Industry 4.0 Readiness Factor Calculation: Criteria Evaluation Framework

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Industry 4.0 concept today is an imperative for every manufacturing, but also the service company. In the most demanding situation are SMEs because of the high level of the financial investment during the digitalization period required. To make the investment and strategic plan as accurate and with less waste as possible the readiness factor should be calculated. It demonstrates the current situation in the company and gives the overview needed for the comparison with ideal Industry 4.0 model. There are several methods for readiness factor calculation already presented in the literature, but none of them has been shown as detailed enough for this situation. Since there are many influential criteria during the digitalization period, the multicriteria decision support has been chosen for the readiness factor calculation as a novel approach. In this paper the model for criteria structuring and evaluation will be presented with framework for the final calculation.

Keywords: *Industry 4.0, Readiness Factor, Decision support, Multicriteria optimization*

1. INTRODUCTION

Concept of Industry 4.0 is the result of the digitalization period within the company [1]. New technologies, flexible manufacturing, smart products, horizontal and vertical integration, new methods of human resources management and many more have to be achieved in the near future in order to remain certain competitiveness level on the market [2].

Changes in the hardware and software level require high financial investments which may seem as a hard challenge to the small and medium enterprises (SMEs) [3]. The big players on the market have already started the digitalization period, some are pretty much at the end of it and soon they will be able to offer high quality specialized products in the short period with less cost which results in lower prices [4]. This will strengthen their position as the market leaders and the gap between them and SMEs will get bigger with time. That is why is important as well for SMEs to accept the concept of the Industry 4.0 and start to invest in the future.

The benefits of accepting Industry 4.0 concept are following [5]:

- Mass-customisation of products to suit customer demands
- Real-time data on processes and equipment.
- More efficient maintenance
- Accelerated development of better products.
- Greater resource efficiency
- Reduced overheads
- Opportunities to access new markets and supply chains

That is why the readiness factor should be calculated as an accurate indicator of the current state within the company and the distance to the ideal state, the ideal model by the requirements of Industry 4.0. It will enable to create accurate strategic and investment plan for the transitional digitalization period.

2. LITERATURE REVIEW

Readiness factor has been a trending research topic in the last few years and most of them refer to the readiness by the terms of 4th industrial (r)evolution.

Readiness factor is being calculated by the online-forms in the study held RWTH Aachen where in which 289 Germany companies took part. The criteria were structured by six main influential factors: strategy and organization, smart factory, smart operations, smart products, data-driven services and human. The evaluation was provided on scale from 1 to 5 for every criterion, and the average result of each has been calculated and put a company into one of the five categories: outsider, beginner, intermediate, experienced, expert and excellence [6].

The similar self-assessment method has been developed by the pwc which enables identification of the need for action and does the benchmark against the other companies on the market. The evaluation is made on the two scales from 1 to 5, from which one is the scale that describes the actual state, while the second one is the target value which is wanted to be achieved within the next five years [7].

The Rockwell automation has conducted a study based on the six criteria: customer-focused innovation, process improvement, supply-chain management and collaboration, human-resource management, sustainability and global engagement. The possible result levels were: none, inadequate for current requirements, adequate but limited for current requirements and state-of-the-art and able to provide long term support [8].

Received: May 2019, Accepted: June 2019
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doi:10.5937/fmet1904841T
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One of the most scientifically recognized readiness factor calculation method is the Industry 4.0 Maturity model which includes nine dimensions and maturity items: Strategy, Leadership, Customers, Products, Operations, Culture, People, Governance and Technology. Maturity items have been rated on a Likert-scale reaching from "not important" to "very important". The maturity level was in the end calculated with as weighted average [9].

Another maturity level calculation method is three-stage maturity model. The new concept is being achieved in the fields of energy, electronics, digital businesses and advanced metal mechanic in three stages - Vision, Roadmap and Projects. Vision involves capacity and resources analysis and understanding of Industry 4.0; roadmap involves requirements and technology identification; projects involve training capacitation, risk management and projects definition [10].

In Croatia, the University of Split has conducted an analysis of current state of Croatian manufacturing enterprise based on the principles of the four industrial revolutions. The position within the four levels has been defined by the poll results by the criteria of product development, technology, production management, production monitoring, materials inventory management, management of stocks of finished products, quality assurance, PLM and TPS/GALP [11].

There are also several studies conducted by the large consulting companies like McKinsey and Co. [12] and Boston Consulting Group [13] which involves polls based on Industry 4.0 awareness and knowledge within the German and Austrian companies.

