European Research Studies Journal
Volume XXIV, Special Issue 4, 2021

pp. 65-86

Quantification of the Process Improvement Exigency Related to Industry 4.0

Submitted 20/09/21, 1st revision 02/10/21, 2nd revision 28/10/21, accepted 30/11/21

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Abstract:

Purpose: *The main objective of this paper is to develop the I4 necessity index for quantification of process improvement exigency related to I4.*
Design/Methodology/Approach: *Based on literature review and previous research, we decided to develop a new I4N index. This index is not intended to identify the current state of Industry 4.0 or the company's readiness for this concept, but to assess the need to implement I4. By implementing I4 we mean mostly the deployment of intelligent technologies, informatization and automation of business processes. Our philosophy is to develop a simple design for a minimum number of factors that may give rise to an internal or external need to implement I4. The secondary output of the I4N index is the quantification of the level of process improvement potential related to the selected production and logistic processes.*
Findings: *We emphasize, it as a demand or more specifically, an exigency, rather than a readiness for Industry 4.0. We developed an Industry 4.0 necessity index (I4N index). We assigned weights to individual factors in order to quantify the process improvement exigency related to I4 and we used the list of manufacturing and logistic processes from previous research. We did not apply the list of intelligent technologies, although most indexes of the I4 readiness also take these technologies into account.*
Practical Implications: *The basic approach of our research was to create a mathematical model that could easily quantify the potential for improving business processes related to Industry 4.0.*

Keywords: *Process improvement, Industry 4.0, necessity index, exigency factors.*

JEL classification: *C4, I1, I2, I3, M21, D04.*

Paper Type: *Research study.*

Acknowledgement: *The paper is funded under the program of the Minister of Science and Higher Education titled "Regional Initiative of Excellence" in 2019–2022, project number 018/RID/2018/19, the amount of funding PLN 10788423,16.*

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1. Introduction

Based on the response to previous research focused on quality managers and their future technological expectations related to Industry 4.0 (I4), we decided to analyse the exigency factors to implement Industry 4.0 (Borowiecki *et al.*, 2021). We know that intelligent technologies are an essential part of Industry 4.0 (Dróżdź *et al.*, 2020). However, not all industrial companies need to implement Industry 4.0. The exigency of the I4 implementation depends on many factors. For the simplicity and speed of analysing the pressure on the company to implement I4, we have defined a set of 8 factors.

Factors of the I4 necessity represent two external factors such as customer pressure to use smart technologies and supplier pressure to use smart technologies. Another group of factors are internal factors that do not examine specific intelligent technologies, but organizational context as a production system classification, product variability and existence of manufacturing and logistic processes. The most significant internal factors of the I4 necessity are factors as a level of the process informatization, level of the process automation and level of the process integration to the Manufacturing Executive System (MES) or to the Enterprise Resource Planning system (ERP). Exigency of the Industry 4.0 is expressed as the sum of recalculated partial factors causing pressure on the application of Industry 4.0 in existing production and logistic processes.

Our proposed I4N index is applicable to any process. Based on the definition of 8 factors of the need to implement I4, we have developed a new simple I4 necessity index (I4N index) following our previous research. This index takes into account the existence of a given production and logistic process running in the organization and the influence of index factors on these processes. It is not an index of I4 readiness, but an identification of internal and external exigency to implement I4, mostly to automate and to provide information about selected processes on the one hand and to analyse customer and supplier demands for using intelligent technologies on the other. The objectives of our paper are:

(1) to determine a group of exigency factors conditioning Industry 4.0 implementation,
(2) to follow up on the previous research focused on quality managers and their future technological expectations related to Industry 4.0,
(3) to develop the simple Industry 4.0 necessity index as a tool for quick identification of the processes improvement potential related to the selected exigency factors involved in the I4N index,
(4) to verify developed I4N index in the real industrial environment,
(5) to identify improvement potential of production and logistic processes resulting from I4N index verification.

2. Literature Review

Since Industry 4.0 has emerged as many maturity models were developed. We focus on pressure affecting the selected production and logistic processes either internally or externally. That pressure on process improvement is expressed through determined exigency factors. Literature review help us to understand how the other authors perceive I4 readiness, I4 maturity and what factors are most important for our research and for I4N index developing.

Our literature review started with a general analysis of I4. More than 10,000 papers related to I4 where offered in Web of Science and Scopus. We selected papers describing factors of I4 readiness and I4 maturity. Nazarov and Klarin (2020) prepared taxonomy of Industry 4.0 through mapping scholarship and industry insights. According to Nazarov and Klarin (2020), the state-of-the-art review of the entire scholarship of Industry 4.0 demonstrates three broad clusters – the implications of automation on industry, the integration of technologies and technological advancements driving the Fourth Industrial Revolution. Kosacka-Olejnik and Pitakaso (2019) analysed the main contributions published on the topic of Industry 4.0. Ghobakhloo (2020) prepared a study which could serve Industry 4.0 stakeholders – leaders in the public and private sectors, industrialists, and academicians - to better understand the opportunities that the digital revolution may offer for sustainability, and to work together more closely to ensure that Industry 4.0 delivers the intended sustainability functions around the world as effectively, equally, and fairly as possible. General view on I4 offers also Schott *et al.* (2020), Culot *et al.* (2020), Mana *et al.* (2018) and Pessot *et al.* (2020).

Jesus and Lima (2020) determined key factors for the development of generic and specific maturity models for I4. They identified factors for the development of specific maturity models, oriented towards unique conditions, located in specific contexts, and that can cover both the need for self-diagnosis of the level of preparation, as well as the actions that aim to achieve a progressive reconfiguration and guided by continuous improvement towards Industry 4.0. Their systematic literature review of 67 articles was conducted and resulted in the identification of five factors for development of a specific maturity model, context characterization, conceptual characterization, interaction with practitioners and experts, development of surveys, and qualitative research.

