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Non-comparative, Industry 4.0 Readiness Evaluation for Manufacturing Enterprises

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***Abstract* – The industry of 21st century, the series of innovations, developments in information and communication technology (ICT), Cyber-physical systems (CPS) and the introduction of tools and services in the production process, which in turn affects the economic players, thus influence regional competitiveness and behaviour. Industry 4.0 has become by now a global slogan and its ideas can be recognized in the industry development and industry digitalization policies pursued by individual countries and the priority of which is to improve the competitiveness of the given country. For measuring the positions of countries and enterprises there are many comparative Industry 4.0 Readiness evaluation methods, mainly based on the recommendations of international consulting firms. The paper proposes a total different approach by the illustrated, non-comparative Industry 4.0 readiness evaluation method that is fully personalized to the manufacturing company evaluated.**

I. INTRODUCTION

The industry of 21st century Europe faces significant challenges. The ever-decreasing raw material supply, the rising energy prices and the demographic changes necessitate the modification of the existing model in the intensifying competition.

The Hannover Fair of 2011 opened a new era in the German industry: this is when a new scientific project, Industrie 4.0 – the Fourth Industrial Revolution, was first published; according to which in the future smart products will be manufactured in smart factories for the global market [1].

The series of innovations, developments in information and communication technology (ICT), Cyber-physical systems (CPS) and the introduction of tools and services in the production process, which in turn affects the economic players, thus influencing regional competitiveness.

However, the Industry 4.0 concept can be found in politics, media and technology and also among scientists and manufacturers [1], moreover well-known international consulting firm analyse and evaluate it, but many open questions, uncertainties and challenges are to be solved in order to realize the 4th Industrial Revolution.

In the paper the Abstract and the Introduction is followed by the description of the comparative Industry 4.0 Readiness measurement methods on macro and on micro levels, too. The next paragraph contains the introduction of the non-comparative, personalized Industry 4.0 Readiness measurement that is the main aim of the paper; it is followed by an illustration of an example readiness evaluation using the proposed methodology at a key manufacturing company. Conclusions, acknowledgement and references close the paper.

II. COMPARATIVE INDUSTRY 4.0 READINESS MEASUREMENT

Measurement of the advancement together with its success, the evaluation of the related performance and the comparison of the competition positions is a natural, daily demand. One can differentiate comparisons and evaluation on macro and micro level, where macro level is in relation to the countries, while the micro level is valid among enterprises and other market members.

A. Macro level competitiveness and Industry 4.0 readiness measurement

Industry 4.0 has become by now a global slogan and its ideas can be recognized in the industry development and industry digitalization policies pursued by individual countries and the priority of which is to improve the competitiveness of the given country [3] by enhancing its innovation capability and digitalization.

The demand of measuring progress and success being made as well as the need to compare and match individual performances and the exact presentation of competitive positions is a common expectation and forms a part of our everyday life. Although Krugman [4] and

Porter [5] have an opposite view of whether competition between countries can be interpreted at all, the need for comparison appears in many contexts.

The present chapter provides a brief overview of the relevant macro and microeconomic rankings and surveys underlying the practically all publicised surveys of Industry 4.0.

The relevant annual publication of the World Economic Forum (WEF), "The Global Competitiveness Report" is a macro level competitiveness index of great significance.

This is a derived ranking resulting from complex, multivariate analysis and information concentration, which includes direct or indirect criteria relevant for us concerning industry, R&D&I and digitalization. The document provides a detailed description of the structure, the calculation method, the input data and the resulting competitiveness ranking of the Global Competitiveness Index (WEF GCI) [6]. The competitiveness index defines 15 so-called pillars (Fig. 1: The pillars of the Global Competitiveness Index [6]), which provide the final ranking of the countries derived from 300 indicators.