One additional readiness factor calculation approach is based on the level of standardization within the company where the conclusion is made that with increase of standardized processes the company is closer to achieving the Industry 4.0 concept [14].

2.1 The gap detection

By the projects and studies conducted in the literature, the problem structuring has been done within the entire company, based on the general criteria. Ideal model of Industry 4.0 hasn't been defined as the main goal of the transformation process and a referring point for comparison. The digitalization must be provided for both manufacturing and service companies in which the different criteria tend to be influential with different weights, which hasn't so far been taken into calculations. Also, each company can be divided into departments, and, in example, the accounting doesn't need to be on the same level of digitalization as the manufacturing department. The average number within the entire organization gives the basic overview but doesn't enable to create precise and accurate strategy to create optimal digitalization project. The changes to be made are a decision by several influential criteria. That is why the multi criteria decision support systems are to be tested as an adequate tool to be used for readiness factor calculation.

3. CRITERIA DEFINITION AND EVALUATION

First step in every multi criteria decision support methods is the problem structuring. The influential criteria and alternatives have to be defined by the group of experts, as well as the method for minimizing the human subjectivity influence.

Based on results of previous research, the criteria tree is best to be structured by departments and in this paper the accent will be put on the process planning [15].

3.1 Ideal model – Industry 4.0 reference

As a reference for the evaluation, the ideal model (ideal final state) of the problem observed has to be defined. Within process planning department, the new approach and function within the organization has been presented in the previous research, shown in Figure 1. The basic idea is that theoretical achievements in the field of Industry 4.0 merges process planning with operation sequencing and scheduling to create a “product planning” software. The software handles actions within all three mentioned parts automatically. It includes data mining and DSS as optimization and control system while collecting data from every part of the organization, storing in the databases and is use for the required actions and continuous optimization [16].

3.2 Criteria tree definition and evaluation framework

Based on the requirements of the ideal model the following criteria has been structured by the brainstorming process of group of experts. The criteria are entitled into three major groups: hardware, software and human and organization. In the ideal Industry 4.0 concept every criterion is present and fully digitalized. With the readiness factor calculation, the goal is to determine the presence of certain criteria and the current stage of development. After the criteria definition, their evaluation must be conducted.

Since the evaluation is different for each company, it can be conducted with several methods:

- Semi-structured interview [17]
- Poll [18]

The advantage of semi-structured interview is the fact that is opened to new ideas that could come along with conversation and have an influence on the criteria tree with increase or decrease of criteria number.

The poll can be structured as the Saaty scale for Analytic Hierarchy process [19], but the potential pitfall is that there could be a high risk of inconsistency. Therefore, it can be an option for further phase of readiness factor calculation where the criteria and alternative evaluation can be proceeded with both group of experts and people from the company. Based on the poll, the semi-structured interview is best to be conducted.

The questionnaire is structured in two parts:

1. General information. Info about the company and the person participating in the poll. It gives a descriptive overview of a problem.
2. Technical questions. Based on ideal process planning state (“product planning”) and presents of its features.

The semi-structured interview is to be held in several manufacturing companies in Croatia. The respondents preferably be process planners or managers who are aware of current situation within the department.

