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Overcoming the barriers to the digital transformation of industrial enterprises through the business model selection mechanism

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Abstract

The article describes the main barriers to digital transformation faced by industrial enterprises in various industries, such as: lack of appropriate funding, information security risks, insufficient digital skills of employees, insufficient maturity of current processes, internal resistance to change, insufficient awareness of managers, lack of certainty over the future of digital standards. To analyse the barriers, the author used a three-step approach, including a literature review, a primary research with representatives of the companies, and a qualitative comparative analysis that are based on the Kruskal – Wallis test and used to identify differences between groups of enterprises. To overcome the barriers identified by the author it was offered to use a mechanism of a business model selection, which takes into account the assessment of obtained competitive advantages (improvement of operational, financial and technical efficiency), digital maturity (digital culture level, staff qualifications, the quality of business process organisation and access to digital infrastructure) and risks (non-receipt of expected income from business model implementation, information security, reputational and personnel). The novelty of the proposed business model selection mechanism for an industrial enterprise is to improve the classification and develop a multi-criteria mechanism for choosing a business model, which would be implemented using a knowledge-based system incorporating a fuzzy inference mechanism.

Keywords: digital transformation, business model, industrial enterprises, barriers to digital transformation, business model selection mechanism.

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通过商业模式选择机制克服工业企业数字化转型的障碍

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摘要

本文章介绍了不同行业的工业企业面临的数字化转型的主要障碍：缺乏足够的资助、 信息安全危险、员工的数字技能不足、目前的流程不够成熟性、变革的内部阻力、管理熟悉情况不足、对未来的数字标准缺乏确定性。为了进行障碍的分析，作者采用了一个三步法，包括：文学评论、公司代表者调查以及使用克鲁斯卡尔-沃利斯检验（Kruskal - Wallis test）进行定性比较分析，以确定各组企业之间的差异。作为克服所发现的障碍的工具，作者提出了一个考虑到对所获得的竞争优势（业务、财务和技术效率提高）的评估的选择商业模式的机制。该机制还考虑到了数字成熟度（数字文化、员工能力、业务流程组织的质量和数字基础设施的使用）和潜在风险（未能从商业模式的实施中获得预期收入、信息安全、声誉和人力资源风险）。提出的工业企业商业模式选择机制的新颖性在于改进了商业模式分类并开发了一个通过具有模糊推理机制的知识系统实现的多标准商业模式选择机制。

关键词：数字化转型，商业模式，工业企业，数字化转型的障碍，商业模式选择机制。

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Introduction

Digital transformation (DX) of industrial enterprises is a process of digitisation which allows to optimise production processes, improve product quality, reduce costs and increase the competitiveness of an enterprise. However, despite these prospects, implementation of digital transformation may face certain difficulties. New challenges constantly lead industrial enterprises to new barriers that they have to overcome. Trends in consumer and company behaviour that have a profound impact on manufacturing operations are reviewed below.

Customisation. Many consumers are not satisfied with the production design and mass production. For example, in response to rapidly changing social media tendencies, consumers wish that products would fulfill their personal choices. In addition to that, they want these customised items to be shipped quickly.

Regionalisation. Globalisation is being reversed, since such factors as trade tension, geopolitical conflicts and the COVID-19 pandemic have increased the risks associated with complex supply chains. Wherever possible, companies want to get resources and make products close to their customers.

Digital differentiation. Traditionally, manufacturers'IT departments possess digital skills. Various trends, including remote work, rising labour costs, and wider use of automation in workshops, have transformed digital skills from support capacities to a source of competitive advantage.

Sustainability. For many consumers, climate change has become a reality. Motivated by extreme weather conditions, organised by movements of activists, as well as government regulations and stimulations, an increasing number of consumers are choosing to purchase sustainable products and brands with a low or decreasing carbon footprint. Sustainability also increases value from the point of operations. For example, the recent rise in energy prices all around the world encourages organisations to invest in renewable energy sources.

Business models of digital transformation help in adapting to the above-mentioned trends. In a previous studies two types of such business models were identified: platform business models and "factory-future" business models [Karikova, 2022]. The flexibility and modularity inherent in the "factory-future" business models simplify the customisation of products, while the resiliency of the supply chain encourages regionalisation. Digital culture empowers workers, and sustainable activities assist in achieving climate goals and other important goals related to the well-being of sustainable communities [McGrath, 2010; Heikkilä et al., 2016; Terrenghi et al., 2017; Tesch, Brillinger, 2017].

Digital transformation in industrial enterprises is directly related to the resources, since large amounts of data, energy, materials and other aspects are used in the process of implementation of digital technologies and solutions. Considering the barriers to digital transformation, we rely on the resource-based view, according to which it is necessary to determine and develop the unique resources or capabilities of the company to achieve a competitive advantage. The role of resource theory if developing and maintaining competitive advantage through resource management in the process of digital transformation is gaining popularity in the academic field and stimulates industrial companies [Newbert, 2007; Parmenter, 2020; Rupeika-Apoga et al., 2022].