Key ingredients for evaluating Industry 4.0 readiness for organizations are also described by Sony and Naik (2020) who identified the key ingredients for assessing Industry 4.0 readiness for organizations and the interrelationships that exist between these readiness factors. Their results help the organizations to identify the factors which they need to critically assess before implementing Industry 4.0 in an organization. All those factors are primary related to I4 maturity and I4 readiness. According to Hughes *et al.* (2020), the roadmap towards Industry 4.0 is complex and multifaceted, as manufacturers seek to transition towards new and emerging technologies, whilst retaining operational effectiveness and these factors are further evaluated via the presentation of their new Industry 4.0 framework. A specific view on I4 maturity model for machine tool companies was presented by Rafael et al. (2020), who claims that Maturity Model (MM) can be very useful, since they help to evaluate the initial state of the company and to plan a development road map.

Dominant drivers of I4 integration are societal pressure and public awareness, government policies on support I4, top management involvement and support and government promotions and regulations (Harikannan *et al.*, 2020). Ramingwong *et al.* (2019) underline human factors toward I4. Strategy, leadership and culture are found as key elements of transformation in the journey of I4 and additionally, design and development of the digital twin, virtual testing and simulations were also important factors to consider by manufacturing firms (Narula *et al.*, 2020; Szczepańska-Woszczyna, 2018; Zabolotniaia, Cheng, Dacko-Pikiewicz, 2019; Vasin *et al.*, 2018). Pech and Vrchota (2020) used the Index of Industry 4.0 and confirmed the assumption that the large enterprises have greater opportunities to use new technologies and transform them into smart factories. Hizam-Hanafiah *et al.* (2020) explored many I4 readiness models. According to Hizam-Hanafiah et al. (2020), it is critical for organizations to self-assess their Industry 4.0 readiness to survive. Their review identified 30 Industry 4.0 readiness models with 158 unique model dimensions and they proposed six dimensions (Technology, People, Strategy, Leadership, Process and Innovation) that can be considered as the most important dimensions for organizations.

Another seventeen enablers that can affect the adoption of Industry 4.0 in the manufacturing industry in India have been explored by Jain and Ajmera (2020). A systematic literature review study presented by Hoyer, Gunawan and Reaiche (2020) discusses a comprehensive list of potential factors that influence the implementation of Industry 4.0 and strengthens the idea that further research is necessary in order to address contradictory findings and to develop efficient Industry 4.0 implementation frameworks. Simetinger and Zhang (2020) state that the potential of the Industry 4.0 concept is represented by increased productivity, improved cost efficiency, or higher product attractiveness. The adoption of this concept is related to a high number of challenges and risks. A possible solution to address these challenges and risks is the adoption or implementation of this concept using the maturity models.

The Fourth Industrial Revolution has provided an unprecedented platform for innovation in various spheres (Kruger and Steyn, 2020). It is important to consider all drivers and barriers as a Stentoft *et al.* (2020) who investigated the drivers and barriers for Industry 4.0 readiness and practice among Danish small and medium-sized manufacturers. Rauch *et al.* (2020), Peukert *et al.* (2020) and Herceg *et al.* (2020) investigated small and medium-sized enterprises using a maturity level-based assessment tool to enhance the implementation of I4 and process model for the successful implementation and demonstration of SME-based I4. Cimini *et al.* (2020)

investigated the organisational implications of adopting I4 technologies, giving specific attention to operations. Baseline for determining our exigency factor also comes from Wagire *et al.* (2020) who developed maturity model for assessing the implementation of Industry 4.0. We emphasize, not a maturity, but a real necessity of the I4 implementation as the main goal of this paper. We found the research of Nafchi and Mohelska (2020) to be inspirational. They found the size and type of an organization influence the innovative culture and consequently the readiness of the organization for implementing industry 4.0. Another factor for process improvement could be a cost-driven motives which are precisely described in Stentoft et al. (2020). We will not consider these financial aspects, but a framework for a quality discipline supporting the fourth industrial revolution (Zonnenshain and Kenett, 2020) we will.

Maturity models and I4 implementation frameworks are also described by Kiraz *et al.* (2020), Facchini *et al.* (2020), Santos and Martinho (2019), Tortorella, Giglio and Dun (2019), Pacchini *et al.* (2019), Frederico *et al.* (2019), Gajsek *et al.* (2019), Basl and Doucek (2019), Colli *et al.* (2019), Mittal *et al.* (2018), and Bibby and Dehe (2018). All studies resulted to similar group of factors or maturity levels. The level of informatization, level of automatization, level of the process integration to MES/ERP, customers and suppliers are most important exigency factors which are involved to I4N index. Kuo *et al.* (2020) also proposed a smart system to prevent customer dissatisfaction. Each factor is assessed separately in our proposal. Calculating the I4N index uncovers the process improvement exigency related to I4.

The next factors are focused on production system. Raj *et al.* (2020) describe specific barriers to the adoption of Industry 4.0 technologies in the manufacturing sector. Ivascu (2020) discusses the implications of sustainable manufacturing in the context of Industry 4.0. As we mentioned above, process improvement related to I4 and its quantification is the main goal. It is supported by Queiroz *et al.* (2020) who identified 26 drivers that have an impact on improved business processes. Tupa and Steiner (2019) and Jena, Mishra and Moharana (2020) also underline that production companies are adopting new methods for the improvement of their managing production processes and for sustainable manufacturing. Hahn (2019) and Tortorella *et al.* (2019) explored the relationship between I4 and supply chain improvement. Implications of the literature review are transferred to our I4N index for calculating the process improvement exigency related to I4.

