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# Expert's Model of Managerial Competencies for Engineer 4.0 (EMMCE)

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**Abstract**
The purpose of this article is to present a proposal for an expert's model of managerial competencies in the era of the fourth industrial revolution, called Industry 4.0. This revolution results in the emergence of new competency requirements for employees at every organizational level. In the article, we focused on the requirements for Engineers 4.0, in connection with managerial competencies expected from them. In order to answer the research questions, we conducted expert research by referring to our previous studies.
Findings: The conducted research allowed to develop an expert's model of managerial competencies for Engineer 4.0 (EMMCE). The results of the study allowed to determine the scope of managerial competencies for an engineer in the age of Industry 4.0, thus contributing, in a practical scope, to the creation of requirements for candidates applying for a managerial position in manufacturing enterprises. The model makes it possible for educational and training entities to adapt their teaching programmes and training offer to the modern requirements of the industry.

**Keywords**
Competency model, Manager 4.0, Engineer 4.0, Industry 4.0.

## Introduction

The term Industry 4.0 (Industrie 4.0, Industrial 4.0 – IoT, Industry 4.0) was first used at the Hannover trade fair in 2011 and referred to a German project "Das Zukunftsprojekt Industrie 4.0", which concerned the topic of technological strategies combined with the digitization of production processes (Cao et al., 2015). The aim of the project was to define a strategy for increasing the competitiveness of German manufacturing enterprises through the use of modern technological solutions, including cyberphysical systems, the Internet of Things, and cloud computing (Kagermann et al., 2013). In October 2012, the Working Group for Industry 4.0 presented to the German federal government a set of recommendations for the implementation of Industry 4.0. The recommendations focused on automation and data exchange in manufacturing technologies and processes, which include cyberphysical systems (CPS), the internet of things (IoT), the industrial internet of things (IIOT), cloud computing, cognitive computing and artificial intelligence. Since then, the concept of Industry 4.0 has attracted interest of scientific and practical application communities. The 10-year period of experience in Industry 4.0 has also been summarized (e.g. Kagermann et al., 2022; Jasiulewicz-Kaczmarek et al., 2020).

The increasing number of publications in this field shows researchers' interest in the concept of Industry 4.0. Figure 1 shows the number of publications related to Industry 4.0. Publications indexed in WoS and SCOPUS databases were analyzed. The quantifier was the concept of Industry 4.0, appearing in the title, abstract and/or keywords. The temporal scope included publications in the period from 2012 to 2023.

Interest in the concept of Industry 4.0 is also noticeable on the basis of the analysis of data from Google Trends[1]. The study covered the period from 2011 to September 2022. The scope of the study included queries put in the Google search engine in the form of the following terms: Industry 4.0 and Industrie 4.0.

The concept of Industry 4.0, also called the fourth

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[1]Google provides information about the number, origin, time dependency, and major regions of Google search queries.

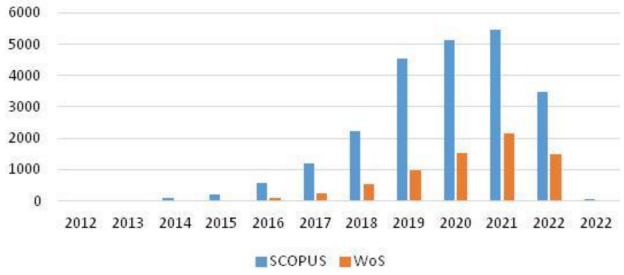


Fig. 1. Number of publications related to Industry 4.0, as of 13 September 2022
Source: author's own development

industrial revolution, is based on 9 pillars: autonomous robots, horizontal and vertical system integration, the Internet of Things, Cybersecurity, cloud computing, additive manufacturing, augmented reality, Big Data, simulation are challenges that are particularly important for "engineers 4.0" in the context of technological challenges (e.g. Leong et al., 2020).

The fourth industrial revolution means worldwide access to the Internet, a radical reduction in the cost of data storage, device mobility (approx. 2 billion smartphones at the end of 2015), smart sensors (including those responding to nearby human presence), renewable energy sources and artificial intelligence (including machine learning) (Gracel, Makowiecki, 2017). This makes the latest industrial revolution have a much wider reach (it affects a much larger number of people) and deeper scope (due to the extent of the technology's involvement into our lives) than the previous revolution (Schwab, 2016).

## Theoretical background

Enterprises wishing to operate in the conditions of the fourth industrial revolution and implementing the necessary new technologies are forced to retrain their employees, adapt new models of work and organization, conduct recruitment in accordance with the needs of Industry 4.0 and engage in strategic planning in the area of employee development. The observed dynamics of the introduced changes is a consequence of the emergence of completely new technological areas that require the development of new skills. The characteristics of employees (e) in individual industrial revolutions (2.0–4.0) are presented in Table 1.

The result of the fourth industrial revolution and the popularization of the concept of Industry 4.0 are changes in competencies which are expected from employees. Since Industry 4.0 is an industrial revolution, the change in the scope of competencies is particularly relevant to engineers.

Competencies can be analyzed at various levels, including individual, group or company-based levels (Korytkowski, 2017). In this article, we focus on employees' individual competencies. In the literature, there are many definitions of competencies, which is demonstrated by many researchers (e.g. Prift et al., 2017). With reference to the known definitions of competencies, Grzelczak et al., (2018) stated that:

- competencies create human potential, including employee potential (taken into account in the article);
- competencies need to be developed;

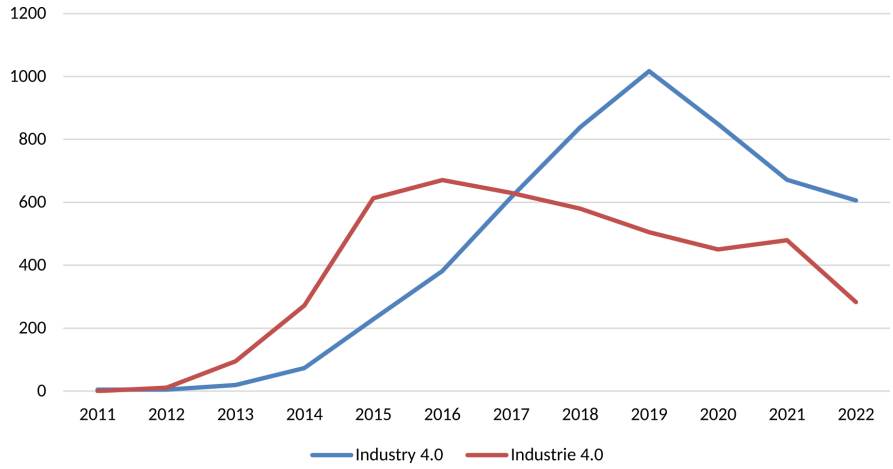


Fig. 2. The number of queries put in the Google search engine in the form of the following expressions: Industry 4.0 and Industrie 4.0 in the period from January 2011 to September 2022
Source: own development based on https://trends.google.pl/trends/explore?date=all&q=Industry%204.0,Industrie%204.0, accessed: 29 September 2020

Table 1
Employees from e2.0 to e4.0

| Characteristics | The second industrial revolution Industry 2.0 | The third industrial revolution Industry 3.0 | The fourth industrial revolution Industry 4.0 |
|---|---|---|---|
| Who do we hire? | Obedient | Smart | Creative |
| Who is involved in day-to-day decision-making? | Boss | Team | Algorithm |
| What are we supposed to do? | Exactly what we are going to tell you... | Execute tasks... | Solve problems and improve algorithms |
| What do we get in exchange for it? | Fixed penalties and rewards (the same for everybody) | Meeting individual needs | Interesting challenges |

Source: https://przemyslprzyszlosci.gov.pl, 2021.