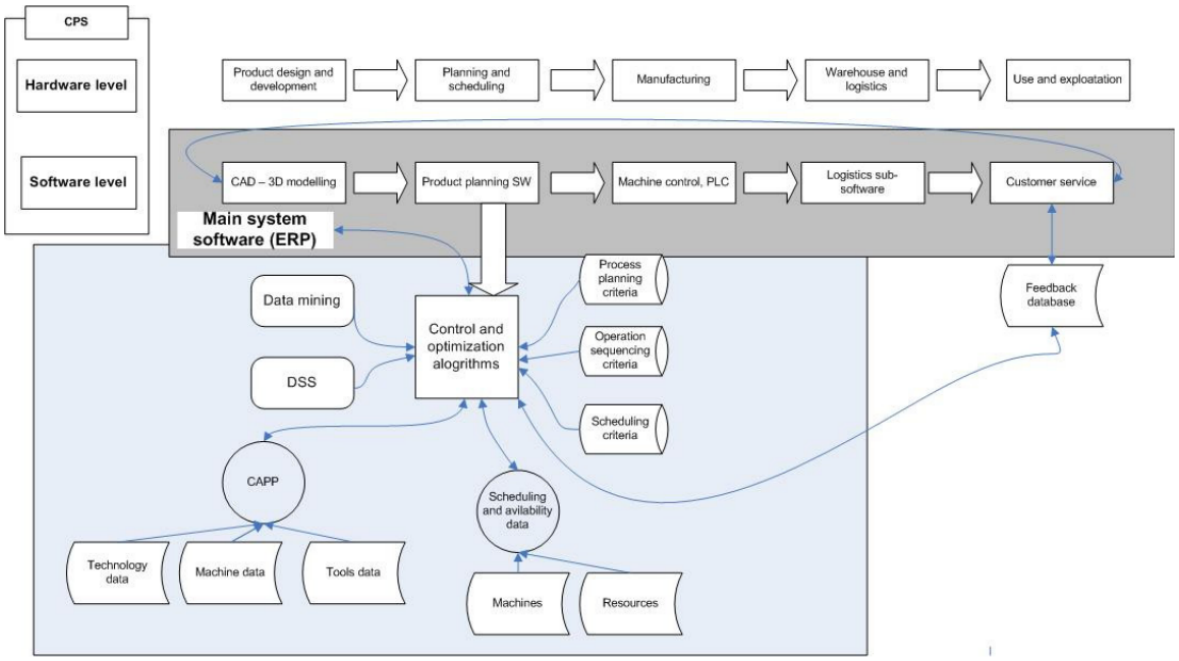

Figure 1. "Product Planning" model [16]

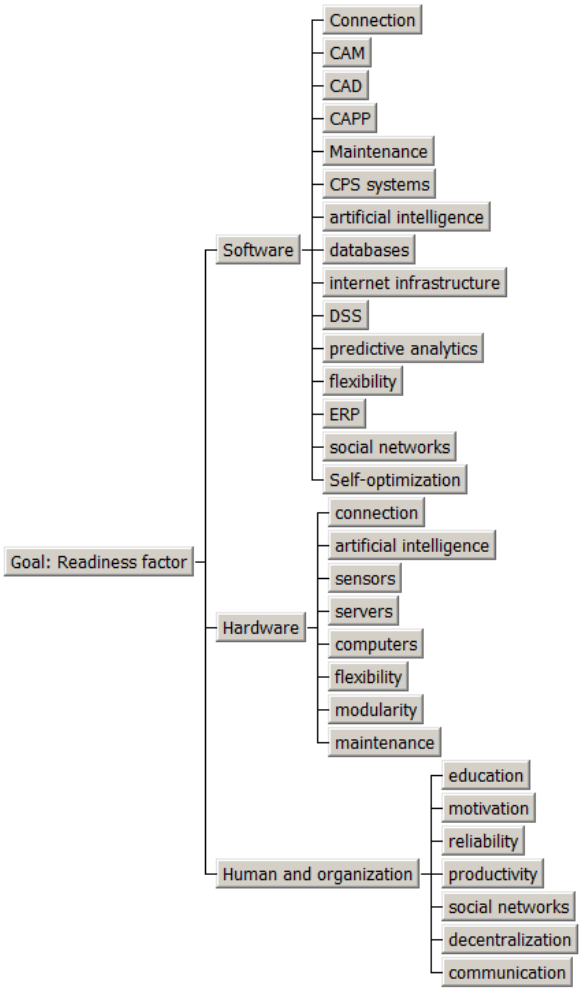

Figure 2. Criteria tree

They will be evaluated individually, and the results will be calculated by use of a single or a combination of multi criteria decision support methods. Also, it is very important to conduct the semi-structured interview with several employees from a single company. The most important one is obviously process planner, but also the upper and lower management should be contacted and examine their visions and impressions of the current state and future goals. Results should be comparable and by means of statistical methodology the average score from a single company should be calculated.

Table 1. Readiness factor survey questions

Question	Criteria	Type
Company name		general
Position		general
Level of education		general
Product type		general
From which countries most of your suppliers and customers come from?		general
Have you heard for Industry 4.0 before?		general/ technical
How often do you exchange information with other departments?	Software/hardware connection/communication	technical
What type of communication is available (oral, e-mail, social network…)?	Software/hardware connection/social networks	
What kind of Internet infrastructure is available?	Connection/servers	
What kind of hardware do you use for process planning?	Computers/sensors	
What kind of maintenance is provided for the hardware and software that you are using?	maintenance	
Are you using CAD software?	CAD	technical
If yes, how often?		technical
If yes, which software are you using?		technical
Are you using CAM software?	CAM	technical
If yes, how often?		general