3. Methodology and Developing the Industry 4.0 Necessity Index

The assumption of study is to develop a new I4N index, that assesses the need to implement I4, meant mostly as the deployment of intelligent technologies, informatization and automation of business processes.

We are aware that there are many views on the implementation of I4 and the analysis of the current state, especially of industrial enterprises, and many authors deal with this in detail. Our philosophy is to develop a simple design for a minimum number of factors that may give rise to an internal or external need to implement I4. The secondary output of the I4N index is the quantification of the level of process improvement potential related to the selected production and logistic processes. It always depends on specific business realities and therefore we decided to verify the proposed I4N index in one real industrial company. The main goals of our methodology approach are:

(1) to determine exigency factors and their significance based on the quick empirical research in the sample of industrial companies,
(2) to propose mathematical relations among the all exigency factors considering existence of given processes,
(3) to describe how results of the I4N index application can help industrial companies identify process improvement potential related to I4.

Limitations of the developed I4N index, but we do not have to talk about limitations, are in the utilization of the I4N index only in the industrial (manufacturing) companies with all or partial set of the determined processes. However, the principle of application of the I4N index is general. In the case of a non-industrial enterprise, it is sufficient to define a different set of business processes and the I4N index is applicable to other organizations. In this case it is necessary to adapt the first two factors of I4N1: a production system and $I4N_2$: Products variability considering real business environment. However, focusing on non-manufacturing organizations will be our goal in further research in the future.

3.1 Determination and Significance of the I4 Exigency Factors

From the analysis of existing research, we selected 8 basic factors that take into account the internal and external pressure on I4 implementation. There are many existing perspectives on I4 implementation and business readiness. In determining the factors, we focused on the basic criteria, which were the simplicity and generality of the developed I4N index. List of internal and external I4 exigency factors consists of these factors: $I4N_1$: Production system, $I4N_2$: Products variability, $I4N_3$: Existence of the process, $I4N_4$: Level of the process informatization, $I4N_5$: Level of the process automation, $I4N_6$: Process integration to the MES/ERP, $I4N_7$: Customer request for using intelligent technologies in the process and $I4N_8$: Supplier request for using of intelligent technologies in the process.

Production system ($I4N_1$) as the first internal factor was divided into 4 basic types of production, namely job-shop production, batch production, mass production and continuous production. All 4 types are the elementary classification of production systems. The review of literature showed that the larger the production volume, the greater the potential pressure to deploy intelligent technologies. However, this factor also fundamentally affects the second factor. The second factor is products variability ($I4N_2$). This factor, although defined separately, is related to the type of production system. The greater the variability of products, the greater the potential pressure to deploy intelligent technologies in business processes. The third factor is the existence of the given production or logistic process ($I4N_3$). Here, the nature of this factor is very simple. If the process exists in the company, logically, potential pressure is created. If the process does not exist, the pressure is zero.

As mentioned above in the paper we followed the known production and logistic process defined in our previous research. The processes involved in the I4N index are: P1: Forecasting, P2: Product development, P3: Prototype production and evaluation, P4: Commercial prototype production planning, P5: Commercial prototype production and evaluation, P6: Demand management, P7: Tool management, P8: Material management, P9: Scheduling, P10: Manufacturing planning and control, P11: Manufacturing, P12: Converting manufacturing processes, P13: Nonconformity management, P14: Continuous improvement, P15: Reporting, P16: Maintenance, P17: Quality Control, P18: Visual management, P19: Waste management, P20: Change management, P21: Purchasing, P22: Warehousing, P23: Dispatching, P24: Transportation, P25: Manipulation and P26: Delivering. The level of the process informatization ($I4N_4$) as the fourth factor represents the percentage ratio between the informatized process activities and all process activities.

Informatisation of an activity means that the input, transformation and output of the activity are recorded in any information system (manually or automatically). The higher the level of informatization, the less pressure there is on the deployment of intelligent technologies. It is similar with a factor such as the level of the process automation ($I4N_5$). Under the term automation of activities, the activity performed automatically without human labour is understood. The higher the level of automated process activities, the less pressure there is on the deployment of intelligent technologies and vice versa. The sixth factor, the process integration to the MES / ERP ($I4N_6$), is related to the fourth factor. We determined the sixth factor separately due to its uniqueness. Informatization activity means that data is recorded to any isolated software and databases. If the information system is integrated and modular as organization overall system, there is a high probability for simpler utilization of intelligent technologies. A category of such systems are MES or ERP.

The last two factors are external pressure to implement I4. One of them is the customer request for using intelligent technologies in the process ($I4N_7$). Yes, the customer may require the organization to deploy a specific type of intelligent technology in a specific process. This is how the customer and the organization are connected. We consider this pressure to be one of the driving forces of the I4 implementation. It is similar to the input. We determined the supplier request for using intelligent technologies in the process ($I4N_8$) as the last factor. In the case of a supplier, mainly logistics processes are interconnected, but interconnection also occurs in production processes.

In previous research (Závadská and Závadský, 2018), we obtained results from 44 industrial companies and their quality managers. We also used the database of cooperating companies for fast empirical research, the main goal of which was to obtain a proposal for the significance of individual exigency factors. The significance of our proposed 8 factors was to be determined by quality managers using weights. We chose the size of the company for the criterion of representativeness. In the reduced sample of enterprises, we chose their representation of the total set of enterprises in Slovakia divided according to the number of employees into micro [1; 9], small [10; 49], medium [50; 249] and large enterprises (more than 249 employees). We selected 16 companies, of which 1 micro, 8 small, 5 medium and 2 large enterprises. Compared to the research from 2018, we also added micro, small and medium Slovak enterprises to the research sample. The condition for inclusion in the research sample were production and logistic processes. The frequencies observed, and the expected (theoretical) frequencies are shown in Table 1.