- competencies are necessary to implement a company's strategy and achieve the set goals;
- competencies cover everything that is needed to carry out tasks (at work, in private life).

For the purposes of the research, we assumed, in accordance with Becker et al., (2002), that competencies are knowledge, skills, abilities or personality traits that directly affect the outcomes of a given person's work. On this basis, we define competencies in a detailed perspective as a set of 3 components: knowledge, skills (soft skills and technical/hard skills) and an attitude reflected in activity, also called social competencies – Fig. 3.

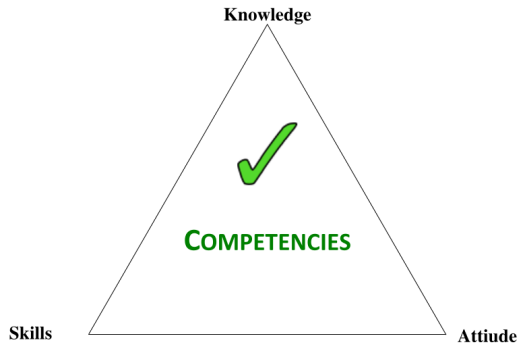


Fig. 3. A triad of the components of competencies
Source: author's own development

The presented research concerns managerial competencies, which we define in accordance with the definition provided by Woodruff (1991) who states that a competent manager must meet three basic conditions when performing their tasks: have knowledge, skills and abilities necessary to perform a managerial function in a given organization, have motivation to perform a managerial function and be ready to devote necessary energy, be able to use their competencies in a business environment.

The aim of our research is to develop an expert's model of managerial competencies for Engineer 4.0. The model is based on the results research on the Model of managerial competencies for Engineer 4.0 – BoMC4E4.0 (Werner-Lewandowska et al., 2022). As we see it, the BoMC4E4.0 model is the resultant (common part) of 3 sets:

1. Competencies for Industry 4.0 – CI4.0,
2. Competencies for Engineer 4.0 – CE4.0,
3. Competencies for Manager 4.0 – CM4.0.

## Competencies for Industry 4.0

Competencies for Industry 4.0 have recently become the subject of interest of many researchers. This results from the popularization of the concept of Industry 4.0 and research conducted in this field (e.g. Prifti in., 2017b; Simic & Nedelko, 2019; Fitsilis et al., 2018; Shevyakova et al., 2021; Bermúdez & Juárez, 2017; Grzybowska & Łupicka, 2017; Grzelczak et al., 2018; Dzwigol et al., 2020; Hecklau et al., 2016). Table 2 summarizes competencies for Industry 4.0 presented in selected scientific publications. Managerial competencies which are desired in the era of Industry 4.0 are boldfaced since they are the subject of further research on managerial competencies for Engineer 4.0.

The summary presented in Table 2 indicates that there is a lack of clearly defined employee competencies related to the fourth industrial revolution. This attests to a cognitive gap in this respect. In the authors' opinion, this gap may result from the subject

Table 2
Competencies for Industry 4.0 – selected typologies

| Source | Category/Area of competencies | Competencies for Industry 4.0 |
|---|---|---|
| Prifti et al., 2017 | Not specified | • communication<br>• IT/technology affinity<br>• Big Data<br>• problem solving<br>• lifelong learning<br>• work in interdisciplinary environments<br>• network technology/M2M communication<br>• modelling/programming<br>• data security/network security business process management<br>• cooperation<br>• teamwork<br>• decision-making<br>• leadership skills<br>• service orientation<br>• creativity<br>• self-management |
| Simic and Nedelko, 2019 | Social competencies | • building relationships<br>• sharing knowledge and experience identification with a company<br>• communication<br>• customer orientation<br>• teamwork/cooperation in a team<br>• resolving a conflict<br>• cooperation within a company<br>• exerting influence |
| | Personal competencies | • striving for results (entrepreneurship) innovation and flexibility<br>• analytical thinking<br>• independence<br>• decision-making<br>• problem solving<br>• precision/reliability<br>• professional development/readiness to learn<br>• management of each other |
| | Professional competencies | • administration/maintenance of documentation<br>• negotiations<br>• business orientation<br>• procedures – knowledge and application<br>• digital literacy<br>• technical skills<br>• professional knowledge<br>• process management<br>• knowledge of foreign languages |
| | Managerial competencies | • building an efficient organization<br>• possibility of delegating<br>• motivating<br>• strategic thinking<br>• planning<br>• leadership<br>• project management<br>• team management |

Table 2 [cont.]

| Source | Category/Area of competencies | Competencies for Industry 4.0 |
|---|---|---|
| Fitsilis et al., 2018 | personal competencies | • ability to act reflectively and autonomously |
| | social/ interpersonal competencies | • employees' ability to communicate, cooperate and socialize<br>• cooperation |
| | competencies related to activity | • ability to accept individual ideas<br>• collaboration |
| | methodological competencies | • creativity<br>• entrepreneurial thinking<br>• problem solving<br>• resolving conflicts<br>• decision-making<br>• analytical skills<br>• research skills<br>• efficiency orientation |
| Shevyakova et al., 2021 | Technological competencies and skills | • interdisciplinary thinking and activity<br>• mastering complex content<br>• ability to interact with machines<br>• competencies in problem solving and optimization |
| | Process and customer-oriented | • expanding process know-how<br>• participation in innovation processes<br>• ability to coordinate work processes<br>• service orientation<br>• interdisciplinary thinking and activity mastering complex processes content<br>• ability to interact with machines, competencies in problem solving and optimization |
| | Infrastructure/ organization | • leadership competencies<br>• independent solutions<br>• social/communication competencies |
| Bermúdez and Juárez, 2017 | Information and communications technology | • knowledge of big data sets<br>• cloud computing and new technologies<br>• ability to analyze data and use tools to understand business<br>• knowledge and management of software and interfaces that support operations |
| | Innovation management | • virtual cooperation (participation in virtual forums)<br>• knowledge and management of simulation systems<br>• ability to adopt new work and organization models (open to change) |
| | Organizational learning | • developing employee skills<br>• improvement capabilities and processes<br>• encouraging participation in decision-making<br>• knowledge of the methodology, techniques and tools of lean manufacturing |
| | Environment | • creativity in designing a strategy for introducing new practices<br>• developing research with external entities (public or private institutions)<br>• transdisciplinarity |

Table 2 [cont.]

