful benchmark for companies aiming to implement Industry 4.0 technologies in the future.

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