Table 1. *χ^2 - test due to enterprises´ size*

	np_i %	**n_i** No.	%	**$(n_i\text{-}np_i)^2$**	**$(n_i\text{-}np_i)^2/np_i$**
Micro enterprises	11.0	1.0	6.3	22.6	2.1
Small enterprises	51.0	8.0	50.0	1.0	0.0
Medium enterprises	28.0	5.0	31.3	10.6	0.4
Large enterprises	10.0	2.0	12.5	6.3	0.6
Σ	100.0	16.0	100.0		3.0730

Source: *Own study.*

The χ^2 value we achieved is lower than the critical χ^2 value at the level of statistical significance $\alpha = 0.05$ for 3 degrees of freedom (4 - 1), what in particular presents the value of 7.815 (value in statistical tables). Since $3.0730 < 7.815$, we accept the null hypothesis and we state that the sample file of companies represents their theoretical distribution.

We have sent quality managers a list of factors that represent internal and external pressure to implement I4. We sent them this list with a request to determine the significance of individual factors, and the sum of the weights must be 1. At the same time, we gave them the condition that they determine the weights so that the smallest weight can be 0.05 and other weights only as a multiple of an integral number. The result of the weight determination is shown in Table 2. This quick empirical research was carried out in June 2020, when the restriction measures in connection with the COVID-19 disease ended. We sent a request for determining the weights to the respondents who were the quality managers in the given companies. We chose quality managers because we used an existing database of companies from previous research.

Based on the answers of individual quality managers, we compiled the order of importance of individual factors. The most important factors with a weight of 20% are I4N4 Level of process informatization and I4N5 Level of process automation. The other two most important factors are the I4N1 Production system and I4N7 Customer request for using of intelligent technologies in the process. These two factors have a weight of 15%. The factors I4N6 Process integration to the MES / ERP and I4N8 Supplier request for using of intelligent technologies in the process have an importance expressed by a 10% weight. The last two factors of I4N2 Products variability and I4N3 Existence of the process have a significance of only 5%. The results of fast empirical research are the basis for the construction of a mathematical model of our I4N index.

3.2 Mathematical Construction of the I4N Index

Calculating the I4N index is relatively simple. It is true that if the practical value of any of the factors for a given process is lower, the greater the pressure to deploy intelligent technologies. The sum of the partial factors gives the final value. This value represents the pressure to deploy intelligent technologies in a given process and can be interpreted as the amount of process improvement potential related to the process. As a result, we can also calculate the overall I4N index, which as an arithmetic average determines the potential through all the set of involved / existing processes. Mathematical formulas (1) to (9) apply to the calculation of individual partial values of exigency factors *I4N1, I4N2, I4N3, I4N4, I4N5, I4N6, I4N7* and *I4N8.*

Table 2. *Significance of the I4 exigency factors identified through an empirical research*

	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	Avg. weight	St. dev.	Final weight
$I4N_1$	.05	.10	.20	.10	.20	.15	.05	.20	.20	.05	.20	.20	.10	.20	.15	.05	.14	.063	**0.15**
$I4N_2$	.10	.10	.05	.10	.05	.10	.05	.05	.05	.05	.05	.05	.10	.05	.05	.05	.07	.023	**0.05**
$I4N_3$	.10	.10	.05	.10	.05	.05	.10	.05	.05	.10	.05	.05	.10	.05	.05	.10	.07	.025	**0.05**
$I4N_4$	.20	.15	.20	.15	.25	.25	.15	.20	.20	.15	.20	.25	.15	.20	.20	.15	.19	.036	**0.20**
$I4N_5$	.20	.15	.15	.15	.25	.25	.25	.15	.20	.25	.15	.25	.15	.10	.20	.25	.19	.050	**0.20**
$I4N_6$	.10	.15	.10	.15	.05	.05	.15	.10	.05	.15	.10	.05	.15	.10	.10	.15	.11	.039	**0.10**
$I4N_7$	.15	.20	.10	.20	.10	.10	.10	.10	.10	.10	.10	.10	.20	.25	.15	.10	.13	.049	**0.15**
$I4N_8$	.10	.05	.15	.05	.05	.05	.15	.15	.15	.15	.15	.05	.05	.05	.10	.15	.10	.047	**0.10**
Σ	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1			**1**

Source: *Own study.*

$I4N_1$: Production system

$I4N_{ij} = 25 \vee 50 \vee 75 \vee 100$ [%]; (1)

where $i = (1; 2; \ldots; n)$ and $n = 8$ as a number of all exigency factors; j = (1; 2; …; m) and $m = 26$ as a number of all processes; value 25 represents job-shop production, value 50 represents continuous production, value 75 represent batch production and value 100 represents mass production. The higher the value, the higher the pressure to introduce I4.

I4N$_2$: Products variability

$$I4N_{2j} = 25 \vee 50 \vee 100\ [\%]; \quad (2)$$

where value 25 represents low products variability (1; 10), value 50 represents middle products variability (11; 50) and value 100 represents high products variability (more than 50 standardized products). The higher the value, the higher the pressure to introduce I4. This factor and its value are always the same for all processes. The factor $I4N_{2j}$ and also *I4N1* thus characterize the basic attributes of the production system.

I4N$_3$: Existence of the process

$$I4N_{3j} = P_{3j} \times 100\ [\%]; \quad (3)$$

where $P_{3j} = 1 \vee 0$; if $P_{3j} = 1$, then the given process is running in the organization or if $P_{3j} = 0$, then the given process is not running in the organization. This factor can take only two extremes, namely value 0 or value 100. If the value is 0, there is no pressure, if the value is 100, we calculate the maximum pressure, which is of course reduced by the weight of the factor in the result of the I4N index.