1. Literature review

The company's resources can be both tangible and intangible. Tangible resources include physical assets such as financial and human resources, while intangible resources include an organisation's reputation, culture, knowledge or know-how, accumulated experience, and relationships with customers, suppliers, or other key stakeholders. Implementation of digital transformation is a complex process with many challenges in resource and other barriers that need to be overcome. In the research, barriers to sustainable digital transformation are identified through the resource theory approach. Table 1 represents a summary of the available literature on the topic of identification of the barriers or obstacles in the process of digital transformation.

The literature review identifies a number of barriers, including lack of sufficient funding, information security risks, insufficient digital skills of employees, lack of maturity of current processes, internal resistance to change, lack of managerial awareness, uncertainty regarding the future of digital standards, etc. All identified barriers are related to resources, since, as for example, lack of suitable financing options relates to financial resources. The resources of the companies can be conditionally divided into five categories: financial, human, educational, emotional and physical resources. As mentioned earlier, according to the resource theory, effective resource management provides the company with a competitive advantage.

Competitive advantage allows a company to produce goods or services better or at lower costs than competitors. According to Michael Porter's theory of competitive advantage, governments and enterprises should pursue policies aimed at producing high-quality goods that can be sold at high market prices. In terms of competitive advantages, various characteristics of companies are considered, such as company size, location, corporate governance, etc.

Competitive advantages that are based on economies of scale are often used to highlight advantages from the side of suppliers such as the purchasing power of a retail chain. Nevertheless, there are also advantages from the demand-side – usually called network effects, they occur when the service becomes more valuable to all users and the number of users of that service accordingly increases. The advantage of large companies is that they can pay higher wages and provide their employees with more job placements than small companies. Large corporations often provide their employees with health and life insurance, stock options, retirement benefits, and various assistance programmes. It is usually more complicated for small businesses to access high-quality digital infrastructure, solve data security and privacy issues, and adapt

Table 1
Literature review on the topic of digital transformation barriers

Authors	Barriers
[Cichosz et al., 2020]	The complexity of the logistics network and its underlying processes Lack of resources, including qualified resources Technology implementation Resilience to change Data protection and security breach
[Vogelsang et al., 2019]	Absence of necessary skills Technical barriers Individual barriers Organisational and cultural barriers Environmental barriers
[Fanelli, 2021]	Limited support from local politicians Lack of financial resources Lack of experience/skills among employees Inability to hire new employees with relevant skills/experience Absence of consumer demand or limited interest from stakeholders Lack of technological skills High integration costs Difficulties in establishing effective cooperation with suppliers and network partners Competition in the industry
[Abel-Koch et al., 2019]	Lack of appropriate financial opportunities IT security concerns Insufficient digital skills of employees Lack of IT specialists on the external market Internal resistance to change Uncertainty about future digital standards
[Verhoef et al., 2021]	Lack of talented specialists Difficulties with changing corporate culture Lack of understanding and certainty in the accuracy of the chosen courses for all levels of the organisation Limited transparency and data availability Lack of investments in IT systems and technologies
[Bouncken et al., 2019]	Difficulties with company's change management Limited budgets for digital projects Lack of competencies and experience among employees Absence of a digital strategy and action plan

Source: compiled by the author.
to new regulatory environment.

2. Research methodology

To analyse the barriers to digital transformation, three-step approach is used. The first stage is devoted to the literature review. The second stage is based on a survey of company representatives and is aimed at collecting evidence on barriers to DX. At the third stage, in order to identify differences between groups of enterprises, a qualitative comparative analysis is carried out using the Kruskal – Wallis test. First, enterprises were classified according to their size: those with less than 250 employees (small companies), more than 250 employees (medium-sized companies) and more than 500 employees (large companies). In addition to that, enterprises were classified according to their high or low income. Then the enterprises were categorised based on their ability to independently implement digital transformation. Then, the significance of barriers was examined depending on the status of the respondents: employees among the management who are responsible for digital transformation, and rank- and-file workers.

At the first stage, a literature review was carried out to identify potential barriers in the interest of highlighting patterns and facilitating more accurate analysis of the qualitative and quantitative sections. Based on the barriers identified in the literature review, a questionnaire was created. During the second phase, a survey was conducted; the survey included 17 statements and five questions about the status/ position of the respondent in the company, company size, income, business model, and industry sector. The Likert seven-point scale was used to collect answers, as it allows to assess and measure the level of agreement or disagreement with the importance of barriers "which are not at all important" to "the stages extremely important". The survey was conducted among 196 industrial enterprises, the respondents received the questionnaire created on the basis of the literature review presented above. Representatives of the companies were asked to describe the barriers they faced when introducing digital transformation in enterprises. Due to the fact that the chosen sample is multisectoral, a universal combination of barriers in various industries was offered.

In addition, it was examined whether the barriers depend on the ability of enterprises to independently implement digital transformation. The capabilities to introduce digital transformation ranged from 1 (the company cannot carry out digital transformation independently) till 7 (the company can execute digital transformation independently). Then the enterprises were divided into two groups: the companies of the first group, which can independently implement digital transformation (score from 5 to 7), and another group, which cannot execute it independently (score from 1 to 4). Using the Kruskal – Wallis test it was assessed whether there are statistically significant differences between the enterprises of different sizes and two groups based on their ability to implement digital transformation. Finally, the respondents' perceptions of barriers were tested and accordingly divided into two groups: employees among the management who are responsible for digital transformation and rank-and-file workers.