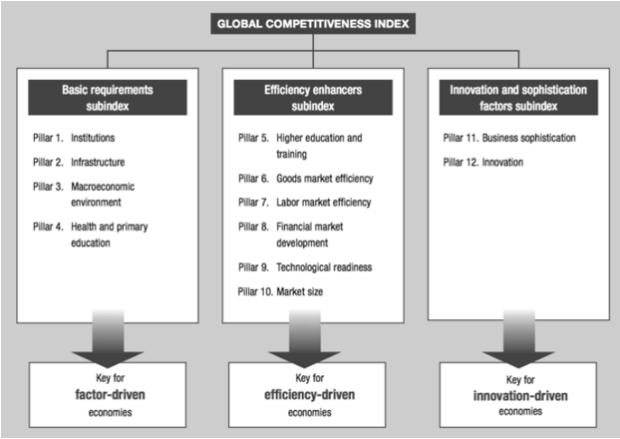

Fig. 1. The pillars of the Global Competitiveness Index [6]

Considering the Industry 4.0 related rankings the mostly referred document is the yearly published study of the Roland Berger consulting firm publishing the so called Industry 4.0 Readiness Index [7].

Table 1. compares in years 2014 and 2015 the WEF CGI index for measuring the economy ranking of the individual countries and their ranking according to the Roland Berger Readiness Index. It represents clearly their strong correlation with positive sign, indicating if a country is ahead according to the Industry 4.0 Readiness it means it is ahead also according to its economic development. E.g. Sweden is the third according to the Industry 4.0 Readiness Index while it is the fourth in the WEF order.

Table 1. Roland Berger Industry 4.0 Readiness Index ranking the WEF country economy development order comparison representing their strong correlation.

Country	WEF 2015	RB 2015	RB 2014	WEF 2014
Austria	9	9	8	8
Belgium	7	7	3	7
Bulgaria	18	23	22	18
Czech Republic	12	11	11	14
Germany	1	1	1	2
Denmark	6	8	6	6
Estonia	11	14	17	11
Greece	23	22	23	23
Spain	13	13	16	12
Finland	3	4	2	1
France	8	10	10	9
Croatia	22	21	21	22
Hungary	20	12	15	19
Ireland	10	2	4	10
Italy	17	16	13	17
Lithuania	14	15	18	15
Netherlands	2	5	7	3
Poland	16	20	20	16
Portugal	15	19	19	13
Sweden	4	3	5	5
Slovenia	19	17	14	20
Slovak Republic	21	18	12	21
United Kingdom	5	6	9	4

As conclusion, on macro level the Industry 4.0 readiness and country development are in strong correlation, consequently, it is worth to make analysis on micro level, too.

B. Micro level competitiveness and Industry 4.0 readiness measurement

Considering the strong correlation of the competitiveness and the index of industry 4.0 readiness, it is valuable to compare the Industry 4.0 Readiness among companies of a country/economy, too. There are many developments for that approach, mainly operated by well-known consulting firms, as presented in the next paragraphs.

Roland Berger European Industry 4.0 Readiness Index

Concerning the Industry 4.0 there is a Country Ranking referred to by readiness in most cases called Roland Berger Industry 4.0 Readiness Index [7] being published by the German Roland Berger Strategic Advisory Company in March of each year.

The internal structure of the index is composed of the core categories such as Industrial Excellence and Value Network.

Categories have sub-categories, such as production process sophistication, degree of automation, workforce readiness innovation intensity, in the second one high value added, industry openness innovation network

internet sophistication on a scale from one to five.

The combination of the scores obtained in the categories gives the degree of readiness / excellence level of a country in Industry 4.0. This is represented on the vertical axis of a graph, while on the horizontal axis a conventional index, the ratio of the manufacturing industry within the GDP is placed.

The countries in the graph (Fig. 2.: Roland Berger Industry 4.0 Readiness Index 2014 [9]) form four larger groups.

- *Frontrunners* are characterised by broad industrial base, modernized, development-oriented business conditions and application of technologies.
- *Traditionalists* are primarily from the countries of Eastern Europe. They still live from their former industrial base having to some extent even now healthy structure.
- For the group of the *Hesitators* – states of Southern and Eastern Europe – there is a lack of reliable industrial base. Many of them are struggling with serious government finances and are not able to transform their economy with security for the future.
- The former strong industrial base of the *Potentialists* has weakened during the recent years.