| Source | Category/Area of competencies | Competencies for Industry 4.0 |
|---|---|---|
| Grzybowska and Łupicka, 2017 | Creativity | • ability to perceive the world in a new way<br>• finding hidden patterns<br>• combining seemingly unrelated phenomena and generating solutions. |
| | Entrepreneurial thinking | • ability to identify market opportunities<br>• discovering the most appropriate ways and time to use them |
| | Problem solving | • comparing, evaluating and choosing possible solutions<br>• logical thinking |
| | Resolving conflicts | • managing and resolving conflicts<br>• emotional maturity<br>• self-control<br>• empathy |
| | Decision-making | • identifying decisions<br>• collecting information<br>• evaluating alternative solutions |
| | Analytical skills | • visualizations<br>• collecting information<br>• articulating, analyzing<br>• solving complex problems and making decisions |
| | Research skills | • using reliable sources for continuous learning in changing environments<br>• ability to provide detailed information and advice on a given topic |
| | Efficiency orientation | • efficient use of resources as the main determinant of decisions and activity |
| Dzwigol et al., 2020 | Experience and period of work | • specialist knowledge and skills acquired in the course of work<br>• functional precision and experience<br>• managing personal learning and development |
| | Educational, cognitive and creative potential | • primary education, secondary education, academic degree<br>• professionalism<br>• entrepreneurial skills<br>• effective time management |
| | Effective target setting and development | • development of planning and target-setting skills<br>• organization of the activity process in accordance with the management functions<br>• ability to make decisions<br>• ability to effectively delegate power |
| | Communicative, leadership and managerial orthobiosis | • skills of communication and interpersonal and group communication<br>• ability to resist manipulation<br>• ability to respond constructively to criticism<br>• a healthy, reasonable lifestyle<br>• corporate culture of the organization of a work process, workload and leisure |

Table 2 [cont.]

| Source | Category/Area of competencies | Competencies for Industry 4.0 |
|---|---|---|
| Grzelczak et al., 2018 | Technology/ data processing | • data evaluation and analysis<br>• security of information systems<br>• cloud storage<br>• artificial intelligence / algorithms<br>• user support |
| | Process/ customer | • process management<br>• customer relationship management<br>• IT business analysis<br>• e-commerce/online marketing |
| | Infrastructure/ organization | • knowledge of specialized IT systems<br>• administration of networks and databases<br>• architecture of IT systems<br>• privacy policy |
| Hecklau et al., 2016 | Technical | • recent knowledge<br>• technical skills<br>• understanding of processes<br>• media skills<br>• coding skills<br>• understanding IT security |
| | Methodological | • creativity<br>• entrepreneurial thinking<br>• problem solving<br>• resolving conflicts<br>• decision-making<br>• analytical skills<br>• research skills<br>• efficiency orientation |
| | Social | • intercultural, linguistic, communication skills<br>• networking<br>• team working skills<br>• ability to compromise<br>• cooperation<br>• ability to transfer knowledge<br>• leadership skills |
| | Personal | • flexibility<br>• tolerance of ambiguity<br>• motivation to learn<br>• ability to work under pressure<br>• sustainable thinking<br>• conformity |

Source: author's own development

of research. The concept of Industry 4.0 has existed in the industrial and academic consciousness for only one decade. During this time, industrial and theoretical research has focused primarily on the technological and technical aspects of Industry 4.0. According to the authors, it is only recently that the competencies necessary to achieve the goals and assumptions of the fourth evolution have become the subject of interest.

In our previous research (Werner-Lewandowska et al., 2022), as a set of competencies for Industry 4.0, we adopted the most frequently repeated competencies indicated in Table 2.

## Competencies for Engineer 4.0

The requirements for Engineers 4.0 were presented in a report prepared in 2017 by ASTOR (ASTOR, 2017). An engineer of Industry 4.0 is a person who moves smoothly between two levels: "cyber" and "physical". For this reason, Engineers 4.0 will have to combine knowledge of a specific manufacturing process, e.g. working with robots, or readjusting a machine with IT skills, ranging from basic skills (e.g. the use of spreadsheets and interface support) to advanced ones, e.g. advanced programming and performing analyses (ASTOR 2017).

Due to the digitization of production lines, Industry 4.0 technologies require engineers to integrate the IT department with operational departments more closely than before. Software developers must understand very well how and why production uses IT solutions, and production operators should have a full understanding of how IT solutions affect production (ASTOR, 2017).

On the basis of the ASTOR report, entitled "Engineers of Industry 4.0", it is possible to determine the following set of requirements for Engineers 4.0 (ASTOR, 2017): openness to change, continuous learning, acquiring knowledge from other disciplines, processing and analyzing a large amount of data from many sources, assessing the validity and credibility of this information, drawing accurate conclusions from it, understanding terms and concepts from other fields, ability to work in a team, highly developed interpersonal skills, i.e.: effective communication, ability to convince and motivate others, explaining difficult and unpopular decisions, attitude, a system of values and respect for others.

Due to a change in the knowledge, skills and competencies that employees are required to possess in the age of Industry 4.0, the Executive Agency for Small and Medium-sized Enterprises – EASME, part of the European Commission, has developed a document entitled "Skills for Industry, Curriculum Guidelines 4.0: Future-proof education and training for manufacturing in Europe". The aim of this document was to meet the challenges of Industry 4.0 for employees and employers by developing Curriculum Guidelines 4.0, offering suppliers of educational and training services a systematic overview of new ways of organizing educational experiences of people and groups for Industry 4.0. The document also presents the target profile for Engineers of Industry 4.0. The target profile for Engineers of Industry 4.0 consists of 5 components:

1. Basic specialist knowledge in the engineering discipline;
2. Methodological skills, especially process and system thinking;
3. Multidisciplinary knowledge, such as mechanical, electrical and electronic engineering in computer science and data science, and basic knowledge of mechanical, electrical and electronic engineering and computer science for the needs of computer science;
4. Contextual knowledge, i.e. knowledge of conditions, requirements and perspectives in other fields and disciplines;
5. Interdisciplinary skills, especially the ability to work in a team, self-sufficiency, motivation, problem solving skills, learning and adaptation skills, openness and communication skills (EASME, 2020).

The profile is largely based on specialized requirements in various engineering disciplines, and new additions are skills in computer science, data science and data security (EASME, 2020). New qualification requirements in the age of Industry 4.0 are also discussed in the literature. Critical literature research in this area was carried out by Jelonek, Nitkiewicz and Koomsap (Jelonek et al. 2020).

In the source literature, one can also find numerous publications related to research on the skills of Engineers 4.0. A systematic review of the literature in this area was carried out by Maisiri, Darwish, van Dyk (Maisir et al., 2019). They showed that technological progress in the age of Industry 4.0 will force a need for a new set of skills. The systematic literature review (SLR) indicated what skills are required within Industry 4.0 for engineers and how they can be developed. The study indicated that non-technical skills are as important as technical skills in the profession of an engineer in Industry 4.0. According to Maisiri et al. (2019), advanced technologies are not intended to replace people in order to increase productivity; rather, they call for close human-machine cooperation.

The development of interdisciplinary skills may be indispensable in Industry 4.0 to ensure the effectiveness of employees in the engineering profession.

## Competencies for Manager 4.0

Competencies for Manager 4.0 show a close relationship with trends in business management resulting from successive industrial revolutions – Table 3.

In 2020, PARP published a report: Description of universal managerial competences, allowed for the development of the evolution of managerial competences in the field of organization management in subsequent industrial revolutions – Table 4.

Table 3
Essential management differences between Industry 2.0, 3.0 and 4.0

| Feature | The second industrial revolution Industry 2.0 | The third industrial revolution Industry 3.0 | The fourth industrial revolution Industry 4.0 |
|---|---|---|---|
| Key notions | Standardization and mechanization | Coordination and automation | Flexibility and autonomation |
| Key technologies | Assembly belt | Digital technologies | Machine learning, artificial intelligence |
| Planning | Precise instructions | Designation of tasks | Principle programming |
| Managing/Motivating | Behavioural | Humanistic | Cognitive |

Source: https://przemyslprzyszlosci.gov.pl, 2021.