In the process of conducting the survey, responders were notified that the collected information would remain confidential. Additionally, digital transformation experts from several universities were asked to preview the proposed questionnaire. Before submitting the questionnaire, some entrepreneurs were asked if the conditions were clear and understandable. The correlation was studied to shift the general method, and according to it, not a single dimension had a correlation above 0.68.

The Kaiser-Meyer-Olkin (KMO) test for sampling adequacy was used to test the adequacy of the sample. According to the result, which amounted to 0.816 (more than 0.5) the adequacy of the factor analysis was confirmed. To determine how closely related groups of elements are connected, Cronbach's Alpha method was used. The Cronbach's alpha for the considered barriers is 0.802, which indicates the reliability of the data.

3. Barriers to digital transformation: Research results

Table 2 systematises the answers of the responders to the question about the serious barriers they faced in digital transformation of their companies. Figure 1 shows the visualisation of the obtained data.

The analysis of the survey shows that the most problematic challenge faced by small businesses is the lack of adequate funding. The most important barrier for medium-sized enterprises is the lack of maturity of current processes and insufficient digital skills of employees. Large enterprises highlighted lack of certainty regarding future digital standards, internal resistance to change, lack of maturity in current processes, and information security risks.

The Kruskal – Wallis test was used to determine if there are statistically significant differences between companies based on their properties (Table 3). Following designations for the barriers under consideration are introduced: lack of adequate funding – FIN, information security risks – IT, insufficient digital skills of employees – DS, insufficient maturity of current processes – MAT, internal resistance to change – IR, lack of awareness among leaders – KN, lack of certainty regarding future digital standards – DS.

According to the results, only two out of the seven barriers are perceived differently depending on their importance. The lack of adequate funding and the lack of awareness among leaders about the implementation of digital transformation have a statistically significant difference between the represented companies. As a result, a lack of finance is more important for small businesses than for medium-sized ones, and the same implies to the awareness of the industry leaders. However, the difference in the importance of all other barriers is not statistically significant depending on the number of the employees. This allows us to conclude that the significance and value of the barriers is uniform for most barriers, and that they can be generalised.

Table 2
Barriers to digital transformation faced by the companies (%)

Barriers	Size	1	2	3	4	5	6	7	Total	Score*
Absence of proper funding	Small	2	6	2	6	26	25	34	100	7
	Medium	3	4	7	16	29	24	17	100	5
	Large	4	11	5	18	34	11	18	100	5
Informational security risks	Small	5	10	8	20	21	24	13	100	6
	Medium	2	11	2	21	31	29	3	100	5
	Large	4	10	6	21	24	27	8	100	6
Insufficient digital skills of employees	Small	3	5	6	16	28	23	18	100	5
	Medium	3	5	12	9	29	32	9	100	6
	Large	2	2	13	9	32	23	20	100	5
Insufficient maturity of current processes	Small	3	4	5	22	26	22	19	100	5
	Medium	2	4	8	15	24	39	8	100	6
	Large	4	5	4	14	14	50	9	100	6
Internal resistance to change	Small	10	10	12	19	24	17	10	100	5
	Medium	6	9	14	24	25	18	3	100	5
	Large	4	11	21	16	13	23	13	100	6
Lack of awareness among leaders	Small	10	10	6	19	30	14	11	100	5
	Medium	4	16	16	21	23	14	6	100	5
	Large	9	23	23	16	14	11	4	100	3
Lack of managerial awareness, uncertainty regarding the future of digital standards	Small	5	6	6	26	23	24	10	100	4
	Medium	3	5	7	29	29	22	4	100	4
	Large	7	7	5	23	20	32	5	100	6

* Likert scale scores correspond to the following responses of company representatives: 3 – slightly important, 4 – neutral, 5 – moderately important, 6 – very important, 7 – extremely important.

Source: compiled by the author.

Table 4 presents the results of a qualitative comparative analysis for two groups classified according to their income.

Qualitative analysis shows that the importance of barriers both for the high-income group (from 1 billion rubles) and for the low-income group (less than 1 billion rubles) is statistically significant due to lack of finances and insufficient experience of leaders, as well as information security problems. The lack of finance and managerial experience is more important for the low-income group than for the high-income group, while information security is more important for the high-income group.

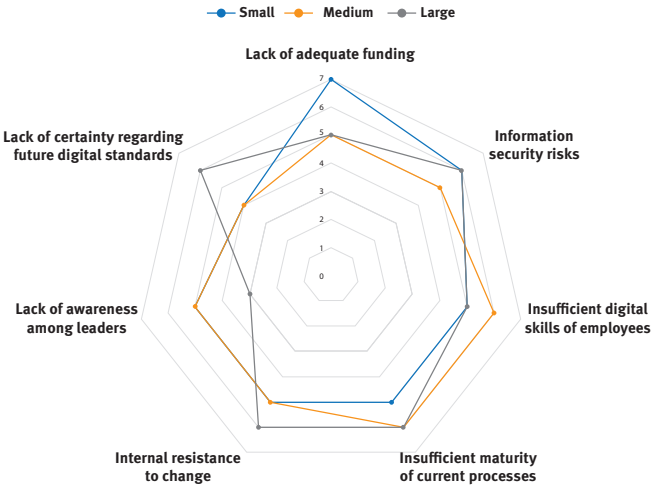
Table 5 presents the results from the analysis of companies that can and cannot independently introduce digital transformation.