I4N$_4$: Level of the process informatization

$$I4N_{4j} = 100 - P_{4j}\ [\%]; \quad (4)$$

$$P_{4j} = \frac{X}{Z} \times 100\ [\%]; \quad (5)$$

where Z represents number of all activities/steps of the given production or logistic process and X represents number of activities which input/outputs are recorded to any information system. The higher the value of P_{4j}, the lower the pressure to introduce I4. Therefore, in formula (4), we had to reverse this value from 100 in order for the value of $I4N_{4j}$ to correspond to the real amount of pressure to introduce I4.

I4N$_5$: Level of the process automation

$$I4N_{5j} = 100 - P_{5j}\ [\%]; \quad (6)$$

$$P_{5j} = \frac{Y}{Z} \times 100\ [\%]; \quad (7)$$

where Z represents number of all activities/steps of the given production or logistic process and Y represents number of activities which are automated and provided without human work. The higher the value of P_{5j} the lower the pressure to introduce I4. Therefore, in formula (6), we subtracted this value in reverse from 100 so that the value of $I4N_{5j}$ corresponds to the real amount of pressure to introduce I4.

$I4N_6$: Process integration to the MES/ERP

$I4N_{6j} = 100 - (P_{6j} \text{ x } 100)$ [%]; (8)

where $P_{6j} = 1 \vee 0;$ if $P_{6j} = 1,$ then the given process is integrated to the MES/ERP or if $P_{6j} = 0,$ then the given process is not integrated to MES/ERP. This factor, like the existence of a process, assumes two extremes 0 and 100. If the process is integrated, then the pressure is at level 0 and if it is not integrated, then the pressure is 100%. In the final calculation, the value is reduced by the weight. We do not consider determining integration similarly to the level of informatization or level of automation. Either the process is integrated or it is not.

$I4N_7$: Customer request for using of intelligent technologies in the process

$I4N_{7j} = P_{7j} \text{ x } 100$ [%]; (9)

where $P_{7j} = 1 \vee 0;$ if $P_{7j} = 1,$ then any of customers request using of intelligent technologies in the given process or if $P_{7j} = 0,$ then all customers do not request using of intelligent technologies in the given process. We believe that if any customer requires the use of intelligent technologies, it is a relevant pressure of 100%.

$I4N_8$: Supplier request for using of intelligent technologies in the process

$I4N_{8j} = P_{8j} \text{ x } 100$ [%]; (10)

where $P_{8j} = 1 \vee 0;$ if $P_{8j} = 1,$ then any of supplier request using of intelligent technologies in the given process or if $P_{8j} = 0,$ then all suppliers do not request using of intelligent technologies in the given process. We believe that if any supplier requires the use of intelligent technologies, it is a relevant pressure of 100%.

Final calculation of the I4N index represents formula (11). In this formula, we took into account the weights of individual factors presented in Table 2. These weights were obtained by performing fast empirical research in the sample of industrial companies. *IN4j* is the value of the pressure for improvement related to Industry 4.0 of the given process *j*.

$$I4N_j = (0.15 \text{ x } I4N_{1j}) + (0.05 \text{ x } I4N_{2j}) + (0.1 \text{ x } I4N_{3j}) + (0.1 \text{ x } I4Nj_4) + (0.2 \text{ x } I4N_{5j}) + \\ + (0.15 \text{ x } I4N_{6j}) + (0.2 \text{ x } I4N_{7j}) + (0.05 \text{ x } I4N_{8j}) \quad (11)$$

Let us be reminded that the range of processes j is individual, because the I4N index can be applied to any process regardless of their total set. We used the known set of 26 production and logistic processes for verification. We know that the factor I4N3 would not have to be used, but since we would like to calculate the overall I4N index as the arithmetic average of all I4Nj, it is necessary to know whether the process is or is not in the organization.

Based on the mathematical construction, we can create a theoretical matrix for the calculation, application and interpretation of results (it is shown in Table 3). Each calculated I4N index for a given process quantifies the pressure to implement the I4 concept. If an enterprise requires the determination of only one value, it can also calculate the overall I4N index as the arithmetic average of all partial I4N indices, as shown in Table 3. The number of m processes depends on the enterprise and if any process in the enterprise does not take place and the value of I4N3 is equal to zero, so this process is added to the total number of m processes when calculating the overall I4N index.

Table 3. *Theoretical matrix for calculation of I4N index*

P	**$I4N_{1j}$ x w_1**		**+ $I4N_{2j}$ x w_2**		**+ $I4N_{3j}$ x w_3**		**+ $I4N_{4j}$ x w_4**		**+ $I4N_{5j}$ x w_5**		**+ $I4N_{6j}$ x w_6**		**+ $I4N_{7j}$ x w_7**		**+ $I4N_{8j}$ x w_8**		**= $I4N_j$**
P_1	$I4N_{1,1}$	.15	$I4N_{2,1}$	.05	$I4N_{3,1}$	.1	$I4N_{4,1}$	.1	$I4N_{5,1}$	.2	$I4N_{6,1}$	.15	$I4N_{7,1}$	.2	$I4N_{8,1}$	.05	$I4N_1$
P_2	$I4N_{1,2}$	.15	$I4N_{2,2}$	.05	$I4N_{3,2}$	.1	$I4N_{4,2}$	.1	$I4N_{5,2}$	.2	$I4N_{6,2}$	.15	$I4N_{7,2}$	.2	$I4N_{8,2}$	.05	$I4N_2$
P_3	$I4N_{1,3}$	.15	$I4N_{2,3}$	.05	$I4N_{3,3}$	.1	$I4N_{4,3}$	.1	$I4N_{5,3}$	.2	$I4N_{6,3}$	.15	$I4N_{7,3}$	.2	$I4N_{8,3}$	.05	$I4N_3$
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
P_j	$I4N_{1,j}$	.15	$I4N_{2,j}$	.05	$I4N_{3,j}$	.1	$I4N_{4,j}$	.1	$I4N_{5,j}$	.2	$I4N_{6,j}$	.15	$I4N_{7,j}$	.2	$I4N_{8,j}$	.05	$I4N_j$
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
.	.	.15	.	.05	.	.1	.	.1	.	.2	.	.15	.	.2	.	.05	.
P_m	$I4N_{1,m}$	.15	$I4N_{2,m}$	.05	$I4N_{3,m}$	.1	$I4N_{4,m}$	.1	$I4N_{5,m}$	.2	$I4N_{6,m}$	.15	$I4N_{7,m}$	.2	$I4N_{8,m}$	.05	$I4N_m$
Overall I4N = $\frac{\sum_{j=1}^{m} I4N_j}{m}$																	