Table 4
Evolution of managerial competencies

| Manager's feature | Traditional model Industry 2.0 | The 20th century model Industry 3.0 | Future Model/Model 4.0 Industry 4.0 |
|---|---|---|---|
| Role | in the centre<br>Employees: objects | building relationships<br>Employees: partners, entities | moderating<br>Employees: partners |
| Skills | organizing work and enforcing its execution;<br>obtaining the necessary information to make the right decisions;<br>reducing employee insecurity;<br>motivating employees | ability to create conditions for effective work;<br>taking care of the broadly understood self-development and development of employees;<br>stimulating employees to creativity;<br>developing innovative solutions;<br>shaping the right organizational culture;<br>managing culturally diverse staff, sometimes in a culturally diverse environment. | team building;<br>resolving conflicts;<br>communication;<br>group decision-making;<br>resolving conflicts in a team;<br>managing in a culturally diverse environment, including diverse staff;<br>developing an organizational culture conducive to the acquisition and sharing of knowledge;<br>enabling employees to maintain a balance between work and personal life;<br>managing change in the organization. |
| Management style | autocratic | democratic | moderating |

Source: own development based on (PARP, 2020)

As shown in Table 4, the Manager of the Future (Manager 4.0) is characterized by the attitude of a moderator, treatment of colleagues based on partnership, team building skills, conflict resolution, communication, group decision-making, managing in a culturally diverse environment, including diverse staff, developing an organizational culture conducive to acquiring knowledge and sharing it (PARP, 2020).

Manager 4.0 enables employees to maintain a balance between work and personal life and is able to manage change in the organization.

## Material and methods

### Scope of research and conceptual model

The subject of the research are the components of Engineer 4.0 managerial competences. (Werner-Lewandowska et al., 2022). The analysis of the literature allowed for the identification of a wide set of components of competences both at the general level of Industry 4.0 and at narrower levels: for the managerial and engineering level (cf. Table 3 and 4). Figure 4

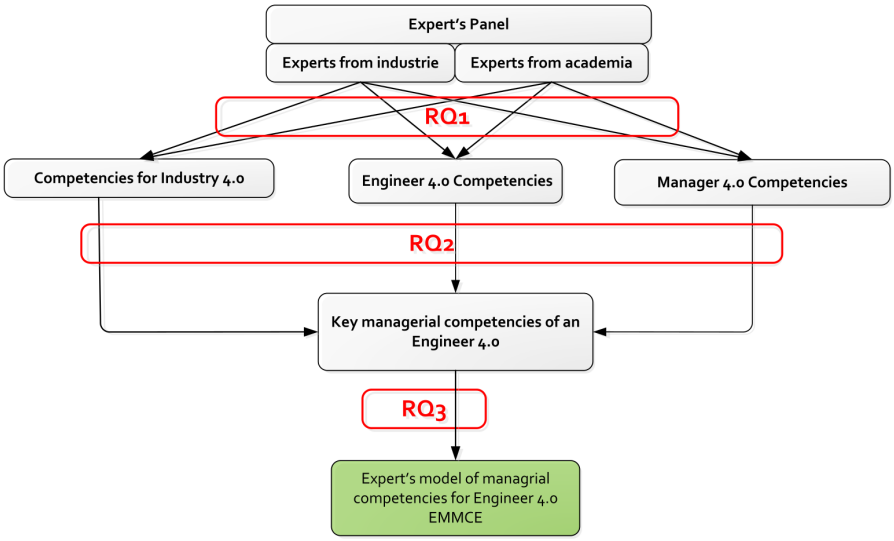


Fig. 4. Conceptual process of developing research questions. Source: author's own development

shows the general concept of the expert qualitative research and the places where the research questions were asked.

The study poses 3 research questions:

*RQ1: What competencies in the area of Industry 4.0, Manager 4.0 and Engineer 4.0 are crucial in experts' opinion?*

*RQ2: What are, in experts' opinion, the key managerial competencies for Engineer 4.0?*

*RQ3: How to define an expert's model of managerial competencies for Engineer 4.0?*

The search for answers to such research questions led to the development of a five-stage research process leading to the achievement of the set goal (step 5 in Figure 5).

## Data for the answers to research questions

The research cycle included two phases and 5 steps. The research steps are described below.

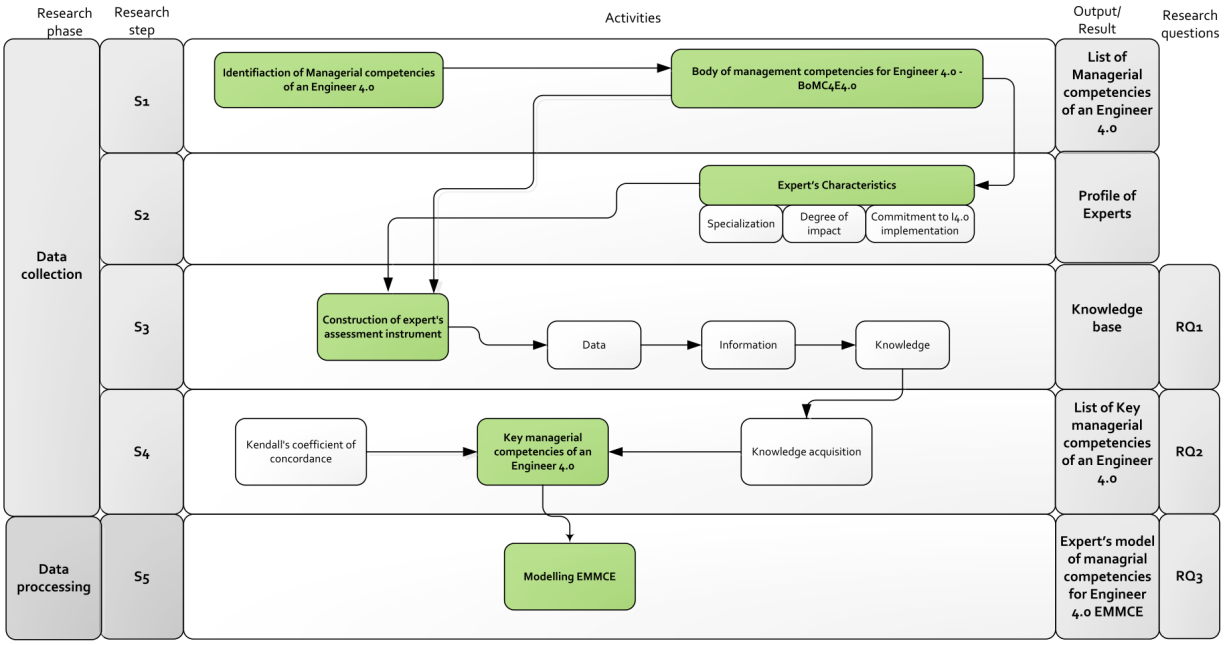


Fig. 5. Research steps. Source: Adapted from Becker et al., 2009; Caiado et al, 2021

**Step 1.** In this step, we used the results of research aimed at developing a *body of management competencies for Engineer 4.0* [35](Werner-Lewandowska et al., 2022). As a result, we received a list of 40 managerial competencies for Engineer 4.0 (MC4E4.0) – Table 5. It became the departure point for further research.