A qualitative analysis of the importance of barriers depending on the company's ability to independently manage digital transformation shows that five out of the seven barriers are perceived differently, while all of them are more important for the enterprises, who cannot implement digital transformation independently than for the second group of respondents. The importance of information security and the lack of awareness among managers regarding the future of digital standards were taken into account.

Table 6 represents the results of testing the importance of barriers depending on the status of the respondent.

The analysis shows that, with the exception of a lack of finance, the leaders and managers of companies equally perceive the importance of barriers.

Fig. 1. Significance of barriers depending on the size of the enterprise



Source: compiled by the author.

According to the data received, the main obstacle to digital transformation for small companies is the lack of adequate funding. Most of the interviewed companies reported a lack of financial resources that are needed to implement technological innovations, as well as significant difficulties in obtaining public and private funding. The most serious problem for small businesses is that, despite the fact that innovative technologies often require significant upfront investment, financial institutions are not ready to lend money for risky projects

Table 3
Differences in barriers depending on the size of the company

	Test statistic						
	FIN	IT	DS	MAT	IR	KN	DS
Chi-square	23.900	0.173	1.552	1.040	0.741	12.032	0.578
Degree of freedom	2	2	2	2	2	2	2
Deviation from the normal distribution	**0.0000**	0.917	0.0460	0.595	0.690	**0.002**	0.749
Number of employees	Mean reciprocal rank						
Small	243.60	211.84	216.63	209.79	215.01	230.31	217.27
Medium	194.03	212.29	205.25	211.72	207.86	209.02	207.93
Large	170.70	219.19	225.63	227.97	222.74	167.38	214.88

Source: compiled by the author.

Table 4
The difference in barriers depending on the company's income

	Test statistic						
	FIN	IT	DS	MAT	IR	KN	DS
Chi-square	41.781	10.367	0.347	1.044	0.641	5.371	0.000
Degree of freedom	1	1	1	1	1	1	1
Deviation from the normal distribution	**0.000**	**0.001**	0.556	0.307	0.423	**0.020**	0.991
Income	Mean reciprocal rank						
Low	241.27	198.87	215.58	217.46	209.46	223.25	212.95
High	163.24	237.86	208.46	205.16	219.23	194.96	213.09

Source: compiled by the author.

connected to technological solutions of small businesses that are operating in a low-margin industry. Similar conclusions were reached by M. Cichosz and co-authors, who stated that the impact of a shortage of human and financial resources is primarily determined by the size of the company [Cichosz et al., 2020]. Financial barriers are especially important for small players with limited financial resources.

The importance of barriers varies depending on the size of the company. Despite the fact that the lack of competencies tends to be less of an issue in larger organisations that can invest in training programmes, this barrier becomes especially noticeable in smaller companies. The Kruskal – Wallis test confirmed some statistically significant differences depending on the company size. In the absence of adequate funding and lack of knowledge of the leader about implementation of digital transformation, statistically significant differences between small, medium and large enterprises were found.

When differences based on the income levels were compared, it was investigated that, as in the case of size comparisons, businesses perceive the same barriers differently. This means that in terms of employees and incomes, small businesses face more pressure in attracting fundings and hiring better managers than medium and large size businesses. Small and medium size businesses face the same problems. In terms of information security issues, an intriguing result was explored: this barrier is more important for high-margin companies than for low-margin ones. This fact can be explained from the point of view of the level of digital implementation, since high-margin companies have already met the basic requirements and are currently dealing with more complex issues.

The results of the study showed that the barriers to digital transformation depend on the ability of enterprises to independently manage this process. The analysis revealed statistically significant differences in almost all barriers, except for information security and future digital standards. As already known, there is no evidence from other studies on how the ability to manage digital transformation affects barriers, but according to this research, there is a difference in expected public support for digital transformation between the two groups. The Kruskal - Wallis test confirmed that the lack of adequate funding, insufficient digital skills of employees, lack of maturity of current processes, internal resistance to change, and the lack of knowledge of leaders about the implementation of digital transformation have a different degree of importance for enterprises and depend on their ability to manage digital transformation. All these barriers are more important for companies that cannot implement digital transformation independently. These companies are hoping for public support to continue their digital transformation. Both groups consider information security issues very significant, while neither of them considers the factor of uncertainty regarding the future of digital standards to be particularly relevant.

Table 5
Differences in barriers depending on the ability of an enterprise to independently manage its own digital transformation

	Test statistic						
	FIN	IT	DS	MAT	IR	KN	DS
Chi-square	28.748	0.023	7.871	8.826	15.025	36.102	1.181
Degree of freedom	1	1	1	1	1	1	1
Deviation from the normal distribution	**0.000**	0.880	**0.005**	**0.003**	**0.000**	**0.000**	0.277
Ability to implement DX	Mean reciprocal rank						
Not able	239.25	214.23	226.99	227.74	232.32	242.68	218.72
Able	175.84	212.44	193.78	192.68	185.98	170.82	205.86

Source: compiled by the author.