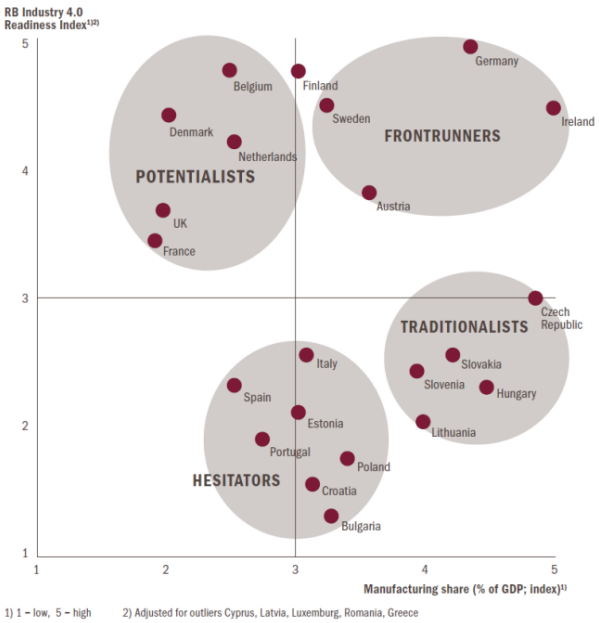

Fig. 2. Roland Berger Industry 4.0 Readiness Index 2014

Capgemini Maturity Model

In 2012 mostly ignoring or denying responses came to the question staying in the focus and title of the research „Are Manufacturing Companies Ready to Go Digital?" [8]. Two years later the situation has changed entirely: the vast majority of manufacturing companies acknowledged the need for digitization and recognized that Digital Transformation is essential for ensuring sustainable competitiveness and is a key driver for profitable growth. The study shows [9] that Digital Transformation has been emerged as a strategic imperative for the manufacturing sector.

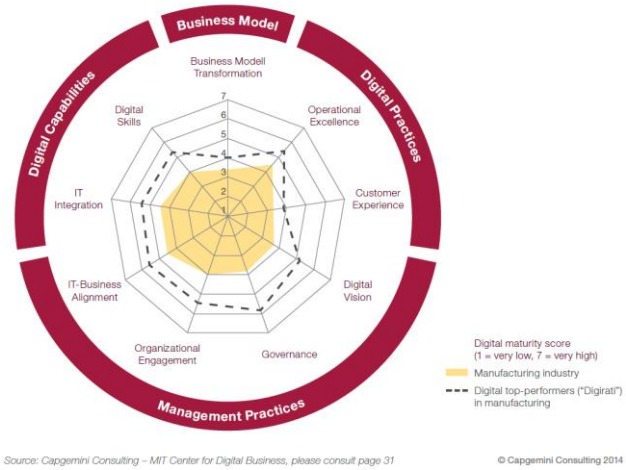

Fig. 3. Capgemini Maturity Model

As a main outcome of the joint research program with the MIT Centre for Digital Business, they have benchmarked the digital maturity of approximately 400 large companies from more than 15 different industries in 30 countries [10].

Despite the recognized needs the average manufacturing company is digitally just „beginner" or „student". The level of digital maturity is still very low in the dimensions of business model, digital practice, management practice and digital capabilities (Fig. 3.: Capgemini Maturity Model [2]). Only at some specific factors such as operational excellence arise the fact that the majority are actually heading towards the digital world.

Fraunhofer Survey

In 2013, 661 people having business experiences were interviewed by the Fraunhofer Institute [11]. 75,5% of them are also senior executives (managers) at the companies participating in the survey. 49% of the respondents came from the machine and equipment industry or from their service industry, 11,5% were interested in the automotive industry. The remaining respondents came from other areas (construction, food industry). 21 leaders are named and widely acknowledged experts, 10 of them were selected from the economy sector, 5 from associations and chambers and 6 from the academic sector (Fig. 4.).

Fig. 4. Fraunhofer survey.

The Fraunhofer has examined the following key questions for this study:

- What kind of development of production works do the German manufacturing (production) companies expect?
- Which solutions for successful production work will result from the use of new technologies such as mobile devices, cyber-physical systems (CPS) and social media in production (manufacturing)?
- What kind of impact will have the megatrend flexibility on the production work (manufacturing)?

Numerous of questions were as follows:

- Questions regarding the enterprise (company and business) (4)
- Issues regarding the industrial production of the future (8)
- Production Management (10)
- Employees in manufacturing (production) (21)
- Rules and regulations (5)
- Cooperation between production and product development (3)

VDMA Questioner

The purpose of the survey [1] of the Verband Deutscher Maschinen- und Anlagenbau (VDMA) was to explore the present dimensions of the imagined future, making the plans tangible and transforming them into business reality. In order to attain this they developed a model taking into account the readiness, skills and capabilities of the companies in the realization of the Industry 4.0 concept. Based on the results of the empirical survey categories have been set up enabling the individual companies to rank their positions in readiness competitions.