**Step 2.** In this step, we determined the profile of an expert for expert research, the minimum number of experts and developed the course of expert research.

In order to achieve a high level of objectivity, the experts were selected according to the following criteria: specialization: scientist, practitioner, level of impact: operational tactical, strategic, degree of involvement in the implementation of I4.0. The characteristics of the expert panel are presented in Table 6. 12 experts were invited to take part in the study, including 6 representing the academic community and 6 with practical experience.

In the expert research, we used the CATI technique using expert questionnaires in repeated individual interviews . The sheet used in the study consisted of 40 alphabetically arranged components of competencies, including knowledge, skills and elements of attitudes (Werner-Lewandowska et al., 2022). The expert's task was to rank the components from the most important to the least important ones in three perspectives. The study was carried out in three parts with intervals of 48–72 hours. The interval was dictated by the need to minimize the impact of short-term memory on the repetition of indications. The primary data were collected from 1 June to 30 August 2022. Figure 6 shows the procedure of the conducted expert tests.

**Step 3.** In this step, based on the developed expert research tool, we obtained data, information and knowledge in the range of the evaluation of 40 competencies for Industry 4.0, Manager 4.0 and Engineer 4.0 ranked from place 1 to 40, where 1 means the competency of the highest importance in the expert's opinion and 40 the least important competency in the examined perspective. The research carried out in this way allowed to obtain an answer to RQ1: *What competencies in the field of Industry 4.0, Manager 4.0 and Engineer 4.0 are crucial in experts' opinion?*

Table 5
List of managerial competencies for Engineer 4.0 in alphabetical order

| Id | MC4E4.0 | Id | MC4E4.0 |
|---|---|---|---|
| C_1 | team building | C_21 | development of organizational culture |
| C_2 | willingness to learn | C_22 | independence |
| C_3 | decision-making | C_23 | respect |
| C_4 | knowledge sharing | C_24 | tolerance |
| C_5 | efficiency | C_25 | research skills |
| C_6 | innovation | C_26 | IT knowledge |
| C_7 | managing a culturally diverse team | C_27 | interdisciplinary knowledge |
| C_8 | communication | C_28 | engineering knowledge |
| C_9 | creativity | C_29 | contextual knowledge |
| C_10 | life balance | C_30 | knowledge of AI |
| C_11 | abstract reasoning | C_31 | knowledge of cybersecurity |
| C_12 | process thinking | C_32 | knowledge of digital solutions |
| C_13 | systems thinking | C_33 | knowledge of different cultures |
| C_14 | openness to changes | C_34 | knowledge of contemporary management models |
| C_15 | basic knowledge of mechanical engineering | C_35 | cooperation |
| C_16 | working in interdisciplinary and multicultural teams | C_36 | time management |
| C_17 | teamwork | C_37 | process management |
| C_18 | entrepreneurship | C_38 | project management |
| C_19 | leadership | C_39 | strategic management |
| C_20 | problem solving | C_40 | team management |

Source: Werner-Lewandowska et al., 2022

Table 6
Characteristics of experts

| expert | Expert's characteristics* | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | S | P | W | M | OP | TT | STRA | 1 | 2 | 3 | 4 |
| E1 | + | | + | | | + | | | | + | |
| E2 | + | | + | | | + | | | | | + |
| E3 | + | | | + | + | | | | + | | |
| E4 | | + | | + | + | | | | | | + |
| E5 | | + | | + | | | + | | | + | |
| E6 | | + | | + | + | | | | | + | |
| E7 | | + | | + | | | + | | + | | |
| E8 | | + | | + | | + | | + | | | |
| E9 | | + | + | | + | | | | + | | |
| E10 | + | | + | | | + | | + | | | |
| E11 | + | | | + | | + | | | + | | |
| E12 | + | | | + | | + | | | + | | |

*where: S – scientists, P – practitioners, W – Woman, M – Man, OP – operational level of impact, TT – tactical level of impact, STRA – strategic level of impact, 1 – involvement to a small extent in the implementation of P4.0, 2 – involvement to a medium extent in the implementation of P4.0, 3 – involvement to a large extent in the implementation of P4.0, 4 – full involvement in the implementation of P4.0
Source: author's own development

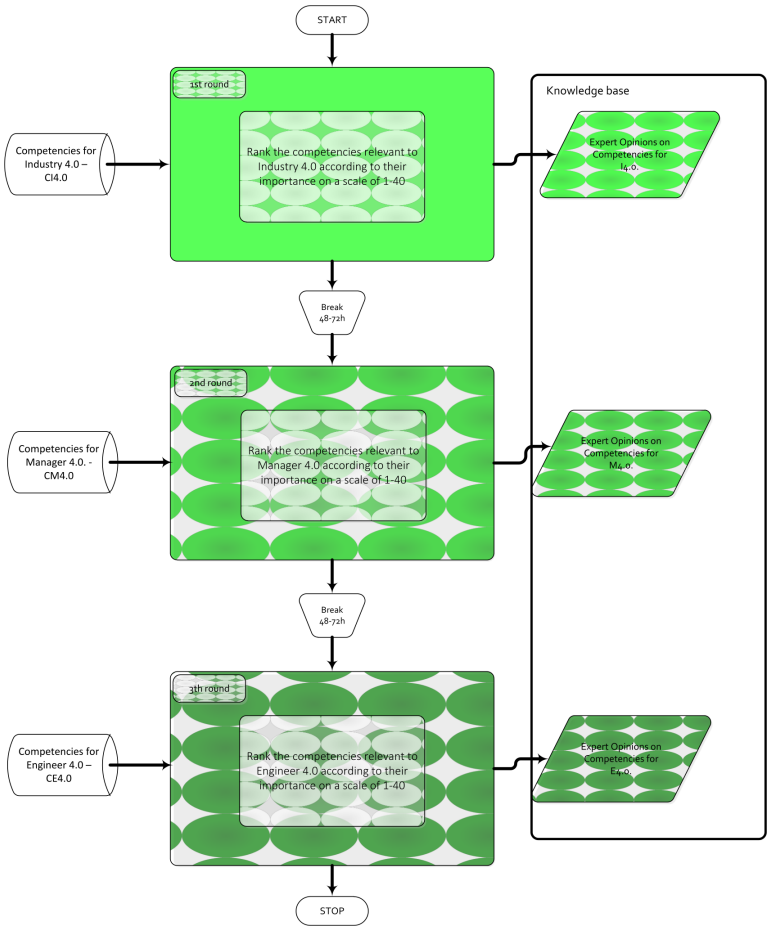


Fig. 6. Expert research procedure. Source: author's own development

We used the Kendall's coefficient to test the concordance of responses (Kendall et al., 1939; Wallis, 1939). The Kendall's Coefficient of Concordance described in the work by Kendall and Babington-Smith (1939) and Wallis (1939) should be considered as an appropriate tool, because we have rankings from various experts and concerning forty ($k \geq 2$) objects, and it is important to assess the concordance of these rankings. The Kendall's coefficient of concordance is determined for the order or interval scale and its value is calculated according to the following formula (1):

$$\tilde{W} = \frac{12\sum_{i=0}^{n} R_{ij}^2 - 3n^2k(k+1)^2}{n^2k\left(k^2-1\right) - nC} \tag{1}$$

where: $n$ – number of different sets of assessments (number of assessors), $k$ – number of ranked objects, $R_{ij}$ – ranks assigned to successive objects ($j = 1, 2, \ldots, k$), separately for each assessor ($i = 1, 2, \ldots, n$), $C$ – correction for tied ranks, calculated from the following formula (2):

$$C = \sum \left(t^3 - t\right) \tag{2}$$

$t$ – numer of cases included in the tied rank means the Kendall's coefficient of concordance in the population and in the sample.