Table 6
Differences in barriers between leaders и managers

	Test statistic						
	FIN	IT	DS	MAT	IR	KN	DS
Chi-square	8.185	0.527	1.154	0.263	0.215	0.598	1.268
Degree of freedom	1	1	1	1	1	1	1
Deviation from the normal distribution	**0.004**	0.468	0.283	0.608	0.643	0.439	0.260
Status of the responder	Mean reciprocal rank						
Leader	232.67	217.63	220.07	216.11	209.20	218.01	220.44
Manager	198.87	209.03	207.38	210.06	214.73	208.77	207.13

Source: compiled by the author.

It was assumed that the barriers to digital transformation differ depending on the status of the respondent. However, research analysis has shown that only for one out of the seven barriers responder's status is statistically significant – the lack of adequate funding. This barrier seems to be more critical for leaders than for managers.

4. The mechanism of a business model selection

Selecting the right business model of the digital transformation for the enterprise can be a tool for overcoming the barriers of the digital transformation. The choice of the optimal business model for the digital transformation of an industrial enterprise should be based on the need (justification of the set of competitive advantages that the enterprise will receive as a result of the implementation of the business model) and the possibility of its implementation (the analysis of the availability of the necessary resources for the implementation). For the business model of an industrial enterprise, the following competitive advantages can be distinguished: improving operational efficiency (digital technologies can help to automate and optimise business processes, speed up production processes and improve product quality); improving financial efficiency (digital technologies can help to generate profits and achieve financial goals by using their resources in the best possible way); improving digital efficiency (level of success of an enterprise that is using digital technologies to improve its production and business processes).

The possibility of implementation of a business model is determined by assessing digital maturity and the risks that may arise during the implementing process of a digital transformation business model. The indicators of digital maturity include the level of digital culture and staff competencies, the quality of business processes and access to digital infrastructure [Linder, 2020]. In terms of risks, the risks of non-receipt of expected income from the business model implementation, information security risks, reputational and personnel risks are the most important ones. To select a business model for an industrial enterprise, it is proposed to use a mechanism that will allow to achieve the goals of the digital transformation in the best possible way and obtain necessary competitive advantages, when assessing company's readiness to implement the selected model, while taking into account its economic potential and minimising risks. Cronbach's alpha method was used to determine the level of interconnection of elements selected for the mechanism. Cronbach's alpha for the considered elements is 0.802, which indicates the reliability of the collected data. The basis for the business model selection mechanism is shown in Fig. 2.

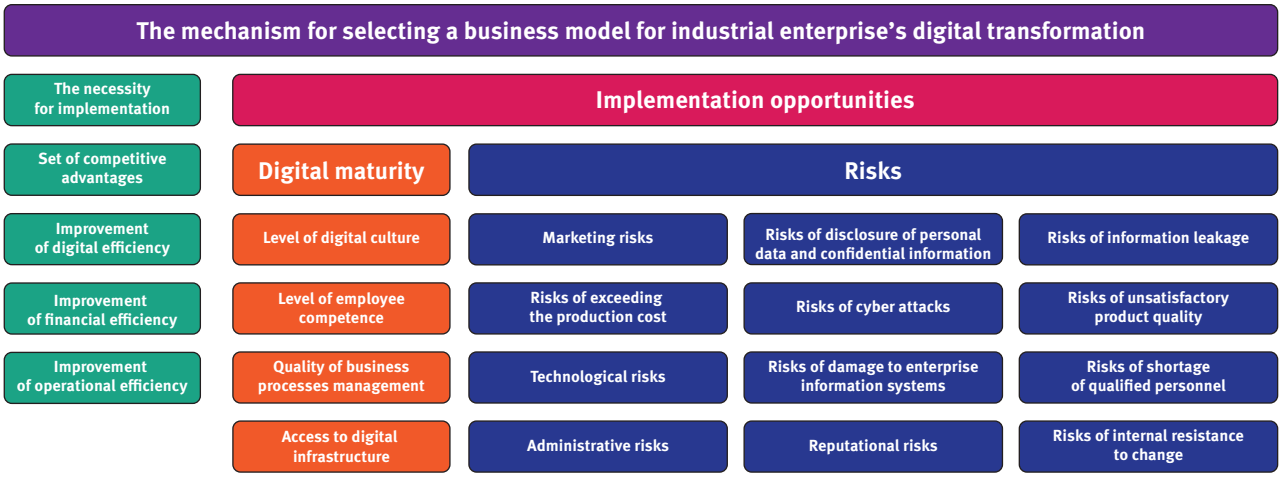
The mechanism for selecting a business model for an industrial enterprise is based on a preliminary clustering of the business model types, on self-assessment of the company and subsequent multi-criteria assessment of the applicability of the selected business model. At the same time the assessment of improving product quality, increasing productivity, increasing the efficiency of the use of resource, reducing production costs and increasing market competitiveness are taken into account

Preliminary clustering was described in detail in previous studies [Karikova, 2022], a brief description of each selected type of a business model is given below.

Digital ecosystems are network structures that unite various market participants (companies, customers, suppliers, partners, etc.) into a single digital space for creating and exchanging their values. To choose this business model of digital transformation, an enterprise must be able to interact with other market participants, have an access to digitalisation technologies and sufficient resources to create and maintain a digital ecosystem.

