The importance of Industry 4.0 technologies when selecting an ERP system – An empirical study

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Abstract: *The paper deals with the issue of the impact of the "Industry 4.0" concept on the process of selection of the enterprise resource planning (ERP) system. Firstly, review of the literature regarding the ERP system selection is presented, with the emphasis on the role of the new technologies in such selection. Secondly, the content of the term "Industry 4.0" is discussed, and put into context with the nature of ERP systems. The main part of the article then presents the results of the survey conducted among the medium and large industrial companies in the Czech Republic. Employees in the position of decision makers in the matter of selecting an ERP system were asked to participate. The survey used the form of questionnaire with close-ended questions with five-point scales, and investigated the attitude of the Czech manufacturing companies to the selected technologies of "Industry 4.0" and the importance of particular criteria for the selection of new ERP system. Investigated criteria were divided into 9 groups, where 5 of them were derived from previous research on the topic of ERP systems selections, and dealt with system price, portability, modularity, user experience and security. The remaining 4 groups were aimed at the selected technologies of "Industry 4.0" – big data, system integration, cloud computing and automatic identification and data capture. Kruskal-Wallis test and Neményi method of post-hoc analysis were used to compare the importance of particular criteria expressed by the respondents. The results show that although the companies are aware of the future challenges raised by the "Fourth Industrial Revolution," in the selection of ERP systems they still emphasise mostly the previously used criteria such as price or modularity. As for the criteria connected to "Industry 4.0," the ability of a system to deal with big data was assessed as the most important one.*

Keywords: *AIDC, big data, cloud technologies, ERP system selection, system integration.*

JEL Classification: *M15.*

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Introduction

Enterprise resource planning (ERP) systems are systems for the seamless integration of all the information flowing through the company, such as finance, accounting, human resource, supply chain, and customer information (Davenport, 1998). Their origins date back to the 1980s when the first Manufacturing Resource Planning systems (the so-called MRP II) began to appear. These enabled much more comprehensive planning compared to previous generations of enterprise information systems and they included not only materials but also other resources across the enterprise. The term "enterprise resource planning" itself, referring to a new generation of planning systems, was then first used by Gartner in 1990 (Katuu, 2020; McCue, 2020). As the use of information systems began to involve an increasing number of business processes, the control of these processes was gradually integrated into ERP systems, which were further developed as a result. Thus, the inclusion of supply chain management (SCM), customer relationship management (CRM), product lifecycle management (PLM) and other processes, along with the use of technological innovations associated with the Internet, have given rise to the post-2000 generation of ERP systems referred to as ERP II. At present, some authors speak of ERP Generation III, which is characterised by the transition to cloud technologies from the technological point of view, service-oriented architecture (Hurbean & Fotache, 2014), and from the functional point of view by an emphasis on marketing and communication with the outside world (Vasilev, 2013).

Nowadays, ERP systems are the backbone of an enterprise's IT landscape (Cebeci, 2009; Verville et al., 2007; Yang et al., 2007), where the information from all business processes is concentrated so that it can be comprehensively analysed and it can serve as a basis for further planning and management. The positive impact of a properly implemented ERP system on business performance is demonstrated by a number of studies, both from the beginning of this millennium, when ERP systems started to become massively popular in companies (e.g., Hunton et al., 2003) as well as from the present time (e.g., Aburub, 2018; AlMuhayfith & Shanti, 2020; Christophe, 2019; Saleh & Thoumy, 2020).

Nevertheless, in order for the system to perform its functions properly and bring the above benefits, it must first be successfully implemented. The implementation of an ERP system is a complex, resource-intensive and high-risk process (Cebeci, 2009; Verville et al., 2007), the failure of which can have a significant negative impact on the performance of a business (Cebeci, 2009; Efe, 2016), and in some cases even threaten its very viability (Davenport, 1998). Many authors have tried to identify the critical factors necessary for the successful implementation of an ERP system – e.g., the review summarising earlier papers on this topic compiled by Leyh and Sander (2015) or more recent studies by Chatzoglou et al. (2017), Wanchai (2017), or Ploder et al. (2021). Nonetheless, a number of experts agree that the most important prerequisite for successful ERP system implementation is the very selection of a suitable product (Gürbüz et al., 2012; Karsak & Özegul, 2009; Kilic et al., 2014).

At the same time, information and communication technologies are currently undergoing rapid changes associated primarily with the development of artificial intelligence, the internet of things (IoT), big data and other technologies. This development has far-reaching implications for the entire economy, which are collectively referred to as the "Fourth Industrial Revolution" (Rojko, 2017; Ross & Maynard, 2021), or the emergence of "Industry 4.0" (Rojko, 2017; Vaidya et al., 2018). It is clear that this technological revolution will bring, among other things, new requirements in terms of capabilities and functionalities of ERP systems, which will have to be capable of interacting with Industry 4.0 technologies. The question is, however, whether companies are currently aware of this fact when choosing an ERP system.

Therefore, our research, presented in this paper, has aimed to evaluate whether companies take into account the capability of each potential system to interact with Industry 4.0 technologies when selecting an ERP system, which of these technologies are regarded as the most important ones with respect to ERP systems, and what importance is attached to the capabilities of ERP systems in this area compared to other, traditional selection criteria.

1. Theoretical background

1.1 Literature review – Selecting an ERP system

Given the impact of ERP system implementation on the company's performance, it is not surprising that the issue of selecting a suitable ERP system systematically by evaluating the set of predefined criteria has received considerable attention in the professional literature. Nikolaos et al. (2005) presented the case study of a woodworking firm that used multi-criteria analysis methods to evaluate three groups of criteria in two phases, including the evaluation of the potential supplier, the system offered, and the specific offers received in the selection process. In the case study by Yang et al. (2007), describing the specific process of selecting an ERP system by a Taiwanese construction firm, the firm compiled a set of 36 evaluation criteria divided into ten groups (e.g., the system adaptability, the quality of consultants, or the amount of costs), on the basis of which the final supplier was then selected. Each criterion was given equal weight in this case. The case study method was also chosen by Verville et al. (2007), who focused on the particular cases of four different firms selecting the ERP system. Also, in these cases, the groups of evaluation criteria were always set at an early stage of the selection process, including the evaluation of a supplier (mainly in terms of its strength, the quality of service provided, and the price offered), the system functionalities offered and the technical sustainability of the system in the future. Nevertheless, the relative importance of each criterion for the particular cases is not mentioned by the authors.

Tsai et al. (2012) suggest measuring the success of the ERP system implementation using the SERVQUAL approach. In their model, they list 11 criteria that should be used to select a quality ERP system, and the quality of the implemented ERP system figures in the model as one of the two elements influencing the users' satisfaction. In order to verify the proposed model, the authors carried out a questionnaire survey, according to the results of which 4 out of 11 suggested selection criteria have a statistically significant impact on the system quality – namely, the consultant's suggestions, the certified high-stability system, the compatibility between the system and the business process and the provision of best practices. Asl et al. (2012) attempted to determine the relevant criteria for the ERP system selection using the Delphi method, whereby the experts identified a total of 14 criteria divided into 4 groups – price, product quality, vendor and software capabilities. The Shannon entropy was then used to compare the importance of these groups, with the criteria falling under the product quality group proving to be the most important, followed by the vendor group.

Many authors suggest the use of the analytical hierarchy process (AHP) as a suitable approach for constructing the structured model of evaluation criteria and determining their weights. Wei et al. (2005) validated this approach through a case study where nine attributes divided into two groups (system attributes and supplier attributes) were defined, which were then assigned weights based on the opinions of three decision-makers. Its functionality was rated as the most important system attribute, followed by flexibility, while in the case of the supplier, its technical capability was rated as the most important. A similar method was applied by Cebeci (2009), who used the AHP fuzzy approach (F-AHP) to determine the weights of individual criteria in his study. Karsak and Özogul (2009) also use AHP for a similar purpose, where they propose to identify the dependencies between the attributes of potential systems and the degree of meeting users' requirements using the fuzzy linear regression, to develop a model based on the linear programming principle describing the problem, and then to select the optimal system by way of weighted zero-one goal programming. Also in this case, the criterion of the functional fit of the system was evaluated as the most important, followed by the quality of service provided by the supplier. Kilic et al. (2014) also use the F-AHP approach to determine the weights of 12 criteria in total divided into three groups (technical, vendor-related, and financial criteria), and then use the TOPSIS approach to select the best alternative. The technical criteria were given the highest weight in the selection process. The approach of Kilic et al. (2014) is also used by Efe (2016), the only difference is the initial set of criteria, where Efe (2016) evaluates the total of 15 criteria divided into 4 groups, with the addition of the ease of use group compared to the previous study mentioned. In his second study, the price-related criteria came out as the most important. Bhatt et al. (2021) first determined a core set of 16 evaluation criteria based on the review of the existing literature on the topic, which they then subjected to the factor analysis. The factor analysis resulted in the identification of 4 constructs (vendor credibility, need fulfilment, user friendliness and security, the cost of deployment) and 10 specific criteria. The F-AHP approach was again used to determine their weights. In this study, the criteria related to the cost of the system were identified as the most important. The specific case of selecting a sustainable ERP system (S-ERP) was addressed by Lacurezeanu et al. (2021), who established the set of 11 selection criteria in total. Compared to the traditional criteria taken from other studies, such as the price or offered functionalities, the set additionally included criteria related to sustainability, e.g., in the form of feasibility or energy efficiency. The AHP approach was also used to determine the criteria weights in this case, of which the quality of documentation was the most important, followed by the level of system supplier's support and price.