**Step 4.** In this step, based on the list of experts' answers, we determined a list of key managerial competencies for Engineer 4.0, which allowed to obtain an answer to RQ2: *What are, in experts' opinions, the key managerial competencies for Engineer 4.0?* We assumed that key competencies could be those that, in experts' opinion, have the greatest significance (items 1–10).

**Step 5.** In this step, based on the previous results, we developed an expert's model of managerial competencies for Engineer 4.0 – EMMCE, which corresponds to RQ3: *How to define an expert's model of managerial competencies for Engineer 4.0?* For this purpose, we used set theory. In the authors' intention, the model is a product (common part) of 3 sets:

- Key competencies for Industry 4.0 – CI4.0,
- Key competencies for Manager 4.0 – CM4.0,
- Key competencies for Engineer 4.0 – CE4.0, which can be written down by means of the following formula (3):

$$\text{EMMCE} \in \text{CI4.0} \cap \text{CE4.0} \cap \text{CM4.0} \tag{3}$$

## Results

The research results obtained in the consecutive steps of the adopted research cycle (Fig. 5) are shown below.

The result of Step 3 was the acquisition of expert knowledge on key competencies in the perspective of Industry 4.0, Manager 4.0 and Engineer 4.0. In each of the scopes, to assess the consistency of the experts' answers, we calculated the Kendall's and Smith's coefficient of concordance – Table 7.

Table 7
Value of the Kendall's and Smith's coefficient of concordance for the research scopes

| | Competencies for I4.0 | Competencies for M4.0 | Competencies for E4.0 |
|---|---|---|---|
| All experts | 0.357 | 0.365 | 0.374 |
| Scholars | 0.625 | 0.277 | 0.500 |
| Practitioners | 0.344 | 0.380 | 0.301 |

Source: author's own development

Based on the experts' answers, we developed lists of competencies for Industry 4.0, competencies for Manager 4.0 and competencies for Engineer 4.0, ranked according to the degree of importance in experts' opinion, where position 1 means the most important competency, and position 40 means the least important competency in experts' opinion – Table 8. Competencies achieving the same result in Table 8, for example for competencies I4.0, positions 10, 13 and 19, are ex aequo (instead of 9 and 10, both competencies rank 10).

The result of Step 4 was the development of a set of key managerial competencies for Engineer 4.0 in experts' opinion (Table 9), which consists of competencies from the first ten places in the ranking:

- Key competencies for Industry 4.0 – CI4.0,
- Key competencies for Manager 4.0 – CM4.0,
- Key competencies for Engineer 4.0 – CE4.0.

The result of Step 5 was the development of an expert's model of managerial competencies for Engineer 4.0 – EMMCE. According to the previously presented concept, the model is a product of 3 sets:

- Key competencies for Industry 4.0 – CI4.0,
- Key competencies for Manager 4.0 – CM4.0,
- Key competencies for Engineer 4.0 – CE4.0.

In Table 9, the competencies indicated in all 3 sets are marked in bold. On this basis, we conclude that EMMCE includes a 6-element set:

$$\text{EMMCE} = \{\text{C\_12}, \text{C\_26}, \text{C\_32}, \text{C\_28}, \text{C\_30}, \text{C\_37}\}$$

Table 8
The importance of competencies in experts' opinion

| Competencies for I4.0 | | | Competencies for M4.0 | | | Competencies for E.4.0 | | |
|---|---|---|---|---|---|---|---|---|
| position | ID | competency | position | ID | competency | position | ID | competency |
| 1 | C_12 | process thinking | 1 | C_12 | process thinking | 1 | C_28 | engineering knowledge |
| 2 | C_13 | systems thinking | 2 | C_13 | systems thinking | 2 | C_12 | process thinking |
| 3 | C_26 | IT knowledge | 3 | C_32 | knowledge of digital solutions | 3 | C_15 | basic knowledge of mechanical engineering |
| 4 | C_32 | knowledge of digital solutions | 4 | C_26 | IT knowledge | 4 | C_26 | IT knowledge |
| 5 | C_28 | engineering knowledge | 5 | C_28 | engineering knowledge | 5 | C_32 | knowledge of digital solutions |
| 6 | C_27 | interdisciplinary knowledge | 6 | C_37 | process management | 6 | C_30 | knowledge of AI |
| 7 | C_38 | project management | 7 | C_27 | interdisciplinary knowledge | 7 | C_31 | knowledge of cybersecurity |
| 8 | C_40 | team management | 8 | C_30 | knowledge of AI | 8 | C_29 | contextual knowledge |
| 10 | C_30 | knowledge of AI | 9 | C_6 | innovation | 9 | C_37 | process management |
| 10 | C_37 | process management | 11 | C_31 | knowledge of cybersecurity | 10 | C_17 | teamwork |
| 11 | C_6 | innovation | 11 | C_38 | project management | 11 | C_11 | abstract thinking |
| 13 | C_8 | communication | 12 | C_40 | team management | 12 | C_8 | communication |
| 13 | C_31 | knowledge of cybersecurity | 13 | C_4 | knowledge sharing | 13 | C_13 | systems thinking |
| 14 | C_14 | openness to changes | 15 | C_2 | willingness to learn | 14 | C_5 | efficiency |
| 15 | C_4 | knowledge sharing | 15 | C_14 | openness to changes | 15 | C_35 | cooperation |
| 16 | C_2 | willingness to learn | 16 | C_29 | contextual knowledge | 16 | C_20 | problem solving |
| 17 | C_29 | contextual knowledge | 17 | C_15 | basic knowledge of mechanical engineering | 17 | C_14 | openness to changes |
| 19 | C_1 | team building | 18 | C_8 | communication | 18 | C_6 | innovation |
| 19 | C_17 | teamwork | 19 | C_25 | research skills | 19 | C_2 | willingness to learn |
| 20 | C_5 | efficiency | 20 | C_17 | teamwork | 20 | C_27 | interdisciplinary knowledge |
| 21 | C_9 | creativity | 21 | C_5 | efficiency | 21 | C_22 | independence |
| 22 | C_20 | problem solving | 22 | C_20 | problem solving | 22 | C_36 | time management |
| 23 | C_25 | research skills | 23 | C_34 | knowledge of contemporary management models | 23 | C_4 | knowledge sharing |
| 24 | C_15 | basic knowledge of mechanical engineering | 24 | C_1 | team building | 24 | C_38 | project management |
| 25 | C_11 | abstract thinking | 25 | C_9 | creativity | 25 | C_9 | creativity |
| 26 | C_3 | decision-making | 26 | C_11 | abstract thinking | 26 | C_40 | team management |
| 27 | C_34 | knowledge of contemporary management models | 27 | C_3 | decision-making | 27 | C_3 | decision-making |
| 28 | C_35 | cooperation | 28 | C_35 | cooperation | 28 | C_25 | research skills |
| 29 | C_39 | strategic management | 29 | C_36 | time management | 29 | C_16 | working in interdisciplinary and multicultural teams |