Value co-creation platforms are digital tools or technology solutions that enable participants to create, exchange and share their value. They provide a framework for collaboration between different participants such as companies, customers, suppliers and other stakeholders who want to solve problems

Fig. 2. Basis for the mechanism for selecting a business model for the digital transformation



Source: compiled by the author.

and achieve common goals. In order to choose this business model for the digital transformation, an enterprise must have the potential to create a platform that will bring together various market participants and create value for all parties.

The implementation of a customised product is a business model that is based on the creation of unique and customised products or services for each client. Choosing this business model, an enterprise must have an opportunity to establish massive production of customised products and services to meet customer needs.

The Smart Factory business model involves the use of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), factory automation, and other digital solutions for optimising operations on the manufacturing site. Smart factories allow companies to significantly improve production efficiency, reduce costs, time and improve product quality.

Factory upgrade and digital engineering are business models that are based on the introduction of modern digital technologies, automation and optimisation of production processes. To select these business models for digital transformation, an enterprise must have the potential to introduce and successfully implement advanced technologies in its production processes.

As a preparatory stage for using the declared mechanism of a business model selection for the digital transformation, the following steps for a preliminary self-assessment of the companies can be highlighted:

1. Customer demand analysis: conducting market research and determining the needs of the company's customers. Identifying the main requirements and expectations of customers about the products and services offered by the company.
2. Analysis of technological capabilities: assessing the technological potential of the enterprise and its abilities to implement digital solutions. Determining the availability of the necessary technologies, infrastructure and competencies within the company.
3. Analysis of expected resultsanalysing the expected results from the implementation of various digital transformation business models. Identifying potential benefits such as process optimisation, market expansion, increase in the number of implemented innovations, and others.
4. Evaluation of resource capabilities: assessing the resource capabilities of the company, such as budget, personnel, infrastructure and other resources needed to implement the chosen business model. Identifying possible limitations and risks associated with these resources.
5. Assessing the culture of the organisation: conducting an analysis of the culture of the organszation and its willingness for changes associated with digital transformation. Identifying the strengths and weaknesses of the organisational culture and determining the appropriate business model that best fits the current culture of the company and contributes to its development.

After a preliminary self-assessment, a proceed of a business model selection starts and bases on the mechanism that is proposed further. After selecting a business model, it is necessary to develop a plan for adapting the chosen business model to the specific conditions of the company. It is important to determine the necessary actions, resources, timelines and expected results for the successful implementation of the chosen business model. The implementation process of the business model for the digital transformation requires constant monitoring and evaluation of its results [Gilsing et al., 2021]. It is necessary to develop a monitoring and evaluation system that will allow to evaluate the effectiveness of the implemented business model and make necessary adjustments in the process of its implementation. The implementation of a business model is a dynamic process and requires constant optimisation and development [Gokhberg et al., 2010; Trachuk, Linder, 2015; Chennell et al., 2020; Khachaturyan, 2022]. The company must analyse the effectiveness of implemented solutions, compare them with business goals, and make adjustments when necessary. Additional optimisation of production processes, technology upgrades, improvement of data analytics systems and AI algorithms, as well as the development of employee competencies and innovative culture may be required. In addition to that, the company should continue monitoring the market changes, analyse upcoming trends in technology development, customer requirements and the competitive environment. This will allow the company to stay ahead of its competitors, adapt to market changes and develop its business model in accordance with new updated requirements and opportunities. Particular attention should be paid to the training and development of the personnel, since the successful implementation of a business model requires training and improvement of the employees' qualifications. The company must provide trainings and assist in developing the competencies of its employees in the field of digital technologies, data analytics, AI and factory automation. This will allow them to efficiently use new solutions and tools, optimise production processes and implement innovations to the company's business model. The implementation of the business model may require significant changes in organisational culture, work processes and interactions between employees. The company must actively manage these changes, provide support and communication to employees to ensure that new decisions and work processes are clearly understood and successfully adopted. Particular attention should be paid to the continuous development and innovation. The company must constantly investigate new opportunities in order to implement technologies, optimise production processes, improve data analytics systems and increase efficiency of the production. This may include the introduction of new technologies, such as Internet of Things (IoT), augmented reality (AR), virtual reality (VR), blockchain and other innovative solutions. With the raising number of connected devices and systems, a company must pay special attention to cybersecurity issues. Protecting

data privacy, preventing unauthorised access, and other aspects of cybersecurity should be prioritised while selecting a business model. The introduction of new technologies and changes in the business processes are always associated with certain risks. The company must actively assess and manage the risks associated with the implementation of the business model, including technical risks, organisational risks, data security risks and others.

Creating a business model selection mechanism requires taking into account the variety of qualitative and uncertain value drivers. For this reason, a system can be used which includes a knowledge base of production rules and unclear withdrawal mechanism that allows to conduct the evaluation and convolution of expert opinions. Unlike score-based models, the usage of the mathematical apparatus of fuzzy logic makes it possible to qualitatively evaluate factors using linguistic variables. Thus, it is possible to fuzzify the quantitative values of the estimated indicators into fuzzy values according to formalised interval scales.