The use of advanced quantitative methods to evaluate and select the optimum ERP system was also proposed by Boltena et al. (2011), who, in their work focusing on developing countries' issues, discussed the possibility of developing a neuro-fuzzy based selection model combining the elements of existing models with the experience from developing countries.

Gürbüz et al. (2012) based their approach on the set of 16 selection criteria divided into 3 groups – criteria related to the system vendor, criteria related to the specific customer, and criteria related to the potential software itself. Subsequently, they determined the relative importance of these criteria through the analytic network process (ANP) and the MACBETH method, and then developed an evaluation function based on the Choquet integral to assess the suitability of the system depending on the selected criteria. The criteria associated with the vendor were found to be the most significant in their study. The use of ANP to determine the weights of individual criteria is also suggested by Kilic et al. (2015), who work with 3 basic groups of criteria – business criteria (or criteria associated with the current market position of individual potential systems), cost criteria and technical criteria. Based on the opinions of surveyed experts, the cost criteria group was clearly evaluated as the most important by ANP. The authors then used the PROMETHEE method for the particular evaluation of individual potential software.

López and Ishizaka (2017) introduced the use of a two-stage ERP system selection method based on two sets of criteria. The first step involves the selection of suitable ERP system suppliers, namely on the basis of 6 criteria related purely to the supplier and not to the system offered. Based on these criteria, the group analytic hierarchy process sorting (GAHPSort) method was used to divide the potential ERP system suppliers into two groups – compliant and non-compliant. The systems offered by the compliant vendors were then evaluated in terms of 22 criteria divided into 4 groups (system-related criteria, criteria related to the system adoption, cost criteria and criteria related to the implementation time). The relative importance of these criteria was then determined using the ANP approach. The group of system-related criteria was evaluated as the most important, with the highest importance given unequivocally to the system security criterion.

Conversely, a different approach to the selection of ERP systems was documented by Poon and Yu (2010), in whose study from the Asia-Pacific region, only one of the four firms defined the formal list of evaluation criteria. According to the authors' findings, the remaining firms evaluated the system only in terms of certain general priorities, which, however, were not precisely defined.

As the literature review shows, the vast majority of authors present the system of selection criteria in their studies, in some cases further divided into sub-criteria, usually divided into several groups. Their relative weights are then determined, as a rule, on the basis of expert opinions obtained in the form of interviews or questionnaire surveys conducted among employees whose opinions can be considered relevant in the ERP system selection. The proposed groups of criteria typically include price-related criteria, technical criteria and criteria related to the evaluation of a particular contractor. However, the relative importance of specific criteria and the groups of criteria vary between individual studies to a large extent, and it is not possible to identify a specific criterion or group that would prove to be decisive in the majority of papers based on the available literature.

However, none of the sets of criteria presented in the referenced studies includes a group that specifically focuses on the technologies associated with Industry 4.0. Nor is this issue systematically reflected in the groups of technical criteria.

1.2 Literature review – Industry 4.0 and ERP systems

The issue of the ERP system readiness for the fourth industrial revolution is currently being given considerable attention in corporate practice, both by individual ERP system suppliers, who declare the readiness of their products for cooperation with Industry 4.0 technologies (Graney, 2017; SAP, 2022), and also by leading consultancy firms, which are mapping the current trends in this area (Accenture, 2020; Delloite, 2022).

On the other hand, the complex relationship between ERP systems and Industry 4.0 has been addressed by a relatively small number of papers so far in the academic sphere. The issue of ERP system readiness for Industry 4.0 has been systematically examined by Basl (2018a; 2018b) and Basl and Nováková (2019), who focuses on both maturity models, which express the readiness of a company (or system) for the fourth industrial revolution, and the way in which the makers of individual ERP systems react to the development of technologies related to Industry 4.0.

Haddara and Erlagal (2015) conducted research that combined the opinions of IT managers, the representatives of ERP vendors and the representatives of integration partners in order to obtain a comprehensive view of the readiness of ERP systems for Industry 4.0. The systems under consideration – SAP and Oracle JD Edwards – have come out of this research as well-prepared for Industry 4.0. Cocca et al. (2018) also arrived at the same conclusion regarding the SAP ERP system. SAP is also used as an example by Perera et al. (2018), who use the term "i-ERP" in their study to refer to the system capable of using machine learning, working with large volumes of data, and creating complex analyses on the automated basis. The authors conclude that SAP is capable of offering such functionalities. The paper also identifies the potential of using individual Industry 4.0 technologies within ERP systems.

Maistorovic et al. (2020) present the model of ERP system suitable for the Industry 4.0 environment, emphasising the system's capabilities in processing large volumes of data in real time.

Of all the studies above, only the one presented by Basl and Nováková (2019) contains a model with defined criteria for assessing the readiness of ERP system for Industry 4.0. However, it is a relatively simple model comprising only 4 criteria, which is in no way related to the issue of the ERP system selection. Thus, the authors of this paper are convinced that there is a research gap in evaluating the extent of ERP system readiness for the fourth industrial revolution, and its inclusion in the ERP system selection process.

1.3 Content of Industry 4.0

The term "Industry 4.0" was originally introduced at the Hannover Fair in 2011. Since then, however, it has become a buzzword that is used in a wide range of marketing and professional documents, but with no generally accepted clear definition of its content (Inkerman et al., 2019; Mubarok, 2020).

Therefore, the definition of specific technologies constituting the fourth industrial revolution is not uniform in the existing professional literature, and the list of technologies varies depending on the particular author's opinion. Some authors emphasise the importance of cyber-physical systems (CPS), the internet of things (IoT) and cloud computing (e.g., Zhong et al., 2017), while others consider augmented reality (Egger & Masood, 2020), digital twin (Novák et al., 2020), collaborative robots (Schmidbauer et al., 2020) or blockchain (Esmaeilian et al., 2020) to be fundamental.

For the purposes of the research presented here, it was thus necessary to first determine a core set of Industry 4.0 technologies from which it would then be possible to identify technologies with a direct relationship to ERP systems that could play a role in the system selection.

The so-called "9 Pillars of Industry 4.0" defined by Rüssman et al. (2015) and subsequently adopted by a number of other authors (e.g., Erboz, 2017 or Silva et al., 2020) were used as this core set of technologies in our study. This term refers to nine technologies (or technological areas) that are the basic building blocks of Industry 4.0. These technologies are big data, autonomous (collaborative) robots, simulation, system integration, internet of things, cybersecurity of cyber-physical systems, cloud technologies, additive manufacturing and augmented reality.

In some cases, the tenth pillar called "other technologies" is added to these general 9 pillars. However, it only includes technologies with a narrower focus, applicable exclusively in certain industries (Büchi et al., 2020), and hence it was not relevant for our research. Nonetheless, the authors of this paper believe, based on the analysis presented in Polívka and Dvořáková (2019), that there is one more general technology used across industries, the development of which has a similar impact on the course of the fourth industrial revolution as the nine pillars mentioned above. This technology is "automatic identification and data capture" (hereinafter referred to as AIDC), which has been added to the nine pillars mentioned in the previous text for the reasons mentioned above.