Table 8 [cont.]

| Competencies for I4.0 | | | Competencies for M4.0 | | | Competencies for E.4.0 | | |
|---|---|---|---|---|---|---|---|---|
| position | ID | competency | position | ID | competency | position | ID | competency |
| 30 | C_36 | time management | 30 | C_16 | working in interdisciplinary and multicultural teams | 30 | C_18 | entrepreneurship |
| 31 | C_19 | leadership | 31 | C_39 | strategic management | 31 | C_34 | knowledge of contemporary management models |
| 32 | C_16 | working in interdisciplinary and multicultural teams | 32 | C_22 | independence | 33 | C_10 | life balance |
| 33 | C_22 | independence | 33 | C_23 | respect | 33 | C_24 | tolerance |
| 34 | C_23 | respect | 34 | C_19 | leadership | 34 | C_21 | development of organizational culture |
| 35 | C_10 | life balance | 35 | C_10 | life balance | 35 | C_23 | respect |
| 36 | C_21 | development of organizational culture | 36 | C_21 | development of organizational culture | 36 | C_1 | team building |
| 37 | C_18 | entrepreneurship | 37 | C_18 | entrepreneurship | 37 | C_39 | strategic management |
| 38 | C_24 | tolerance | 38 | C_24 | tolerance | 38 | C_19 | leadership |
| 39 | C_7 | managing a culturally diverse team | 39 | C_7 | managing a culturally diverse team | 39 | C_7 | managing a culturally diverse team |
| 40 | C_33 | knowledge of different cultures | 40 | C_33 | knowledge of different cultures | 40 | C_33 | knowledge of different cultures |

Source: author's own development

Table 9
Key managerial competencies for Engineer 4.0 in experts' opinion

| No. | ID | CI4.0 | ID | CM4.0 | ID | CE4.0 |
|---|---|---|---|---|---|---|
| 1 | C_12 | process thinking | C_12 | process thinking | C_28 | engineering knowledge |
| 2 | C_13 | systems thinking | C_13 | systems thinking | C_12 | process thinking |
| 3 | C_26 | IT knowledge | C_32 | knowledge of digital solutions | C_15 | basic knowledge of mechanical engineering |
| 4 | C_32 | knowledge of digital solutions | C_26 | IT knowledge | C_26 | IT knowledge |
| 5 | C_28 | engineering knowledge | C_28 | engineering knowledge | C_32 | knowledge of digital solutions |
| 6 | C_27 | interdisciplinary knowledge | C_37 | process management | C_30 | knowledge of AI |
| 7 | C_38 | project management | C_27 | interdisciplinary knowledge | C_31 | knowledge of cybersecurity |
| 8 | C_40 | team management | C_30 | knowledge of AI | C_29 | contextual knowledge |
| 9 | C_30 | knowledge of AI | C_6 | innovation | C_37 | process management |
| | C_37 | process management | C_31 | knowledge of cybersecurity | C_17 | teamwork |
| 10 | C_6 | innovation | | | | |

Source: author's own development

On this basis, we conclude that an expert's model of managerial competencies for Engineer 4.0 (EMMCE) can be defined as a set of competencies such as: process thinking, IT knowledge, knowledge of digital solutions, engineering knowledge, knowledge of AI and process management.

## Discussion

In this article, we proposed a new model of managerial competencies for Engineer 4.0 based on an expert study (EMMCE).

This article fills the research gap by providing a theoretically well-established and methodologically rigorous competency model. Referring to the research questions posed in the introduction, the article also fills the gap in the epistemological and utilitarian aspect.

Creating competency models is not a new endeavor (Prahald, Hamel, 1990; 1997; Szafrański, et al., 2022), but the methodology for developing a model using a multi-step scientific approach is.

The presented model responds to the postulates of quantitative competence models (Prahald, Hamel, 1997) that speak of levels of competence excellence, which we have achieved by selecting expert practitioners. In addition, we secure the postulates of a qualitative view of competence by selecting experts from the field of science.

The realization of the stated goal and the answers to the research questions posed require further research to be able to assess the level of replicability of the study.

No less can be considered that:

- First, our research indicates key competencies in the scope of Industry 4.0, Manager 4.0 and Engineer 4.0 in experts' opinion (RQ1): highlighting 3 sets of key competencies in experts' opinion, which include knowledge, skills and attitude.
- Secondly, the results of our research define a set of key managerial competencies for Engineer 4.0 in experts' opinion (RQ2).
- Thirdly, the EMMCE proposed by us indicates what competencies a manager – an engineer in the era of the fourth industrial evolution – should have.

In terms of the knowledge component, according to our model, an engineer should possess:

- IT knowledge,
- knowledge of digital solutions,
- engineering knowledge,
- knowledge of AI.

In terms of the skills component, according to our model, an engineer should manage processes.

In terms of the attitude component, according to our model, an engineer should perform process thinking.

What is interesting, process thinking was recognized in our research by experts as the most important skill both in the perspective of Industry 4.0 and Manager 4.0 and as the second in terms of importance, immediately after IT knowledge in the case of the competency for Engineer 4.0. The ability to manage processes is also the managerial competency for Engineer 4.0.

## Conclusion

The specificity of the managerial competencies of the Engineer 4.0 may also explain why some competency models focus on generic competencies tied to one's place in the organizational structure and lack the imperative to implement more sophisticated solutions focused on identifying competency needs for the future.

According to the completed research, it is the process orientation that is crucial from the point of view of managing a company in the era of Industry 4.0. This orientation is based on the concentration on the implementation of the main process of a given enterprise, i.e. such a process that adds another value at each subsequent stage from the point of view of the final customer, i.e. the recipient. Managing an enterprise through the prism of processes consists in perceiving the organization system as a system in which places and roles are variable and determined by (operational) activities that need to be carried out in order to create a value that meets the customer's requirements. Process management places the participant in the course of activities as an entirety, and not in a closed space specialized in the performance of homogeneous tasks of an organizational unit, e.g. in a department, division. Employees perform their work from the perspective of its importance for the customer, the recipient, and not from the perspective of satisfying the needs of the superior, which allows for a better understanding of their own work and its meaning, and consequently improves employee efficiency. Over time, this leads to an increase in employees' loyalty to the enterprise and identification with it. Process orientation facilitates adaptation to changing environmental conditions by supporting and developing the intellectual potential of employees, which translates into increased competitiveness.

Regarding directions for further research on managerial competencies for Engineer 4.0, we point to improving the proposed model, and its validation in various sectors of industry.

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## References

Astor, Industrial Engineers 4.0, 2017, https://www.astor.com.pl/images/Industry_4-0_Przemysl_4-0/ASTOR_Inzynierowie_4.0_whitepaper.pdf.

Becker B.E., Huselid M.A. and Ulrich D. (2002), Human resource management scorecard, Oficyna Ekonomiczna, Kraków.

Becker J., Knackstedt R. and Pöppelbuß J. (2009), Developing Maturity Models for IT, *Management, Business & Information Systems Engineering,* No. 1, pp. 213–222. DOI: 10.1007/s12599-009-0044-5.

Bermúdez M.D., Juárez B.F. (2017), Competencies to adopt Industry 4.0 for operations management personnel at automotive parts suppliers in Nuevo Leon, *Proceedings of the International Conference on Industrial Engineering and Operations Management*, Bogota, Colombia, October 25–26.