This allows to display the expert's experience in assessing factors in the knowledge base of fuzzy production rules. In addition, the system of fuzzy rules displays multilevel evaluation models, in which the evaluation of intermediate factors is carried out using the corresponding subset of rules.

The mechanism for choosing a business model is represented in the form of an "AND – OR" graph and is presented in Fig. 3.

Using this mechanism, each of the five previously determined business models is evaluated one by one, which receives a positive or negative value for use with a certain reliability coefficient (in the case of obtaining a positive evaluation by several business models, it is recommended to choose the one with the highest reliability coefficient).

In the business model selection mechanism, the following designations of determinants are used – fuzzy variables with the values "satisfactory" or "not satisfactory", for which the reliability coefficient is set on a scale [0; 1]:

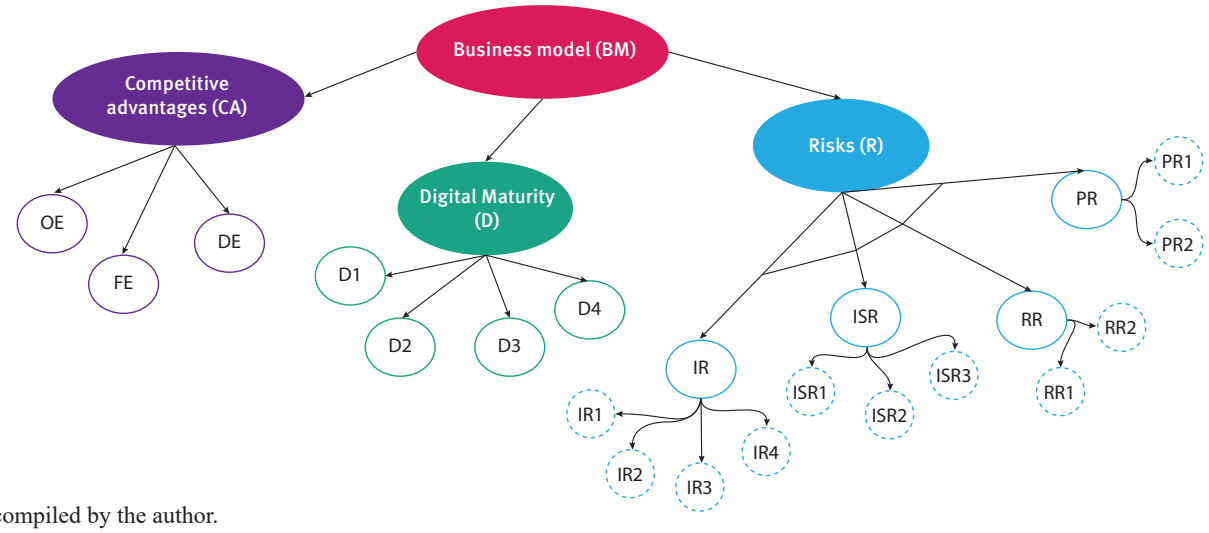
BM – choice of business model;
D – digital maturity;
D1 – level of digital culture;
D2 – level of employee competence;
D3 – quality of business processes management;
D4 – access to digital infrastructure;
CA – competitive advantages;
OE – improvement of operational efficiency;
FE – improvement of financial efficiency;
DE – improvement of Digital Efficiency;
R – risks;
IR – the risk of non-receipt of expected income
IR1 – marketing risks;
IR2 – risks of exceeding the production cost;
IR3 – technological risks;
IR4 – administrative risks;
ISR – information security risks;
ISR1 – risks of disclosure of personal data and confidential information;
ISR2 – risks of cyber attacks;
ISR3 – risks of damage to enterprise information systems;
RR – reputational risks;
RR1 – risks of information leakage;
RR2 – risks of unsatisfactory product quality;
PR – personnel risks;
PR1 – risks of shortage of qualified personnel;
PR2 – risks of internal resistance to change.

Conforming to the production rule of conjunction assessment of digital maturity factors (D), competitive advantages (CA) and risks (R) at the top level of the model a positive or negative assessment of the "business model selection" variables are determined according to formula (1).

$$D \text{ and } CA \text{ and } R \rightarrow BM, \quad (1)$$

where → – implication sigh, – negotion sign.

Fig. 3. Mechanism of selecting a business model for the digital transformation (a simplified version)



Source: compiled by the author.

This production rule in expanded form has the following form:

IF D = *"satisfactory" and CA = "satisfactory" and R =*
="satisfactory" THEN BM="satisfactory". (2)

Each factor is a term of "satisfactory" or "unsatisfactory". If at least one of the factors gets the value "unsatisfactorily", then the type of business model being tested receives an unsatisfactory rating. To operate the product rule, all factors must be satisfied, otherwise the target variable will receive an unsatisfactory value. Factors associated with the assessment of digital maturity and risks reflect the possibilities of implementing a business model, and factors related to improving operational, financial and technical efficiency reflect its competitive advantages.

Similarly, product market rules for estimating digital maturity (D), competitive advantages (CA), risks (R), the risk of non-receipt of expected income from the implementation of the business model (IR), information security risks (ISR), reputation risks (RR) and personnel risks (PR).