2. Research methodology

2.1 Identifying relevant technologies

Not all of these 10 fundamental technologies are directly related to the ERP systems, though. The ERP systems serve as central databases in which data from individual business processes are concentrated and then evaluated to serve as a basis for further planning. At the same time, the processes related to administration, such as invoicing, accounting or sourcing, are usually recorded and managed within the ERP system. On the contrary, the ERP systems usually do not replace all existing IT systems used by the company, but typically coexist with other, narrow-oriented systems (Azevedo et al., 2014; Kähkönen et al., 2014). The reason is that the ERP systems are not primarily designed, and in some cases, due to their logic based on complex databases with extensive relations not even technically suitable for recording and managing operational processes of a physical nature, such as production or logistics. For these purposes, there are specialised, narrowly focused solutions, e.g., in the form of manufacturing execution systems (MES), warehouse management systems (WMS), etc., which are subsequently integrated with the ERP systems (compare Oman et al., 2017 or Wozniakowski et al., 2018).

Therefore, the Industry 4.0 technologies directly related to the ERP systems are those of the above pillars that are primarily related to either the storage and evaluation of data within the central database or the management of processes related to administration. The technologies identified as such by the authors are big data, system integration, cloud technologies and automatic identification and data collection (AIDC)

As for the big data technology, in order to use it, the organisation must be able to collect large volumes of primary data and to store and evaluate this data. In all these phases, ERP systems play an irreplaceable role. As the administrative processes are usually conducted within ERP systems, the data tracking these processes are acquired directly in them, which means that ERP systems serve as one of the primary sources of big data. In the phase of storing and evaluating of the data, the ERP systems, as the central databases of the companies, must contain appropriately designed, sufficiently robust data structures, and have either powerful tools for their evaluation, or at least be able to cooperate with specialized analytical tools.

Concerning the system integration, ERP systems are among typical participants of the integration. From the intracompany point of view, the ERP system serves as a central node, to which the narrowly focused, one-purpose solutions like MES or WMS are connected by the intercompany system integration. Intercompany system integration then concerns primarily mutual business communication, which is from a data point of view represented by the circulation of orders and invoices. These entities are typically registered and processed within the ERP system.

As for the usage of cloud computing technology, ERP system, as the central node of the IT landscape of the company, contains a large amount of data, for the effective processing of which local resources may not be sufficient. At the same time, unlike the physical processes management systems such as MES or WMS, ERP system is typically not a business critical application, the unavailability of which would lead to the complete stop of business operation, inventory losses, etc. ERP systems can be therefore definitely identified as suitable candidates for the transfer from on-premise to cloud hosting, which is proved by the fact that the current version of lead ERP systems such as SAP, Microsoft Business Central or Infor are primarily cloud-oriented.

Although the AIDC technology is seemingly connected mainly with the physical sensors, which read the data from the real world, it is necessary to stress out that the acquisition of raw data is only one part of the whole technology. The other part, which consists of registration of the real entities, the data of which were automatically acquired, and the subsequent management of these entities (i.e., use of the data describing stock levels acquired by the scanning of barcodes in planning, use of the data representing invoice acquired by OCR in accounting, etc.), on the other hand, falls within the competence of ERP systems.

As for the other technologies of the fourth industrial revolution, they are primarily connected either with physical processes (such as autonomous robots or additive manufacturing), or with their software control (such as simulations or cyber-physical systems) and the acquisition of data for this control (via internet of things). These technologies were therefore omitted from the research presented in this paper, which was focused only on the four technologies directly related to the ERP systems, respectively on the importance given to these technologies by decision makers when selecting an ERP system in comparison with the traditional criteria discussed in the literature review chapter.

2.2 Design of the survey

In order to obtain comprehensive information on the extent to which Industry 4.0 technologies are currently used in companies and how these technologies influence the requirements placed on the ERP systems, a questionnaire survey was designed and conducted in companies. Three criteria were applied in the selection of the basic survey population.

The first criterion was geographical, the survey was carried out in companies based in the Czech Republic. The second criterion was the size of companies, where only companies falling under the category of medium-sized and large ones according to the EU classification were selected for the survey. The size criterion has been used to define the basic set because, mainly due to the investment costs involved, the implementation of Industry 4.0 technologies is still mainly a matter of large and medium-sized enterprises (Doyle & Cosgrove, 2019; Masood & Sonntag, 2020). Similarly, the ERP systems are mainly used in medium-sized and large companies, while micro and small companies often make do with simple accounting systems. Therefore, the survey on the defined topic in micro and small enterprises would not provide relevant information. The last criterion was the sector in which the companies operate. The companies of the manufacturing industry, i.e., companies falling under section C of the Czech Statistical Office's classification of economic activities (CZ-NACE), were selected for the basic set. The reason for selecting the specific sector is the fact that the concept of Industry 4.0 is most closely linked to manufacturing and primarily to the so-called "smart factories" (Alcácer & Cruz-Machado, 2019). It is, therefore, logical to examine the current state of the use of Industry 4.0 technologies in this industry.

The questionnaire was divided into three parts. The purpose of the first part was to find out what knowledge of Industry 4.0 the respondents have and what their opinion on the importance of this phenomenon for the sector in which their company operates is. The second part dealt with the current use of the four Industry 4.0 technologies defined above in the respondents' companies. The third part of the questionnaire then presented respondents a set of potential criteria for selecting an ERP system, divided into nine groups. The proposed set included both the "traditional" technical criteria used in previous studies concerning the topic and the groups of criteria comprising individual Industry 4.0 technologies. To ensure completeness and comparability, the set of criteria related to price was also included. On the other hand, the criteria evaluating the quality of suppliers were not included in the set, because they do not concern the attributes of the system as such. The respondents were asked to evaluate the importance of these criteria in the questionnaire.

The questionnaire used close-ended questions with five-point scales of possible responses. Each point on the scale of possible responses was always verbally specified in order to reduce the possibility of misunderstanding of the meaning by the respondents and to ensure construct validity (Hendl, 2017). So as to ensure that the questionnaire is comprehensible and well-formed, it was piloted on two experts from the field of ERP systems. Their comments were reflected in the final design of the questionnaire.

The questionnaire survey was carried out in the period from March to July 2021. Although there may be legitimate doubts about the actuality of such data, it is necessary to stress out that the life cycle of the ERP system generation is typically quite long term with the timespan longer than 10 years – for example first version of previous SAP generation, SAP ERP Central Component, had been publicly released in 2004 and it was replaced by the current generation, SAP S4, no sooner than in 2015 (STechies, 2021). Decision making of both the ERP vendors, regarding the development plans for next generation of their system, and the customers, regarding the plans for acquisition of new ERP, are therefore corresponding to this timespan – the previous version of SAP is planned to be supported by the end of 2027 and the migrations of customers to the current version are expected to proceed until this deadline (Schneider, 2021) which means that even the vendor of the SAP ERP expects that for some customers the decision making process concerning the migration to new version (or, of course, the transition to another ERP system) can take up to 12 years. Given such a timespan of the decision making regarding the ERP systems, the authors of this paper believe that even the 2 years old data are still valid.

Companies matching the above declared criteria were identified using the Albertina database, which collects data about all enterprises in the Czech Republic. The questionnaire was sent out to companies by e-mail in the form of personalised addressing sent to the contacts listed on the websites of individual companies. The firms were also asked to have the questionnaire completed by employees who would be in the position of decision makers if the firms were to select a new ERP system. Typically, these were employees in the position of IT managers, finance directors, etc. In total, 1,758 companies were approached, asking for their participation in the survey. The questionnaire was completed by the representatives of 68 companies; hence, the return rate was about 4%.

3. Results

3.1 Knowledge of Industry 4.0 and views on its future performance

The first part of the questionnaire has aimed to find out how familiar the respondents are with the issues of the fourth industrial revolution and how they think this revolution will influence the industry in which their company operates. For this purpose, the following questions were asked: i) How would you subjectively assess your level of understanding of the Industry 4.0 concept?; ii) Do you expect Industry 4.0 to significantly influence the industry in which your company operates in the next 5 years?

The exact wording of the responses, together with the frequencies of each response, is shown in Tab. 1.