Source: *Own study.*

However, this overall I4N index is not as relevant as partial I4Nj indexes, which take into account all factors and their fact related to the process. By quantifying the partial I4Nj indexes, we determine the exigency of the process improvement related to I4.

I4N index verification in the real industrial environment

The best way to verify our proposed I4N index is to verify it in a real industrial enterprise. The goals of the verification were:

- To select an industrial enterprise that will be willing to participate in the verification of the index, even independently of the enterprises that have been addressed within the determination of the significance of the I4 exigency factors,
- To identify the processes that are running in the selected industrial enterprise,
- To create a tool in the spreadsheet program that will simplify the verification of our I4N index,

- To validate the mathematical model by calculating the minimum and maximum values of the I4N index and determine the intervals of the process improvement exigency,
- To calculate for each process a partial I4Nj index, which quantifies the exigency of the process improvement related to I4, and also calculate the overall I4N index as an informative value.

3.3 Collaborating Industrial Enterprise

As part of our efforts to verify the I4N index, we also searched for a company independently of the database of companies that we contacted in order to obtain the significance of individual exigency factors related to I4N. In the case of verification, we used the cooperation of the Institute of Management Systems of Matej Bel University with industrial companies and selected a specific supplier for the company Whirlpool Slovakia, which is based in the same city as the Institute of Management Systems. The supplier is an industrial enterprise and is a multinational corporation. It belongs to the medium-sized enterprises. The company manufactures components for washing machines. The company has mass production and low product variability, as it focuses on precisely defined components specified by the customer.

3.4 Processes Running in the Industrial Enterprise

After selecting an industrial enterprise, we identified all production and logistic processes running in the company. Our theoretical set of processes contains 26 production and logistic processes. We have identified 20 running processes in the company in real conditions. From our theoretical set from previous research, these were the following processes: P6: Demand management, P7: Tool management, P8: Material management, P9: Scheduling, P10: Manufacturing planning and control, P11: Manufacturing, P13: Nonconformity management, P14: Continuous improvement, P15: Reporting, P16: Maintenance, P17: Quality Control, P18: Visual management, P19: Waste management, P20: Change management, P21: Purchasing, P22: Warehousing, P23: Dispatching, P24: Transportation, P25: Manipulation and P26: Delivering. The first group of processes such as Forecasting, Product development, Prototype production and evaluation, Commercial prototype production planning, and Commercial prototype production and evaluation are not running. This is because the processes are assured at the headquarters of the multinational company and the national branches are not responsible for these processes. We identified the set $m = 20$ processes.

3.5 Transformation of the Mathematical Model to Spreadsheet Application

For a simpler application of the I4N index, we decided to use a spreadsheet application, where we transformed mathematical relations into formulas between individual cells in that application. The structure is shown in Figure 1.

3.6 Validation of the I4N Index in the Spreadsheet Program

After developing the tool in the spreadsheet program, we validated it by determining the maximum and minimum values that individual exigency factors I4N1 to I4N8 can acquire. The minimum value for any of the factors is 0 and the maximum value of the given I4Nj index for the given process is 100. By validating and defining the minimum and maximum values, we checked the internal structure of cells and their relations. Based on this validation, we also defined a qualitative evaluation of the results of the I4N index, while this qualitative evaluation is based on the intervals:

– $I4N_j$ = (0;50] - low necessity for process improvement related to I4,
– $I4N_j$ = (50;75] - middle necessity for process improvement related to I4,
– $I4N_j$ = (75;100) - high necessity for process improvement related to I4.

We know that when dividing intervals into 3 parts, we should follow a regular division. However, we decided to determine the intervals so that the low necessity for the process improvement related to I4 is defined on the first half of the permissible values from 0 to 50. In this way we do not want to create enormous pressure on companies to automatically improve the process. We defined the pressure as high at values from 75 to 100.

3.7 Calculation of the Partial $I4N_j$ Indexes

If we know the set of ongoing processes, we have created a tool in the spreadsheet program, we can start with a real analysis of individual processes, as described in section 3.2 of this paper. The first two factors are common to all *m = 20* processes. Factor *I4N1j* = 100, because it is a mass production. Factor *I4N2j* = 25 because the variability of the products is low. The same applies to the existence of the process, i.e., all the processes involved in the company run, so always the factor *I4N3j* = 1.

We had to perform a detailed analysis for all other factors. In the analysis of the level of informatization of the given process I4N4j, we identified the number of activities that the given process necessarily has, to achieve the required outputs. For each activity, we identified that it was recorded electronically. The share of informatized activities in percentages for all activities of a given process is shown in Table 4. We proceeded similarly in the quantification of the factor I4N5j, where we identified the degree of automation.

We already had a list of activities, so we calculated the proportion of those that take place without human intervention. The sixth factor was relatively easy to calculate, as I4N6j always takes a value of 1 or 0. We found that the company has a modular ERP system and some of its production and logistics processes are integrated into the ERP system. We did not examine the integration at the level of individual activities, but we examined whether the inputs and outputs of the process as a whole are recorded in the ERP system.