The model is composed of four dimensions closely related to Industry 4.0 as well as of two other ones that can be interpreted in general terms. Each dimension is divided into further sub-categories.

VDMA has 6 dimensions:

- Strategy and organisation
- Smart factory
- Smart operations
- Smart products
- Data-driven services
- Employees

If the phenomenon Industry 4.0 is commonly understood as the progressive convergence and merging of the physical and virtual world by the development of informatics, ICT and manufacturing automatization, we can say that the dimensions 2 and 4 form the physical world while dimension 3 and 5 refer to the virtual mapping of the physical world. The dimensions 1 and 6 introduce two universal criteria into the study.

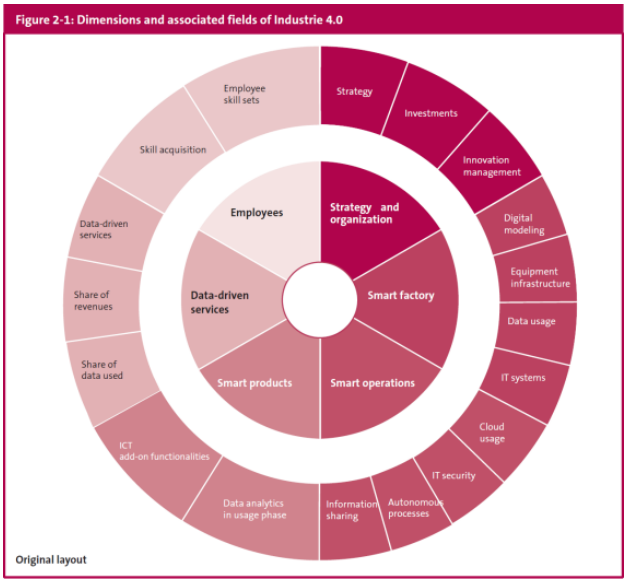

Fig. 5. Structure of VDMA questionnaire.

These 6 dimensions are gradually expanded (detailed, explicated) over several levels until we reach the minimum requirements (Fig. 5. Structure of VDMA questionnaire). Responses to the questions put to these requirements will be incorporated into the qualification of the Industry 4.0 Readiness Index through assigned scoring.

The original survey of IMPULS included 214 companies from more than 20 industry segments representing both SMEs and large companies.

III. NON-COMPARATIVE INDUSTRY 4.0 READINESS MEASUREMENT

The previous paragraphs described and proved how valuable are Industry 4.0 evaluations using comparative measuring methods, among countries on the macro level and among enterprises in micro level. These analyses are very useful in order to appoint development and strategy directions and to allocate the related resources efficiently. On the other side the evaluation methods are comparative

resulting in that they require collaboration and information sharing of the member countries and enterprises. Consequently, an active, continuously operated comparative analysis requires huge efforts from the members and also from a central organization that manages the complete network. E.g. nowadays it is performed typically by the big international consulting firms on macro level and by many other kinds of organisations like benchmarking clubs on the micro level. The paper introduces a total opposite approach enabling companies to evaluate themselves without the need of any cooperative networks, so on a non-comparative way.

A. Non-comparative, personalized Industry 4.0 readiness measurement

The proposed approach requires an information source about advanced, recent Industry 4.0 examples that can be used by the company that needs to be evaluated according to its Industry 4.0 Readiness. In the other aspect the non-comparative evaluation should be personalized reflecting on the given company market position and working environment; consequently, the content of the Industry 4.0 Readiness analysis is changing and different company-by-company.

In the concrete case the readiness measurement was performed by a collaboration of the research institute and the manufacturing company of the authors.