As the results in Tab. 1 show, the term "Industry 4.0" is now well established, at least in the environment of manufacturing companies. Only 8 respondents have no concrete idea about the meaning of the term. On the contrary, 29 out of 68 respondents believe they have a good or very good understanding of the concept content – they can name concrete

Tab. 1: Responses to Questions 1 and 2 – knowledge and expected future significance of Industry 4.0

Question 1: How would you subjectively assess your level of understanding of the Industry 4.0 concept?		Question 2: Do you expect Industry 4.0 to have a significant impact on the industry in which your business operates in the next 5 years?	
Possible responses	**Absolute frequency of responses**	**Possible responses**	**Absolute frequency of responses**
1 – I do not know this concept at all or have no concrete idea about it.	8	**1** – Definitely not	3
2 – I understand it rather poorly. I only understand the basic idea of the concept.	0	**2** – Rather not	6
3 – I understand it moderately. I understand the idea of the concept, I can list some typical attributes and technologies of "Industry 4.0."	31	**3** – I have no clear opinion	14
4 – I understand it quite well. I understand the idea of the concept, I can list the majority of typical attributes and technologies of Industry 4.0, I have an idea of the links between the different technologies.	22	**4** – Rather yes	30
5 – I understand it very well. I understand its overall idea, I can list its typical characteristics and technologies and I understand the links between them.	7	**5** – Definitely yes	15
Average	3.29	Average	3.71

Source: own

technologies associated with Industry 4.0 and understand the links between them.

In terms of the potential impact of the fourth industrial revolution on the future, 45 out of 68 respondents think that Industry 4.0 will have a significant impact on their industry in the next five years. In contrast, only 9 respondents believe that the industry in which their company operates will be more or less unaffected by the fourth industrial revolution.

Although the answers to both questions seem to be consistent with each other, a detailed look at the results shows that the set of respondents who have no specific idea about Industry 4.0 overlaps with the set of respondents who do not think that Industry 4.0 will have an impact on their industry in the future only in the case of two respondents. On the contrary, 4 of the respondents who assessed their knowledge of Industry 4.0 as the worst answered "Definitely yes" to the second question.

In order to evaluate whether there is a general dependence between the answers to the first and second questions, the following null hypothesis was tested:

$H1_0$: Answers to Questions 1 and 2 are independent of each other.

Hypothesis was tested against the right tailed alternative hypothesis, which represents the positive correlation between the answers to both questions. As the responses to Question 2 had failed the normality test because of their skewness, nonparametric Spearman's rank correlation coefficient, which is robust against such a situation, was used to test this hypothesis. Formula of this coefficient is:

$$r_s = 1 - \frac{6\sum_{i=1}^{n}(R_i - Q_i)^2}{n(n^2-1)} \quad (1)$$

where: n – the number of paired ordinary random variables X and Y; R_i – the rank of random variable X_i; Q_i – the rank of random variable Y_i.

The computed value of the coefficient was then tested against the critical value determined by formula:

$$r_s^*(\alpha; n) = \frac{u_{1-\alpha}}{\sqrt{n-1}} \quad (2)$$

where: $u_{1-\alpha}$ – the $(1 - \alpha)$ quantile of normalised normal distribution.

The value of the coefficient was computed to be 0.11, while the critical value of the r_s^* is 0.20 on significance level $\alpha = 0.05$, respectively 0.28 on $\alpha = 0.01$. The $H1_0$ hypothesis, therefore, cannot be rejected. Therefore, it was not possible to identify a correlation between the respondent's level of knowledge of the Industry 4.0 concept and the importance they attach to it in the future. In other words, there are both the respondents who have good knowledge of Industry 4.0, but at the same time, they do not believe that Industry 4.0 will influence the industry in which they operate in the near future, and the respondents who expect a significant impact of Industry 4.0 in the next five years, yet without being familiar with the concept.

3.2 Current use of selected Industry 4.0 technologies in manufacturing companies

The second part of the questionnaire looked into the current use of the four Industry 4.0 technologies defined in the preceding text, which are directly related to the ERP systems in the surveyed companies. For the purpose of this question, the system integration technology was divided into intracompany (i.e., integration of various information systems in one company) and intercompany (i.e., integration of information systems among business partners in supply-chain) integration, which were evaluated individually. The results of this part have been analysed and discussed in detail in the study by Polívka and Dvořáková (2021), and only a brief summary of the answers will be presented here for the sake of clarity. It will be referred to as "Question 3" in the following text for easier identification. The results for Question 3 are shown in Tab. 2.

The survey has shown that the most widely used technology of the fourth industrial revolution directly related to the ERP systems is currently the intracompany system integration, with more than 70% of the respondents evaluating its extent of use as 4 or 5. The fact that the use of intracompany system integration is greater in the surveyed companies than in the case of other technologies, and is not only a sample bias, was also confirmed by the statistical analysis. As the obtained data did not pass the normality test, a nonparametric approach, based on the use of the Kruskal-Wallis test and the Neményi method, was used. The general principles of which will be described in following sections.

Tab. 2: Responses to Question 3 – current use of the selected Industry 4.0 technologies

Technology	Frequency of responses on the scale from 1 to 5 (1 = no technology is used at all, 5 = technology is used as intensively as possible)					Average
	1	2	3	4	5	
A – Big data	9	12	29	11	7	2.93
B – Intracompany system integration	4	4	12	19	29	3.96
C – Intercompany system integration	24	17	8	16	3	2.37
D – Cloud solutions	14	19	29	4	2	2.43
E – AIDC	26	11	15	14	2	2.34

Source: Polívka and Dvořáková (2021)

Looking at the data in more detail then shows that, with the exception of intracompany system integration and the cloud, all other technologies are significantly (at levels 4 and 5) used by about a quarter of companies. By contrast, only 6 respondents reported the higher use of cloud technologies in the questionnaire, while almost half of the companies make little or no use of cloud option (levels 1 and 2).

3.3 Importance of Industry 4.0 technologies in selecting the ERP system

The respondents were presented with a total of 27 potential criteria for selecting the ERP system divided into 9 groups of 3 criteria each in the third part of the questionnaire. For better clarity, the individual groups and criteria were marked with the notation from 1.I. to 9.III. Eight groups concerned the technical and functional attributes of the system, four of which reflected the fourth industrial revolution technologies directly related to ERP systems. The ninth group included criteria related to the system price. The list of groups and individual criteria, including their precise definitions, are available from authors upon request.

The respondents had to evaluate the importance of each criterion in the event that they were currently selecting a new ERP system on a scale of 1 to 5, where the value of 1 represented "not at all important," while the value of 5 represented "very important." If the respondent was unable to evaluate the importance of the particular criterion, they could use the response "I cannot judge it." Two respondents out of 68 chose this answer for all the criteria offered. Their responses were therefore excluded from further processing, resulting in a total of 66 sets of responses. In the other sets of responses, the statement "I cannot judge it." occurred in 43 cases in total, which accounts for 2.41% of all responses. In view of the low relative number of these ambiguous responses, the "I cannot judge it." values were replaced by the modal response value for the given criterion in order to obtain a balanced sample size for the further statistical processing. For the sake of clarity of the following text, this question will be referred to as "Question 4." The aggregated results for the individual criteria and their groups are presented in Tab. 3.

As is evident from the table, the respondents placed the greatest emphasis on the technical criteria related to security, both in terms of securing the database against attacks from outside the system and in terms of securing access to data within the system. Considerable emphasis is put also on the modularity of the system. In contrast, the least importance is, perhaps somewhat surprisingly, attached to the possibility to access the system from different types of devices, either through native clients for different operating systems or through a web application. Similarly, the relatively little weight currently placed on the cloud may seem surprising.

The results were then put to statistical hypothesis testing in order to verify whether the different weight placed on each group of criteria is indeed a statistically significant phenomenon or whether it is just a random deviation within the sample. Null hypothesis:

$H2_0$: The importance of a particular criteria group does not vary significantly.

Tab. 3: Responses to Question 4 – importance of individual criteria for selecting the ERP system

Group of criteria	Criterion average in the group			Group average
	.I	.II	.III	
1 – Price criteria	3.88	3.82	3.76	3.82
2 – Portability	2.20	2.70	3.06	2.65
3 – Modularity	3.65	3.97	4.14	3.92
4 – User experience	3.44	3.77	3.68	3.63
5 – Security	4.05	3.76	4.05	3.95
6 – System integration	3.91	2.73	2.85	3.16
7 – Big data	3.68	3.36	3.47	3.51
8 – Cloud	3.14	2.85	3.14	3.04
9 – AIDC	2.85	3.62	3.39	3.29

Source: own

As the obtained data did not pass the normality test, the nonparametric Kruskal-Wallis test, which check whether the distribution functions of several random variables are identical, was chosen as a testing instrument for this hypothesis. Its test criterion can be calculated according to the following equation:

$$H = \frac{12}{N(N+1)} \sum_{i=1}^{C} \frac{R_i^2}{n_i} - 3(N+1) \qquad (3)$$

where: C – number of groups; n_i – number of observations in the group; N – total number of observations in all groups; R_i – sum of the order of members in the i-th group.