Caiado R.G.G., Scavarda L.F., Gavião L.O, Ivson P., de Mattos Nascimento D.L. and Garza-Reyes J.A. (2021), A fuzzy rule-based industry 4.0 maturity model for operations and supply chain management, *International Journal of Production Economics*, Vol. 231. DOI: 10.1016/j.ijpe.2020.107883.

Cao B., Wang Z., Shi H. and Yin Y. (2015), Research and practice on aluminium Industry 4.0, *2015 Sixth International Conference on Intelligent Control and Information Processing.*

Dzwigol H., Dzwigol-Barosz M., Miskiewicz R. and Kwilinski A. (2020), Manager competency assessment model in the conditions of industry 4.0, *Entrepreneurship and Sustainability Issues*, No. 4, Vol. 7, pp. 2630–2644. DOI: 10.9770/jesi.2020.7.4(5).

EASME, Skills for Industry, Curriculum Guidelines 4.0: Future-proof education and training for manufacturing in Europe, FINAL REPORT, Komisja Europejska, Luksemburg, 2020. DOI: 10.2826/097323

Fitsilis P., Paraskevi P., Tsoutsa P. and Gerogiannis V. (2018), Industry 4.0: required personnel competences, *Industry 4.0*, Issue 3, Vol. 3, pp. 130–133.

Gracel J. and Makowiecki M. (2017), Key competences of a manager in the era of the Fourth Industrial Revolution – Industry 4.0, *Acta Universitatis Nicolai Copernici, Management, XLIV*, No. 4, Vol. 201. DOI: 10.12775/AUNC_ZARZ.2017.054.

Grzelczak A., Kosacka M. and Werner-Lewandowska K. (2018), Employees Competences For Industry 4.0 In Poland– Preliminary Research Results, *DEStech Transactions on Engineering and Technology Research.* DOI: 10.12783/dtetr/icpr2017/17598.

Grzybowska K. and Łupicka A. (2017), Key competencies for Industry 4.0, *Economics & Management Innovations*, No. 1, Vol. 1, pp. 250–253.

Hecklau F., Galeitzke M., Flachs S. and Kohl H. (2016), Holistic Approach for Human Resource Management in Industry 4.0, *Procedia CIRP*, Vol. 54, pp. 1–6. DOI: 10.1016/j.procir.2016.05.102.

Janik A. and Ryszko A. (2018), *Mapping the field of Industry 4.0 based on bibliometric analysis, Proceedings of the 32nd International Business Information Management Association Conference (IBIMA) – Vision 2020: Sustainable Economic Development and Application of Innovation Management from Regional Expansion to Global Growth*, Seville, Spain 15–16 November 2018, pp. 6316–6330.

Jasiulewicz-Kaczmarek M., Legutko S. and Kluk P. (2020), Maitenece 4.0 technologies – new opportunities for sustainability driven maintenance, *Management and Production Enineering Review*, No. 2, Vol. 11, pp. 74–87. DOI: 10.24425/mper.2020.133730.

Jelonek D., Nitkiewicz T. and Koomsap P. (2020), Soft Skills of Engineers in View of Industry 4.0 Challenges, *Conference Quality Production Improvement – CQPI*, No. 1, Vol. 2, pp. 107–116. DOI: 10.2478/cqpi-2020-0013.

Kagermann H., Wahlster W. and Helbig J. (eds.) (2013), Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0 Working Group.

Kendall M.G. and Babington-Smith B. (1939), The problem of m rankings, *Annals of Mathematical Statistics*, Vol. 10, pp. 275–287.

Korytkowski P. (2017), Competences-based performance model of multi-skilled workers with learning and forgetting, *Expert Systems with Applications*, Vol. 77, pp. 226–235, ISSN 0957-4174. DOI: 10.1016/j.eswa.2017.02.004.

Leong W.Y., Chuah J.H. and Tee B.T. (2020), The Nine Pillars of Technologies for Industry 4.0, *IET Digital Library.* DOI: 10.1049/PBTE088E.

Maisiri W., Darwish H. and van Dyk L. (2019), An investigation of industry 4.0 skills requirements, *The South African Journal of Industrial Engineering*, No. 3, Vol. 30, pp. 90–105. DOI: 10.7166/30-3-2230.

PARP (2020), Description of Universal Managerial Competences, Polish Agency for Enterprise Development https://www.parp.gov.pl/storage/grants/documents/96/ZAL_12_Opis_uniwersalnych_kompetencji_menaderskich_20200228.pdf, (accessed: 18.07.2022).

Prahalad C.K. and Hamel G. (1990), The Core Competence of the Corporation, *Harvard Business Review,* No. 3, Vol. 68, pp. 79–91.

Prahalad C.K. and Hamel G. (1997), The Core Competence of the Corporation, In: Hahn D., Taylor B. (eds), Strategische Unternehmungsplanung / Strategische Unternehmungsführung. Physica, Heidelberg.. DOI: 10.1007/978-3-662-41482-8_46.

prnews, *OChK a strategic partner of Microsoft, a regional technology hub will be established in Poland* [20 lipca 2022], https://prnews.pl/ochk-strategicznym-partnerem-microsoft-w-polsce-powstanie-regionalny-hub-technologiczny-450929.

Prifti L., Kniggeb M., Kienegger H. and Krcmar H. (2017), *A Competency Model for "Industrie 4.0" Employees*, Improvement of Warehouse Operations Management by Considering Competencies of Human Resources.

Prifti L., Knigge M., Kienegger H. and Krcmar H. (2017), *A Competency Model for "Industrie 4.0" Employees*, in Leimeister, J.M.; Brenner, W. (Hrsg.): Proceedings der 13. I nternationalen Tagung Wirtschaftsinformatik (WI 2017), St. Gallen, 46–60, https://wi2017.ch/images/wi2017-0262.pdf.

Schwab K. (2016), *The Fourth Industrial Revolution*, World Economic Forum, Geneva, Switzerland.

Shevyakova A., Munsh E., Arystan M. and Petrenko Y. (2021), Competence development for Industry 4.0: Qualification requirements and solutions, Insights into Regional Development, No. 1, Vol. 3, pp. 124–135. DOI: 10.9770/IRD.2021.3.1(7).

Simic M. and Nedelko Z. (2019), *Development of competence model for industry 4.0: a theoretical approach*, 37th International Scientific Conference on Economic and Social Development "Socio Economic Problems of Sustainable Development", Baku, 14–15 February 2019.

Szafrański M., Gutmen S., Graczyk-Kucharska M. and Weber G-W. (2022), Modeling IT specialist Competency in the era of Industry 4.0, *Innovations in Mechatronics Engineering*, pp. 257–269.

Wallis W.A. (1939), The correlation ratio for ranked data, *Journal of the American Statistical Association*, Vol. 34, pp. 533–538.

Werner-Lewandowska K., Radecki A. and Więcek-Janka E. (2022), Management competencies for engineer 4.0 (BoMC4E4.0) – model proposal, *European Research Studies Journal*, Issue 2B, Vol. XXV, pp. 204–214. DOI: 10.35808/ersj/2954.

Woodruffe Ch. (1991). *Competent by any other name.* Personnel Management, No. 23.

https://przemyslprzyszlosci.gov.pl/czym-rozni-sie-zarzadzanie-zespolem-w-przemysle-2-0-3-0-i-4-0/, access: 13.09.2021.