Considering the content of the evaluation, the main topics of the comparative analysis are applied in most of the cases; however their deepness and some individual topics shall be harmonized to the measured company. In harmonization with the comparative analysis the following main aspects are proposed for the non-comparative Industry 4.0 Readiness evaluation:

- Strategy
- Leadership
- Offered Products and Services
- Customers
- Company Culture
- People
- The following three technical aspects are personalized:
    - Production Support
    - Production Execution
    - Digital Production
- Critical areas of intervention

The measurement method is a questioner in which many questions and topics in the above listed aspects are asked form the key, typically functional and general management people of the analysed company. Each question is measured in two aspects by a discrete scale:

- Rating of Level of Completion
- Rating of Relevance for Successful Implementation

This measuring technique results in qualitative values of the individual questions, however after the fill-in of the questioner personal interviews extend (significantly) the numerical measures.

The above, not personalized aspects (Strategy, Leadership, etc.) were also modified in comparison to the comparative analysis, typically less detailed and more personalized questions are formulated.

The following paragraph represents some examples of these individual viewpoints personalized for the evaluated company.

B. Examples on non-comparative, personalized Industry 4.0 readiness measurement

A general questioner was prepared, discussed and harmonized with the analysed company experts in order to prepare the personalized questioner. The following part gives three examples for the individual questions per the above appointed aspects with comments about the experiences about the required modification of the general questioner.

- Strategy
    - Availability of resources for Industry 4.0
    - Compatibility of Industry 4.0 with company strategies
    - Industry 4.0 position of your company in relation to competitors

    In this aspect the number of the general questions were decreased and simplified, mainly because the parties know the company behaviour relatively well.
- Leadership
    - Management competences and methods to realize Industry 4.0
    - Existence of central coordination for the realization of Industry 4.0
    - Availability of Industry 4.0 business models

    In this viewpoint the amount of questions was decreased significantly because of the prescribed management structure of the company.
- Offered Products and Services
    - Possibility to individualize products
    - Existence of embedded systems in products
    - Possibility to digitalize products

    Because the product structure is relative simple and fixed, the questions were fully personalized.

- Customers
  - Openness of partner plants to new technology
  - Competence of partner plants with digital solutions
  - Integration of partner plants into company activities

  The very specialized market presence of the company indicated the individual formulation of the related questions.
- Company Culture
  - Inclusion of employees into change process
  - Openness of external stakeholders to innovation
  - Adaptability of the company culture to Industry 4.0

  In this aspect not too many modifications were implemented.
- People
  - Openness of employees to new technology
  - ICT competence of employees
  - Motivation to create and promote innovative ideas

  The original questioner was not modified significantly in comparison to the general content.
- Production Support
  - Automatic process plan generation with incorporating knowledge from operators and production data (process plan re-definition)
  - Production plan information sharing (for suppliers)
  - Early failure detection solutions

  This aspect was created in a general way but personalized through detailed discussions.
- Production Execution
  - Unique product identification
  - Component incorporation tracking
  - Auto-configuration of the resources (new/modified functionalities)

  Production execution is a general topic in all manufacturing plants and after the creation of a general question list; (typically) many questions were deleted or re-formulated according to the given specialities.
- Digital Production
  - Digital simulation of the production environment
  - Digital forecast of the production based on simulation
  - Software support for applied lean techniques

  Digital production is an aspect prepared especially for Industry 4.0 readiness viewpoints of manufacturing firms. Many examples were collected and personalized by common discussions.
- Critical areas of intervention

  This aspect is discussed according to the hierarchical management and organisational structure of the analysed company.

The above list highlights some examples and comments of the personalized, non-comparative Industry 4.0 readiness evaluation in the collaboration of the research institute and the manufacturing company of the authors.

IV. CONCLUSIONS

The paper introduced a novel, non-comparative Industry 4.0 readiness evaluation methodology personalized for individual manufacturing enterprises as a special form of company diagnostics. There exist many comparative techniques to evaluate the Industry 4.0 readiness of enterprises but they need significant efforts for cooperating and information sharing among many companies. To overcome this management issue the introduced method is proposed.

The proposed approach does not need an extensive company collaboration it requires only an information source about advanced, recent Industry 4.0 examples that can be used by the company that needs to be evaluated according to its Industry 4.0 Readiness. In the other aspect the non-comparative evaluation is also personalized reflecting on the given company market position and working environment; consequently, the content of the Industry 4.0 Readiness analysis is changing and different company-by-company.

The paper describes the applied questioner structure and shows some examples of an individual, personalized Industry 4.0 readiness measurement method prepared for a key manufacturing enterprise.

V. ACKNOWLEDGEMENT

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