In this case, the value of the test criterion was 220.01. This value was then compared with the critical value given by the χ^2 distribution with (C – 1) degrees of freedom, which takes the value of 20.09 at the $\alpha = 0.01$ significance level. Since the value of the H test criterion exceeds the critical value, it was possible to reject the null hypothesis $H2_0$. The differences between the evaluation assigned by respondents to each group of criteria are, therefore, statistically significant.

Nevertheless, the Kruskal-Wallis test only proves that some of the examined random variables have different distribution functions. However, it cannot identify in itself which pairs of variables are different from each other and which are identical in this respect. In order to obtain this information, the post-hoc analysis was therefore carried out using the Neményi method, which allows for the mutual comparison of individual pairs. The principle of this method is to compare the absolute value of the difference in the average order of each of the two groups examined with the test criterion value, which is calculated for the given sampling range according to the following equation:

$$K = q_\alpha(C,\infty)\sqrt{\frac{1}{12}C(C_m+1)} \qquad (4)$$

where: $q_\alpha(C, \infty)$ – critical value of the C distribution of independent random variables with the normalised normal distribution at the α significance level; m – sampling range in one group.

In our case, the value of the testing criterion at the significance level $\alpha = 0.01$ is 185.69 and 160.43 at the significance level $\alpha = 0.05$.

The results of the Neményi method for the mutual comparison of individual groups of criteria are presented in Tab. 4. The differences significant at the $\alpha = 0.05$ level are marked with one asterisk, and the differences significant at the $\alpha = 0.01$ level with two asterisks. Given the symmetry of the values along the diagonal, the values below the diagonal are not filled out.

As the results presented in Tab. 4 show, the importance of the four groups of criteria that were identified by the respondents as the most important for selecting the ERP system do not differ from one another in terms of statistical significance. These are the groups of criteria related

Tab. 4: Results of the Neményi method for the mutual comparison of the significance of individual criteria

Group of criteria	1 Price criteria	2 Portability	3 Modularity	4 User experience	5 Security	6 System integration	7 Big data	8 Cloud	9 AIDC
1 – Price criteria	0	498.03**	42.09	84.96	70.01	281.22**	139.48	346.89**	230.88**
2 – Portability		0	540.12**	413.07**	568.04**	216.81**	358.55**	151.14	267.15**
3 – Modularity			0	127.05	27.92	323.31**	181.57*	388.97**	272.97**
4 – User experience				0	154.97	196.27**	54.53	261.93**	145.93
5 – Security					0	351.23**	209.49**	416.90**	300.89**
6 – System integration						0	141.74	65.66	50.34
7 – Big data							0	207.40**	91.40
8 – Cloud								0	116.00
9 – AIDC									0

Note: *The differences significant at the α = 0.05 level; **differences significant at the α = 0.01 level.

Source: own

to modularity, user experience, security, and price. Thus, these groups of criteria form a kind of block of the individual components which are of similar significance in selecting the ERP system, while also being perceived as more significant than the other groups of criteria examined.

As for the groups of criteria related to the Industry 4.0 technologies, none of them unambiguously fall under the block of the most significant criteria defined above. However, with some reservation, the group of criteria related to big data could be included in this block, the importance of which differs only in comparison with the criteria related to security, while the differences in relation to the groups of criteria related to price, modularity and user experience are not statistically significant.

The groups of criteria related to the capability of the ERP system to interact with Industry 4.0 technologies then constitute the second, less important block. Again, the differences between the importance attached to each group of criteria (i.e., to each Industry 4.0 technology) in this block are not statistically significant, except for the difference between big data and cloud technologies.

The criteria related to the portability of the ERP system then form the last, separate block, which have been found to be less statically significant for the selection of the ERP system compared to all other groups except for the group of cloud technologies. However, even in this case, the absolute value of the difference in their average order is very close to the critical *K* value at the 0.01 significance level.

The analysis of the data obtained from the respondents, therefore, shows that when selecting the ERP system, its capability to interact with the Industry 4.0 technologies is still attached relatively less importance compared to the traditional technical criteria (with the exception of portability) and the price of the system. Within the Industry 4.0 related criteria, those related to big data have been identified as the most significant. On the other hand, whether and under what conditions the ERP system is ready for running in the cloud is assigned relatively less importance by the respondents.

3.4 Importance dependence of the criteria related to Industry 4.0 on other facts

Having evaluated the importance that the respondents attach to the capabilities of individual potential systems to interact with the Industry 4.0 technologies when selecting the ERP system, the question arises whether this importance depends on the respondent's answers to the questions from the preceding parts of the questionnaire, which mapped both the respondents' opinion on the future importance of Industry 4.0 and the existing extent of the use of Industry 4.0 technologies by the respondent's company. In other words, whether the particular respondent's answers to Questions 2 and 3 correlate with the evaluation given to criteria 6.I.–9.III. within Question 4.

The existence of such correlations was determined using the Spearman's correlation coefficient. The results of the Spearman's coefficient, evaluating the correlation between the respondents' answers to Question 2 (the expected future importance of Industry 4.0 in the respondent's industry) and the importance assigned by the respondent to criteria 6.I.–9.III. (i.e., to all criteria related to Industry 4.0) in Question 4, are presented in Tab. 5.

Whether the value of a particular correlation coefficient is statistically significant (i.e., whether it is possible to reject the null hypothesis of its insignificance in favour of the right-tailed alternative hypothesis) was tested by comparing the computed value with the critical value r_s^* computed by Formula (2). The correlation coefficient values significant at the α = 0.05 level are marked with one asterisk, and the differences significant at the α = 0.01 level with two asterisks.

A rather surprising conclusion can be drawn from Tab. 5. Some correlation between the respondent's expectations of the future importance of Industry 4.0 and the weight they have attached to particular Industry 4.0 related criteria when selecting the ERP system can be found. Nevertheless, this correlation is rather weak, as it is significant only on 0.05 significance level, and it is close to the critical value in all cases. What is more, it does not even apply on all criteria.

Tab. 6 then provides the results of the Spearman's rank correlation coefficient for the answers to Question 3 (the extent of the use of individual Industry 4.0 technologies in the respondent's company) and the evaluation of criteria 6.I.–9.III. in Question 4. Since the system integration technologies in Question 3 were divided into intra-(A) and inter-(B) company integration in order to obtain more detailed information on the use of specific Industry 4.0 technologies, the dependence of the evaluations of criteria 6.I.–6.III. in Question 4 on the extent of the use of the given technologies was also examined separately. Again, the asterisks notation was used to identify the statistically significant correlations.

Tab. 5: Correlation between the expected future importance of Industry 4.0 and the importance of criteria related to it when selecting the ERP system

Group of criteria	System integration			Big data			Cloud technologies			AIDC		
Criterion	**6.I.**	**6.II.**	**6.III.**	**7.I.**	**7.II.**	**7.III.**	**8.I.**	**8.II.**	**8.III.**	**9.I.**	**9.II.**	**9.III.**
r_s	0.24*	0.23*	0.12	0.15	0.20*	−0.03	0.20*	0.21*	0.07	0.07	0.15	0.25*

Note: *The correlation coefficient values significant at the α = 0.05 level; **differences significant at the α = 0.01 level.

Source: own

Tab. 6: The dependence between the existing usage level of each Industry 4.0 technologies in the company and the importance of the criteria related to them when selecting the ERP system

Group of criteria	A – Intracompany system integration			B – Intercompany system integration			C – Big data		
Criterion	**6.I.**	**6.II.**	**6.III.**	**6.I.**	**6.II.**	**6.III.**	**7.I.**	**7.II.**	**7.III.**
r_s	−0.02	0.00	0.29**	0.15	0.10	0.18	0.34**	0.60**	0.40**
Group of criteria	**D – Cloud technologies**			**E – AIDC**					
Criterion	**8.I.**	**8.II.**	**8.III.**	**9.I.**	**9.II.**	**9.III.**			
r_s	0.50**	0.68**	0.55**	0.22*	0.29**	0.32**			

Note: *The differences significant at the α = 0.05 level; **differences significant at the α = 0.01 level.

Source: own

Tab. 6 shows that in case of big data (C), cloud technologies (D) and AIDC (E), there is a strong and significant dependence between the fact whether the respondent's company uses these technologies and the importance the respondent would attach to its capability when selecting the ERP system. On the other hand, this correlation has not been identified for the other Industry 4.0 technologies.