If yes, which software are you using?		technical
Have you heard for CAPP?	CAPP	technical
Do you have an archive database of product's technological processes?	database	technical
Do you use data from the archive for generating process plans of new products?	Predictive analytics/	technical
Is process planning done by single or more persons?	Automation level	general
Do you have a database of technologies, machines and tools for process planning?	Databases/ERP	technical
If yes, is it digital or physical?	Databases/ERP	technical
If is digital, is which software is it developed?	Predictive analytics	technical
How do you define technological times and product prices?	flexibility	general
Can you define every element of cost for a single product?	Databases, productivity	general
Can you define every element of time for production of a single product?	flexibility	general
Do you have product and process control mechanisms and strategy?	Maintenance, self-optimization, artificial intelligence	technical
If yes, which one?		general
Are the failures within the processes achieved and analysed?	Self-optimization	technical
If yes, is the archiving and analysis process digital or manual?		technical
How would automation influence on your process planning department?	reliability	general
When process planning, what is more important - manufacturing time or price?	Flexibility/CAPP	general
Do you choose machines based on availability or the quality?	CAPP	general
Do you use work study methods?	CAPP/CAM	technical
Do you have product manufacturing times achieved?	CAPP/ERP/databases	technical
How do you calculate single product manufacturing time?	CAM	technical
Do you, as a process planner, receive a feedback about product from your customers?	communication	technical
How much human subjectivity is involved in process planning?	Decentralization/communication	general
Are you connected with product design and construction department?	Communication/social network	technical
If yes, how fluent is your communication?		general
Are you connected with manufacturing department?	Communication/social network	technical
If yes, how fluent is your communication?		general
Has the machine availability influence on the process planning?	flexibility	general
How much of waste on average is being generated in the process?	Education/databases	general
Do you archive the waste generated in the process?	education	technical
Do you use lean tools and methods?	education	general
If yes, which?		general
How useful do you think are the lean tools in your department?		general
Do you accept innovative ideas and methods regarding process planning department optimization and improvement?	Productivity, motivation	general
Do you have a specific algorithm by which you define technology and its features?	CAPP/CAM	technical
If yes, which?		general
Do you have a specific algorithm by which you define operation sequencing?	CAPP/CAM	technical
If yes, which?		general
Do you use software in process planning?	CAPP/CAM/CPS systems	technical
If yes which?		general
If no, why not?		general
How would digitalization influence on process planning department improvement?	education	general

3.3 Data analysis framework

Only one person from the interview in a single company might not give the accurate data. That is why several employees will be interviewed and the accuracy of their answers will be tested with the help of the following statistical methods.

Since the sample size is rather small and the most variables are qualitative and non-normal the non-parametric tests are to be used. The main method will be Kruskal-Wallis test [20] to prove the similarity between two or more samples which could come from either the same or different population. The resulting average ranks will be used as a suitable metric for defining the decision support software parameters.

4. CONCLUSION

Industry 4.0 concept as the result of the digitalization period is a goal which every both manufacturing and service company should aim at. Changes to be done are significant and may require high financial investments. Any mistakes in the digitalization process might cause of big waste in the future. To avoid possible threats, to minimize the risk and optimize the digitalization strategy, readiness factor calculation is advised to be calculated. There have been several research projects in the literature which give a general overview about the

knowledge of Industry 4.0 and rough readiness calculation based on general criteria. Novel method of readiness factor calculation presented in this work uses multi criteria decision support methods. The criteria are to be structured by departments and generated by the theoretical structure and characteristics of "product planning software" from the previous research within the project and brainstorming process of group of experts. Based on criteria, the questions for semi-structured interview are defined and grouped. Future work includes interview realization and results evaluation by multi criteria decision support methods whose final result will be readiness factor.

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РАЧУНАЊЕ ФАКТОРА СПРЕМНОСТИ ЗА ИНДУСТРИЈУ 4.0: ТЕОРИЈСКА ПОСТАВКА ЕВАЛУАЦИЈЕ КРИТЕРИЈУМА

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Концепт Индустрије 4.0 данас је императив у сваком производном саставу, али такође и у услужном сектору. Највећи изазов се поставља пред мала и средња предузећа због потребе високих инвестиција током периода дигитализације. Како би инвестицијски и стратешки план били оптимално постављени уз што мање губитака, потребно је израчунати фактор спремности.

Ради се о показатељу тренутке ситуације и поређењу с идеалним моделом Индустрије 4.0. У научној литератури је доступно неколико метода прорачуна, но нити једна од њих није се показала довољно детаљном. Будући да се ради о проблему с много утицајних критеријума, метода вишекритеријумског оптимизирања одабрана је за прорачун фактора спремности као иновативан приступ решавању проблема. У овом раду биће представљен модел структурирања стабла критеријума, њихова евалуација уз теоријску поставку коначног прорачуна фактора спремности.