For the last two factors I4N7j and I4N8j, we focused on customer and supplier requirements. We found out if any customer or supplier required the application of intelligent technologies in any process. If so, we assigned a value of 1 to the given factor, and if not, we assigned the factor a value of 0. We were also able to identify the proportion of those customers of all who require smart technologies. The same for suppliers. But, if any customer makes such a request, we can see it as pressure to improve the process. The values of the individual I4N factors are shown in Table 4.

***Figure 1**. Utilization of the spreadsheet program for the I4N index application*

	A	B	C	D	E	F	G	H
1	**$I4N_1$: Production system**	Mass Production	100					
2	**$I4N_2$: Products variability**	High	100					
3								
4		**$I4N_3$: Existention of the process**	**$I4N_4$: Level of the process informatization**	**$I4N_5$: Level of the process automation**	**$I4N_6$: Process integration to the MES/ERP**	**$I4N_7$: Customer request for using of intelligent technologies in the process**	**$I4N_8$: Supplier request for using of intelligent technologies in the process**	**Partial process improvement exigency**
5		Yes = 1, No = 0	%	%	Yes = 1, No = 0	Yes = 1, No = 0	Yes = 1, No = 0	
6	P1: Forecasting	1	0	0	0	1	1	100
7	P2: Product development	1	0	0	0	1	1	100
8	P3: Prototype production and evaluation	1	0	0	0	1	1	100
9	P4: Commercial prototype production planning	1	0	0	0	1	1	100
10	P5: Commercial prototype production and evaluation	1	0	0	0	1	1	100
11	P6: Demand management	1	0	0	0	1	1	100
12	P7: Tool management	1	0	0	0	1	1	100
13	P8: Material management	1	0	0	0	1	1	100
14	P9: Scheduling	1	0	0	0	1	1	100
15	P10: Manufacturing planning and control	1	0	0	0	1	1	100
16	P11: Manufacturing	1	0	0	0	1	1	100
17	P12: Converting manufacturing processes	1	0	0	0	1	1	100
18	P13: Nonconformity management	1	0	0	0	1	1	100
19	P14: Continuous improvement	1	0	0	0	1	1	100
20	P15: Reporting	1	0	0	0	1	1	100
21	P16: Maintenance	1	0	0	0	1	1	100
22	P17: Quality Control	1	0	0	0	1	1	100
23	P18: Visual management	1	0	0	0	1	1	100
24	P19: Waste management	1	0	0	0	1	1	100
25	P20: Change management	1	0	0	0	1	1	100
26	P21: Purchasing	1	0	0	0	1	1	100
27	P22: Warehousing	1	0	0	0	1	1	100
28	P23: Dispatching	1	0	0	0	1	1	100
29	P24: Transportation	1	0	0	0	1	1	100
30	P25: Manipulation	1	0	0	0	1	1	100
31	P26: Delivering	1	0	0	0	1	1	100

X-square | Factors | I4N_min | **I4N_max** | I4N_verif | Lists | Intervals | Graph

***Source:** Own study.*

***Table 4.** Values from $I4N_{4j}$ to $I4N_{8j}$ exigency factors*

	$I4N_{4j}$	$I4N_{5j}$	$I4N_{6j}$	$I4N_{7j}$	$I4N_{8j}$
P6: Demand management	90	10	1	1	0
P7: Tool management	30	10	0	0	0
P8: Material management	80	10	1	0	1
P9: Scheduling	80	10	1	0	0
P10: Manufacturing planning and control	70	10	1	0	1
P11: Manufacturing	40	40	1	0	1
P13: Nonconformity management	20	10	0	1	1
P14: Continuous improvement	10	0	0	0	0
P15: Reporting	90	50	1	0	0
P16: Maintenance	50	10	1	0	0
P17: Quality Control	50	20	0	1	1
P18: Visual management	40	5	0	0	0
P19: Waste management	30	10	0	0	0

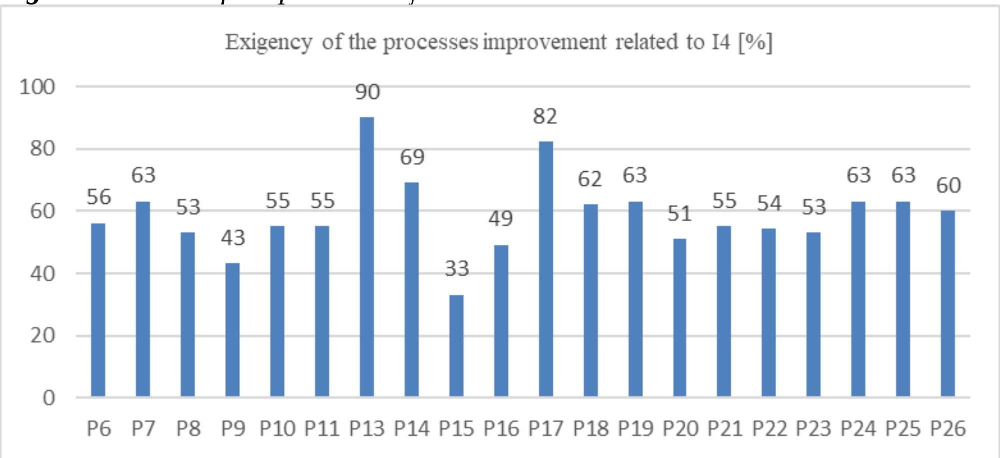
P20: Change management	40	10	1	0	0
P21: Purchasing	70	10	1	0	1
P22: Warehousing	80	5	1	0	1
P23: Dispatching	80	10	1	0	1
P24: Transportation	40	0	0	0	0
P25: Manipulation	20	20	0	0	0
P26: Delivering	80	0	1	1	0
Ratio [%]			60	20	40
Average [%]	55	13			

Source: *Own study.*

If we know the values of I4N factors for individual processes, we can also calculate the vertical values of factors as a ratio or average expressed in percentage as optional information. In Table 4 in its last two rows we can see what is the given exigency factor and its value for the whole set *m = 20* processes. The total level of informatization in the organization is 55%, the level of automation is 13%, the degree of integration of processes into the ERP system is 60%, the pressure of customers is 20% of processes and the pressure of suppliers is up to 40% of production and logistic processes. Of course, the pressure from customers and suppliers exists, because the range of intelligent technologies used is low in the given processes. If we look at the processes horizontally, we calculate the partial I4Nj indices for specific j processes. The values are shown in Figure 2.