4. Discussion

The evaluation of the data obtained through the questionnaire survey suggests that the Industry 4.0 concept is already well established in the environment of manufacturing companies, at least at the level of the Czech Republic. In the majority of cases, employees in positions where they can influence the further development of the IT landscape of individual companies claim to be quite familiar with this concept and expect that the fourth industrial revolution will significantly influence the industry in which the company operates within the next 5 years. At the same time, the technology of intracompany system integration, which is considered to be one of the cornerstones of Industry 4.0, is widely used in companies, and also the technologies of intercompany system integration, big data, and AIDC are intensively used by about a quarter of companies. However, it is necessary to stress out that these results are based on the subjective claims of the respondents. On the contrary, up-to-date research of Castelo-Branco et al. (2023), which is based on the Eurostat data, shows that the level of implementation of Industry 4.0 and the preparedness to this concept in the Czech companies is rather low.

As for the importance of particular criteria in the process of evaluation of candidate ERP systems, security, modularity, price-related criteria and user-experience were assessed as the most important by the respondents, with only small, statistically insignificant differences among them. These results are in general consistent with the findings of papers discussed in the literature review, the results of which are rather mixed. The security aspects were previously identified as extremely important by the research of Kilic et al. (2014), which also stressed out the role of user experience and modularity, and by López and Ishizaka (2017). The importance of criteria corresponding to modularity of system and provided user experience was then emphasised by Wei et al. (2005), Karsak and Özegul (2009) and Asl et al. (2012), while the role of price-related criteria was highlighted by Kilic et al. (2015), Efe (2016) and Bhatt et al. (2021). Results of our research, therefore, confirm that potential customers expect the ERP system to possess a complex set of features and characteristics. This finding may suggest to ERP vendors that they should prefer balanced, complex development of their system rather than focus on one particular direction.

In comparison with these traditionally used criteria, the capability of candidate ERP systems to interact with the Industry 4.0 technologies would only play a secondary role in the selection of the new system. In other words, although employees in the positions from which they can influence the future of information systems in their company generally understand the importance of the fourth industrial revolution, they have not yet fully translated this understanding into their demands on the ERP system capability and functionality. This is also indicated by the lack of correlation between the expected future impact of Industry 4.0 and the importance attached to the capability of the ERP system to interact with the Industry 4.0 technologies. It can be therefore stated that even the IT managers and key users of the information systems in the Czech manufacturing companies do not fully appreciate the potential benefits of the complex integration of the individual Industry 4.0 technologies with the ERP system. This may seem rather surprising, because for example Slusarczyk et al. (2021) show positive correlation between the knowledge of Industry 4.0 and the likeliness of implementing and exploiting its technologies.

Another remarkable finding is that although the surveyed companies use the technology of intracompany system integration massively, they would not attach much importance to this capability of potential system when selecting the new ERP system. The same applies to the intercompany system integration, even though its usage is not as widespread.

On the other hand, in the case of AIDC, cloud computing and big data technologies, it is evident that the company which already uses these technologies would place an emphasis on being able to continue using them effectively with the new system when selecting the new ERP system. A possible explanation for this different approach is the fact that although the system integration is classified as the Industry 4.0 technology, it is not really new in corporate practice. It is, therefore, possible that the respondents perceived the capability of the ERP system to use these technologies as so self-evident that they did not feel the need to assign high importance to them. Conversely, the technologies of cloud and big data are not yet fully supported by all the relevant ERP systems on the market due to their relative novelty. Thus, if a company is interested in using them, it must place specific emphasis on the capability of the system in these areas when selecting the ERP system. However, this is only one possible explanation, and this different approach to individual Industry 4.0 technologies is certainly a promising topic for further research.

The comparatively low preference for cloud technologies certainly deserves specific attention. Not only is their existing level of use in the respondents' companies relatively low, but the low importance of criteria 8.I.–8.III. in the potential selection of the new ERP system indicates that the respondents do not plan to move their information systems to the cloud in the future. On the one hand, it might seem consistent with the conclusions of some authors, who claim that cloud ERP systems are suitable primarily for small enterprises, while the medium and large companies still prefer on-premise solutions (Marinho et al., 2021; Perera et al., 2018). On the other hand, this cloud skepticism among respondents contradicts both the general global trend of cloud services development and the trends directly in the field of ERP systems, where, e.g., the current generation of SAP or Microsoft Business Central are already primarily cloud solutions. Thus, there are two possible topics for further research. Firstly, whether this observed skepticism towards the cloud is caused by the geographic definition of the respondents (and is it therefore typical of Czech companies), by the industry definition (and it is therefore typical of manufacturing companies), or whether it is general attitude among the large companies. Secondly, in case it is a general attitude, what are the causes and effects of such discrepancy between the intentions of ERP vendors, who decisively prefer providing their systems via the cloud, and ERP users, who prefer on-premise solutions.

As for the contributions of this paper, the main theoretical contribution lies in identifying the inconsistency between the expected future significance of Industry 4.0 and projecting this significance into the requirements placed on the ERP system. The IT managers and key users of the ERP systems in the Czech manufacturing companies still lack the understanding of the potential of incorporating the technologies of Industry 4.0 into ERP systems.

As for the practical contribution, according to this research, the ERP system vendors should concentrate mainly on the security, modularity and user-friendliness of their system, so as to maximise their chances in the selection process. Providing features associated with the technologies of Industry 4.0, though being assessed positively by the decision makers, plays only a limited role in the selection process.

Conclusions

The presented research addressed the issues of ERP system selection in the context of the fourth industrial revolution. This revolution has brought about new technologies, some of which at least have a direct impact on the requirements concerning architecture, technical design, or functionalities of ERP systems. Our research has therefore aimed to find out whether employees in manufacturing companies who would find themselves in the role of decision makers in the case of selecting a new ERP system are aware of these requirements, and to what extent they would take these requirements into account when selecting the new system compared to other criteria. For this purpose, the questionnaire survey was conducted in the medium-sized and large manufacturing companies in the Czech Republic.

The survey findings show that the employees working in positions where they can influence the further development of the IT landscape of their companies are generally aware of the importance and challenges of the fourth industrial revolution. However, in the case of selecting the new ERP system, they would attach main importance to other criteria such as security, modularity, user-friendliness of the system and its price, all of these criteria being assessed to be similarly important. The capability of ERP system to operate in the Industry 4.0 environment is not yet perceived as a factor of equal importance, though.

From the point of view of business practice, obtained results can be used by the

ERP system vendors as one of the inputs of the process of planning of the future development of their systems. From the theoretical point of view, this paper can serve as an initial point of further research with the aim to find out, whether the rather low importance given to the Industry 4.0 related criteria is simply caused by the respondents' ignorance and their insufficient understanding of the complex links between Industry 4.0 technologies and the ERP system, or whether the ERP system attributes in this area are really perceived by the respondents as secondary even with the full understanding of the implications.

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References

Aburub, F. (2018). Impact of ERP usage on organisational effectiveness: An empirical investigation. In Proceedings of *4th International Conference on Computer and Technology Applications (ICCTA)* (pp. 106–110). IEEE. https://doi.org/10.1109/cata.2018.8398665

Accenture. (2020). *2020 ERP trends*. Retrieved September 15, 2022 from https://www.accenture.com/_acnmedia/PDF-119/Accenture-ERP-Report-2020.pdf

Alcácer, V., & Cruz-Machado, V. (2019). Scanning the Industry 4.0: A literature review on technologies for manufacturing systems. *Engineering Science and Technology, an International Journal*, *22*(3), 899–919. https://doi.org/10.1016/j.jestch.2019.01.006

AlMuhayfith, S., & Shaiti, H. (2020). The impact of enterprise resource planning on business performance: With the discussion on its relationship with open innovation. *Journal of Open Innovation: Technology, Market and Complexity*, *6*(3), 87. https://doi.org/10.3390/joitmc6030087

Asl, M. B., Khalilzadeh, H. R., Youshanlouei, H. R., & Mood, M. M. (2012). Identifying and ranking the effective factors on selecting enterprise resource planning (ERP) system using the combined Delphi and Shannon entropy approach. *Procedia Social and Behavioral Sciences*, *41*, 513–520. https://doi.org/10.1016/j.sbspro.2012.04.063

Azevedo, P. S., Azevedo, C., & Romao, M. (2014). Application integration: Enterprise resource planning (ERP) systems in the hospitality industry. *Procedia Technology*, *16*, 52–58. https://doi.org/10.1016/j.protcy.2014.10.067