Risk assessment (R) depends on the conjunction of factors associated with the risks of non-receipt of expected income (IR), information security risks (ISR), reputational risks (RR) and personnel risks (PR) (formula (3)).

$$IR \text{ and } ISR \text{ and } RR \text{ and } PR \rightarrow R. \quad (3)$$

The risks of non-receipt of expected income from the implementation of the business model (IR) are determined by the conjunction of assessments of marketing risks (IR1), risks of exceeding the production cost (IR2), technological risks (IR3) and administrative risks (IR4) (formula (4)).

$$IR1 \text{ and } IR2 \text{ and } IR3 \text{ and } IR4 \rightarrow IR. \quad (4)$$

Similar to that, information security risks (ISR), reputational risks (RR) and personnel risks (PR) are defined.

Each of the risks listed above must be associated with a certain component of the platform business model or the "factory-future" business models, aimed at its leveling. Due to this, in order to assess the risk by one or another factor ($Fact_i$) while selecting the type of business model, it is necessary to obtain an expertise assessment about the quality (reliability) of the component used (*Comp*) to eliminate the risk factor, which at one time puts a fuzzy assessment of the reliability coefficient on a scale [0; 1] and correlates with the risk factor assessment:

$$Comp_i \rightarrow FactR_i, \quad (5)$$

where $FactRi \in \{IR1, IR2, IR3, IR4, ISR1, ISR2, ISR3, ISR4, RR1, RR2, PR1, PR2\}$.

An expanded presentation of the production rule is represented in the following formula:

IF $Comp_i$ ="satisfactory" *THEN* $\oplus < FactR_i$,"satisfactory", $F_i(FactR_i) >$, (6)

where $\oplus$ – represents the fuzzy addition operator; F_i – membership functions, that calculates the reliability coefficient for a variable on a scale of [0; 1].

The nature of the membership function is determined by the type of the variable $FactR_i$, in the simplest case, by some number in the interval of [0; 1].

Digital maturity assessment factors, unlike risk factors, have an additive reinforcing character. Therefore, their influence on the overall assessment of digital maturity D is considered using production rules one by one:

$$FactMj \rightarrow D, \quad (7)$$

where $FactM_j \in \{D1, D2, D3, D4\}$.

An expanded presentation of the production rule is represented in through the following formula:

IF $FactM_j$ = "satisfactory" THEN $\oplus <$ D, "satisfactory", $F_i(D) >$, (8)

where $\oplus$ – represents the fuzzy addition operator; F_j – membership functions, that calculates the reliability coefficient for a variable on a scale of [0; 1].

The nature of the membership function is determined by the type of the variable $FactM_j$, in the simplest case, by some number in the interval of [0; 1].

In this case each production rule $FactM_j \rightarrow D$ forms some fuzzy estimation of reliability coefficient of digital maturity factor separately on the scale of [0; 1].

Competitive advantage (CA) is assessed in a similar way.

To evaluate the maturity and competitive advantages of a business model through the algorithm, it is necessary to set an acceptable threshold value of the reliability coefficient at which the variables receive a satisfactory value, as for example 0.8.

To accept a positive assessment of the final choice of the business model type, a threshold level of the reliability coefficient can also be set, for example it can be assumed as 0.8.

The implementation of a multi-criteria model for evaluating the selection of a business model type under conditions of fuzzy interpretation of qualitative factors using the tools of a knowledge-based production system, together with the preliminary classification of model types according to certain characteristics, will allow to formalise the decision-making process and justify the effectiveness of selected business model for the digital transformation of industrial enterprises.

5. Conclusions and future research areas

Based on a literature review and a primary research, seven key barriers that enterprises face during digital transformation and that are common to all industries, were identified: lack of appropriate funding, information security risks, insufficient digital skills of employees, insufficient maturity of current processes, internal resistance to changes, insufficient awareness of managers, lack of certainty over the future of digital standards. The resource theory was used as a managerial basis for determining the critical resources of a company used to achieve a sustainable competitive advantage, since each identified barrier is associated with one or more resources, for example: the lack of appropriate funding is a financial resource, the lack of digital skills among employees is a human resource, etc. According to the conducted research, it can be concluded that the importance of barriers varies depending on the size of the company, its level of income and its ability to independently introduce digital transformation. In this case, most often the barriers associated with inadequate funding and a lack of awareness among the leaders on the

topic of introducing and adapting digital transformation are perceived differently depending on these characteristics. The research also proposes a business model selection mechanism, which takes into account the assessment of the competitive advantages obtained (improvement of operational, financial and technical efficiency), digital maturity (the level of digital culture, staff competence, the quality of business processes and access to digital infrastructure) and risks (risk of non-receipt of expected income from the implementation of the business model, information security, reputational and personnel).

At the heart of the mechanism, it is proposed to use a knowledge-based system with a set of product rules that implement uncertain conclusions on the quality factors (variables). The novelty of the proposed mechanism of a business model selection is to improve the classification and develop a multicriteria mechanism for choosing a business model for an industrial enterprise, which is executed using a knowledge-based system incorporating fuzzy inference mechanism. In the future studies, it is recommended to study the barriers to digital transformation that cause the risks described in the mechanism in more details, and propose a system of key indicators for assessing the operational, financial and digital efficiency of the chosen business model.

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