We interpret the value of any partial I4Nj index as the pressure or exigency to improve a given process in relation to Industry 4.0. Improving the process in relation to I4 means deploying one of the intelligent technologies. We remind you that the final values of the partial I4Nj indices are reduced values according to the significance of individual factors.

Figure 2. *Values of the partial* $I4N_j$ *indexes*



Source: *Own study.*

Figure 2 shows that P13 processes have a high necessity to implement intelligent technologies and improve the process: Nonconformity management a P17: Quality Control. Middle necessity of process improvement achieved processes P6: Demand management, P7: Tool management, P8: Material management, P10: Manufacturing planning and control, P11: Manufacturing, P14: Continuous improvement, P18: Visual management, P19: Waste management, P20: Change management, P21: Purchasing, P22: Warehousing, P23: Dispatching, P24: Transportation, P25: Manipulation and P26: Delivering. Low necessity achieved only 3 processes P9: Scheduling, P15: Reporting and P16: Maintenance.

4. Discussion and Possible Extension of the I4N Index

Our I4N index for quantification of the process improvement exigency related to I4 is primarily applicable in industrial enterprises. As we stated earlier, this is not the limit for its application in another business environment. As we can see from the example of its verification in a real company, it can answer the need to improve processes according to individual exigency factors related to I4.

As shown by the verification in Table 4 and Figure 2, only two processes have been identified as having a high need for improvement, with improvement meaning the deployment of intelligent technologies. Most processes were in the interval of moderate need for improvement. If we analysed these partial I4Nj indexes, we would find that most of them are in the lower part of the interval. Three processes were identified with a low need for improvement related to I4. Of course, the need for improvement expressed in numbers does not refer to specific improvement measures. The I4N index highlights those processes that could be improved as a matter of priority. However, if we focus on specific I4N exigency factors in a specific process, then we will see which values are low and which are high.

If we identified a high need for improvement in two processes (P13: Nonconformity management and P17: Quality Control), we can analyse it in detail according to the importance of factors. Take the process P13 as an example. The most important factors are the level of informatization and the level of automation. As we can see in Table 4, the values of these factors are 20% and 10%. Therefore, the improvement in terms of increasing the share of informatization and automation of P13 process activities seems to be critical. The way to do this depends on the management of the company. Other important factors are the requirements of customers / customers or suppliers / suppliers for the implementation of intelligent technologies. The P13 process is under pressure from both the supplier and the customer. Therefore, the value of the partial I4N13 for the P13 process is so high. The priority of the company is therefore on processes that have reached values from 75 to 100.

Of course, the company can also decide for one overall number, which will be the arithmetic average of the partial I4Nj indices. In the case of our selected industrial enterprise, we calculated the overall I4N index as the arithmetic average of 20 values from Figure 2. The result I4N = 56% can be assessed in a global view as a limit of medium or even low need to improve processes. However, this arithmetic mean is only informative and it is important to know the partial values of the indices so that we can decide to improve a particular process. The expansion of our I4N index presupposes making several adjustments if it is implemented in a company other than a company with production and logistics processes. For example, if we wanted to define the I4N index in a company that provides services, we would have:

- to determine the set of m processes that we want to subject to quantification of process improvement exigency related to I4,
- to define the factor I4N1, which would characterize the type of enterprise, for example in terms of its size expressed by the number of employees,
- to define the factor I4N2, which would characterize the variability of services provided or the variability of customer needs.

We would like to implement the application of the I4N index in a non-industrial enterprise as follow-up research, therefore we currently do not consider the applicability of the I4N index only in manufacturing companies as a limitation.

5. Conclusion

The aim of our study was to create a mathematical model that could quantify the potential for improving processes related to Industry 4.0. We analysed these aspects in terms of the pressure that can actually act on the processes. We cannot determine in advance what measures the company must take, but we can identify where there is the greatest urgency to improve the process. Since process improvement is an elementary and fundamental part of the quality or integrated management systems, we have just designed our I4N index.

Our first goal was to determine a group of exigency factors conditioning Industry 4.0 implementation. We have defined 8 factors. We defined the factors with respect to the theoretical set of 26 production and logistic processes from previous research, thus fulfilling the second goal, which was to follow up on the previous research focused on quality managers and their future technological expectations related to Industry 4.0. Based on these two goals, we agreed that the main goal will be to develop the simple Industry 4.0 necessity index as a tool for quick identification of the processes improvement potential related to the selected exigency factors involved into the I4N index.

We designed the index as a system of mathematical relationships, which we also applied in a specific spreadsheet program. We validated I4N and determined the intervals of the process improvement necessity and then we verified the I4N index in the real industrial environment and quantified improvement potential of production and logistic processes coming from I4N index verification. We met the goals and we verified their fulfilment in the real practice of an industrial company. In the future, we have other research goals that we want to meet. The first is to modify the I4N index for service companies and the second is to apply the developed I4N index in a larger sample of enterprises.

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