Basl, J. (2018a). Analysis of Industry 4.0 readiness indexes and maturity models and proposal of the dimension for enterprise information systems. In A. M. Tjoa (Ed.), *Lecture notes in business information processing 310* (pp. 57–68). Springer International Publishing. https://doi.org/10.1007/978-3-319-99040-8_5

Basl, J. (2018b). Penetration of Industry 4.0 principles into ERP vendors' products and services – A Central European study. In A. M. Tjoa (Ed.), *Lecture notes in business information processing 310* (pp. 81–90). Springer International Publishing. https://doi.org/10.1007/978-3-319-94845-4_8

Basl, J., & Nováková, M. (2019). Analysis of selected ERP 4.0 features and proposal of an ERP 4.0 maturity model. In P. Doucek (Ed.), *Lecture notes in business information processing 375* (pp. 3–11). Springer International Publishing. https://doi.org/10.1007/978-3-030-37632-1_1

Bhatt, N., Guru, S., Thanki, S., & Sood, G. (2021). Analysing the factors affecting the selection of ERP package: A fuzzy AHP approach. *Information Systems and E-Business Management*, *19*(2), 641–682. https://doi.org/10.1007/s10257-021-00521-8

Boltena, A. S., Gomez, J. M., & Rieken, M. (2011). Development of a conceptual model to support ERP system selection in developing countries. In M. M. Cruz-Cunha (Ed.), *Communications in computer and information science* (pp. 190–197). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-24358-5_19

Büchi, G., Cugno, M., & Castagnoli, R. (2020). Smart factory performance and Industry 4.0. *Technological Forecasting and Social Change*, *150*, 119790. https://doi.org/10.1016/j.techfore.2019.119790

Castelo-Branco, I., Amaro-Henriques, M., Cruz-Jesus, F., & Oliveira, T. (2023). Assessing the Industry 4.0 European divide through the country/industry dichotomy. *Computers & Industrial Engineering*, *176*, 108925. https://doi.org/10.1016/j.cie.2022.108925

Cebeci, U. (2009). Fuzzy AHP-based decision support system for selecting ERP systems in textile industry by using balanced scorecard. *Expert Systems with Applications*, *36*(5), 8900–8909. https://doi.org/10.1016/j.eswa.2008.11.046

Chatzoglou, P., Chatzoudes, L., Fragidis, L., & Symeonidis, S. (2017). Examining the critical success factors for ERP implementation: An explanatory study conducted in SMEs. In E. Ziemba (Ed.), *Information technology for management: New ideas and real solutions 277* (pp. 179–201). Springer International Publishing. https://doi.org/10.1007/978-3-319-53076-5_10

Christophe, S. E. (2019). The impact of adopting ERP on key performance indicator by the mediation effect of critical success factors and performance indicators in automobile ancillary industries. *International Journal of Recent Technology and Engineering*, *8*(2S3), 116–121. https://doi.org/10.35940/ijrte.b1019.0782s319

Cocca, P., Marciano, F., Rossi, D., & Alberti, M. (2018). Business software offer for Industry 4.0: The SAP case. *IFAC PapersOnLine*, *51*(1),1200–1205.https://doi.org/10.1016/j.ifacol.2018.08.427

Davenport, T. H. (1998). Putting the enterprise into the enterprise system. *Harvard Business Review*. Retrieved September 15, 2022 from https://hbr.org/1998/07/putting-the-enterprise-into-the-enterprise-system

Delloite. (2022). *Industry 4.0 – Is your ERP system ready for the digital era?* https://www2.deloitte.com/content/dam/Deloitte/de/Documents/technology/Deloitte_ERP_Industrie-4-0_Whitepaper.pdf

Doyle, F., & Cosgrove, J. (2019). Steps towards digitization of manufacturing in an SME environment. *Procedia Manufacturing*, *38*, 540–547. https://doi.org/10.1016/j.promfg.2020.01.068

Efe, B. (2016). An integrated fuzzy multi criteria group decision making approach for ERP system selection. *Applied Soft Computing*, *38*, 106–117. https://doi.org/10.1016/j.asoc.2015.09.037

Egger, J., & Masood, T. (2020). Augmented reality in support of intelligent manufacturing – A systematic literature review. *Computers & Industrial Engineering*, *140*, 106195. https://doi.org/10.1016/j.cie.2019.106195

Erboz, G. (2017). How to define Industry 4.0: Main pillars of Industry 4.0. In *Managerial trends in the development of enterprises in globalization era* (pp. 761–767). Slovak University of Agriculture in Nitra.

Esmaeilian, B., Sarkis, J., Lewis, K., & Behdad, S. (2020). Blockchain for the future of sustainable supply chain management in Industry 4.0. *Resources, Conservation and Recycling*, *163*, 105064. https://doi.org/10.1016/j.resconrec.2020.105064

Graney, G. (2017). Industry 4.0: An introduction. In *QAD Blog July 11, 2017.* Retrieved September 15, 2022 from https://www.qad.com/blog/2017/07/industry-4-0-introduction

Gürbüz, T., Alptekin, S. E., & Apltekin, G. I. (2012). A hybrid MCDM methodology for ERP selection problem with interacting criteria. *Decision Support Systems*, *54*(1), 206–214. https://doi.org/10.1016/j.dss.2012.05.006

Haddara, M., & Elragal, A. (2015). The readiness of ERP systems for the factory of the future. *Procedia Computer Science*, *64*, 721–728. https://doi.org/10.1016/j.procs.2015.08.598

Hendl, J., & Remr, J. (2017). *Metody výzkumu a evaluace* [Research and evaluation methods]. Portál.

Hunton, J. E., Lippincott, B., & Reck, J. L. (2003). Enterprise resource planning systems: Comparing firm performance of adopters and nonadopters. *International Journal of Accounting Information Systems*, *4*(3), 165–184. https://doi.org/10.1016/S1467-0895(03)00008-3

Hurbean, L., & Fotache, D. (2014). ERP III: The promise of a new generation. In Proceedings of *The 13th International Conference on Informatics in Economy, Education, Research & Business Technologies. ASE Bucharest*. https://doi.org/10.13140/2.1.3906.1765

Inkerman, D., Schneider, D., Martin, N. L., Lembeck, H., Zhang, J., & Thiede, S. (2019). A framework to classify Industry 4.0 technologies across production and product development. *Procedia CIRP*, *84*, 973–978. https://doi.org/10.1016/j.procir.2019.04.218

Kähkönen, T., Maglyas, A., & Smolander, K. (2014). ERP system integration: An inter-organizational challenge in the dynamic business environment. In J. Cordeiro, S. Hammoudi, L. Maciaszek, O. Camp, & J. Filipe (Eds.), *Enterprise information systems* (pp. 39–56). Springer International Publishing. https://doi.org/10.1007/978-3-319-22348-3_3

Karsak, E. E., & Özegul, C. O. (2009). An integrated decision making approach for ERP system selection. *Expert Systems with Applications*, *36*(1), 660–667. https://doi.org/10.1016/j.eswa.2007.09.016

Katuu, S. (2020). Enterprise resource planning: Past, present, and future. *New Review of Information Networking*, *25*(1), 37–46. https://doi.org/10.1080/13614576.2020.1742770

Kilic, H. S., Zaim, S., & Delen, D. (2014). Development of a hybrid methodology for ERP system selection: The case of Turkish

Airlines. *Decision Support Systems*, *66*, 82–92. https://doi.org/10.1016/j.dss.2014.06.011

Kilic, H. S., Zaim, S., & Delen, D. (2015). Selecting the best ERP system for SMEs using a combination of ANP and PROMETHEE methods. *Expert Systems with Applications*, *42*(5), 2343–2352. https://doi.org/10.1016/j.eswa.2014.10.034

Lacurezeanu, R., Chis, A., & Bresfelean, V. P. (2021). Integrated management solution for a sustainable SME – Selection proposal using AHP. *Sustainability*, *13*(19), 10616. https://doi.org/10.3390/su131910616

Leyh, C., & Sander, P. (2015). Critical success factors for ERP system implementation projects: An update of literature reviews. In D. Sedera (Ed.), *Lecture notes in business information processing 198* (pp. 45–67). Springer Verlag. https://doi.org/10.1007/978-3-319-17587-4_3

López, C., & Ishizaka, A. (2017). GAHPSort: A new group multi-criteria decision method for sorting a large number of the cloud-based ERP solutions. *Computers in Industry*, *92–93*, 12–25. https://doi.org/10.1016/j.compind.2017.06.007

Maistorovic, V., Stojadinovic, S., Lalic, B., & Marjanovic, U. (2020). ERP in Industry 4.0 context. In B. Lalic (Ed.), *APMS 2020: Advances in production management systems. The path to digital transformation and innovation of production management systems* (pp. 287–294). Springer International Publishing. https://doi.org/10.1007/978-3-030-57993-7_33

Marinho, M., Prakash, V., Garg, L., Savaglio, C., & Bawa, S. (2021). Effective cloud resource utilisation in cloud ERP decision-making process for Industry 4.0 in the United States. *Electronics*, *10*(8), 959. https://doi.org/10.3390/electronics10080959

Masood, T., & Sonntag, P. (2020). Industry 4.0: Adoption challenges and benefits for SMEs. *Computers in Industry*, *121*, 103261. https://doi.org/10.1016/j.compind.2020.103261

McCue, I. (2020). The *history of ERP*. Oracle NETSUITE, August 12, 2020. Retrieved September 15, 2022 from https://www.netsuite.com/portal/resource/articles/erp/erp-history.shtml

Mubarok, K. (2020). Redefining Industry 4.0 and its enabling technologies. *Journal of Physics: Conference Series*, *1569*(3), 032025. https://doi.org/10.1088/1742-6596/1569/3/032025

Nikolaos, P., Sotiris, G., Harris, D., & Nikolaos, V. (2005). An application of multicriteria analysis for ERP software selection in a Greek industrial company. *Operational Research, an International Journal*, *5*(3), 435–458. https://doi.org/10.1007/bf02941130

Novák, P., Vyskočil, J., & Wally, B. (2020). The digital twin as a core component for Industry 4.0 smart production planning. *IFAC PapersOnLine*, *53*(2), 10803–10809. https://doi.org/10.1016/j.ifacol.2020.12.2865

Oman, S., Leskovar, R., Rosi, B., & Baggia, A. (2017). Integration of MES and ERP in supply chains: Effect assessment in the case of the automotive industry. *Tehnicki Vjesnik – Technical Gazette*, *24*(6), 1889–1896. https://doi.org/10.17559/tv-20160426094449

Perera, A. G., Dionisio, P. S., & Jiménez, A. J. (2018). ERP systems in the context of Industry 4.0. Advances, challenges and implications. *DYNA*, *93*(1), 592–596. https://doi.org/10.6036/8835

Ploder, C., Bernsteiner, R., Schlögl, S., & Walter, J. (2021). Critical success factors of hybrid-ERP implementations. In L. Uden (Ed.), *KMO 2021: Knowledge management in organizations* (pp. 305–315). Springer International Publishing. https://doi.org/10.1007/978-3-030-81635-3_25

Polívka, M., & Dvořáková, L. (2019). Využití automatické identifikace a sběru dat prostřednictvím radiofrekvenčních technologií v prostředí průmyslu 4.0 [Use of automatic identification and data capture based on radio frequency technologies in the environment of Industry 4.0]. *Trendy v podnikání*, *9*(2), 53–61. https://doi.org/10.24132/jtb.2019.9.2.53_61

Polívka, M., & Dvořáková, L. (2021). The current state of the use of selected Industry 4.0 technologies in manufacturing companies. In Proceedings of *The 32nd International DAAAM Virtual Symposium "Intelligent Manufacturing & Automation"* (pp. 0652–0659). https://doi.org/10.2507/32nd.daaam.proceedings.092

Poon, P., & Yu, Y. T. (2010). Investigating ERP systems procurement practice: Hong Kong and Australian experiences. *Information and Software Technology*, *52*(10), 1011–1022. https://doi.org/10.1016/j.infsof.2010.04.003

Rojko, A. (2017). Industry 4.0 concept: Background and overview. *International Journal of Interactive Mobile Technologies*, *11*(5), 77. https://doi.org/10.3991/ijim.v11i5.7072

Ross, P., & Maynard, K. (2021). Towards a 4th Industrial revolution. *Intelligent Buildings*

International, *13*(3), 159–161. https://doi.org/10.1080/17508975.2021.1873625

Rüssman, M., Lorenz, M., Gerbert, P., Waldner, M., Engel, P., M., H., & Justus, J. (2015). Industry 4.0: The future of productivity and growth in manufacturing industries. *BCG*. https://www.bcg.com/publications/2015/engineered_products_project_business_industry_4_future_productivity_growth_manufacturing_industries

Saleh, T., & Thoumy, M. (2020). The impact of ERP systems on operational performance in Lebanese wholesale engineering companies. *International Journal of Services and Operations Management*, *37*(4), 509–529. https://doi.org/10.1504/ijsom.2020.111821

SAP. (2022). *Make Industry 4.0 your everyday reality*. Retrieved September 15, 2022 from https://www.sap.com/products/supply-chain-management/industry-4-0.html

Schmidbauer, C., Komenda, T., & Schlund, S. (2020). Teaching cobots in learning factories – User and usability-driven implications. *Procedia Manufacturing*, *45*, 398–404. https://doi.org/10.1016/j.promfg.2020.04.043

Schneider, G. (2021). *Timeline for SAP S/4HANA migration extended*. USU. Retrieved May 7, 2023 from https://blog.usu.com/en-us/sap-s4hana-migration-extended

Silva, E. R., Shinohara, A. C., Nielsen, C. P., Lima, E. P., & Angelis, J. (2020). Operating digital manufacturing in Industry 4.0: The role of advanced manufacturing technologies. *Procedia CRIP*, *93*, 174–179. https://doi.org/10.1016/j.procir.2020.04.063

Slusarczyk, B., Nathan, R. J., & Pyplacz, P. (2021). Employee preparedness for Industry 4.0 in logistic sector: A cross-national study between Poland and Malaysia. *Social Sciences*, *10*(7), 258. https://doi.org/10.3390/socsci10070258

STechies. (2021). *SAP versions release and history of evolution*. Retrieved May 7, 2023 from https://www.stechies.com/about-sap-erp-solution-different-versions/

Tsai, W., Lee, P., Shen, Y., & Lin, H. (2012). A comprehensive study of the relationship between enterprise resource planning selection criteria and enterprise resource planning system success. *Information & Management*, *49*(1), 36–46. https://doi.org/10.1016/j.im.2011.09.007

Vaidya, S., Ambad, P., & Bhosle, S. (2018). Industry 4.0 – A glimpse. *Procedia Manufacturing*, *20*, 233–238. https://doi.org/10.1016/j.promfg.2018.02.034

Vasilev, J. (2013). The change from ERP II to ERP III systems. In Proceedings of *3rd International Conference on Application of Information and Communication Technology and Statistics in Economy and Education (ICAICTSEE) 2013* (pp. 382–384). https://doi.org/10.13140/2.1.5109.7609

Verville, J., Palanisamy, R., Bernadas, C., & Halingten, A. (2007). ERP acquisition planning: A critical dimension for making the right choice. *Long Range Planning*, *40*(1), 45–63. https://doi.org/10.1016/j.lrp.2007.02.002

Wanchai, P. (2017). Key factors for succesfull ERP implementation: Case studies from private and public organisations in Thailand. In F. Piazolo (Ed.), *Lecture notes in business information processing 285* (pp. 3–16). Springer Verlag. https://doi.org/10.1007/978-3-319-58801-8_1

Wei, C., Chien, C., & Wang, M. J. (2005). An AHP-based approach to ERP system selection. *International Journal of Production Economics*, *96*(1), 47–62. https://doi.org/10.1016/j.ijpe.2004.03.004

Wozniakowski, T., Jalowiecki, P., Zmarzlowski, K., & Nowakowska, M. (2018). ERP systems and warehouse management by WMS. *Information System in Management*, *7*(2), 141–151. https://doi.org/10.22630/ISIM.2018.7.2.13

Yang, J., Wu, C., & Tsai, C. (2007). Selection of an ERP system for a construction firm in Taiwan: A case study. *Automation in Construction*, *16*(6), 787–796. https://doi.org/10.1016/j.autcon.2007.02.001

Zhong, R. Y., Xu, X., Klotz, E., & Newman, S. T. (2017). Intelligent manufacturing in the context of Industry 4.0: A review engineering. *Engineering*, *3*(5), 616–630. https://doi.org/10.1016/j.eng.2017.05.015