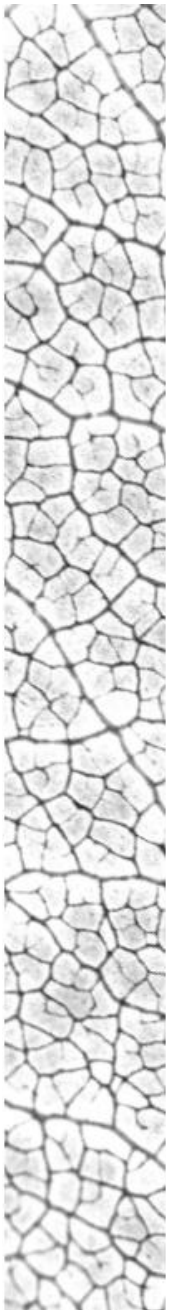

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A methodology to assess innovation performance in digital economy

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Abstract
The paper addresses a methodology to assess the innovation performance of an enterprise adapted for the context of the digital economy, automation and robotisation. The problem of developing modern assessment methodologies is extremely relevant, as the transition to the digital economy is increasingly marked by the adoption of digital technology in production processes. Such technologies make principal elements of the production chain and facilitate the enterprise's innovation potential. HR approaches are changing. Beyond just facilitating certain functions, humans emerge as a principal agent of intellectual effort and initiative and control robotisation-driven production processes. Change also occurs in organisational structures; new approaches emerge, such as intrapreneurship, which relates to high-risk projects run by proactive staff using internal resources of the enterprise. New forms of cooperation between businesses and the state are shaped, envisaging partnerships and information exchanges. All the above changes should be taken into account in the assessment of an enterprise's innovation performance. The aim of this paper is to develop a methodology to assess innovation-related indicators, taking into account the digital transition. The problem bears high relevance as enterprises constantly need to assess their own and their competitors' innovation standing. The primary scholarly contribution reflects the alignment of the proposed methodology with the requirements and specifics of the digital economy. The findings are applicable in real business environments, which substantiates their practical significance. The paper relies on a variety of research methods, primarily analysis and synthesis. These methods combined make the research tool.

Keywords: assessment method, innovation potential, innovation activity, innovation operations, innovation, digital economy, indicators

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INTRODUCTION

The digital economy transforms the conventional structures of the industrial economy, shaping the leading role of innovation for business development and competitiveness. Innovation potential and innovation activity are variables describing innovation operations and defining the respective function.

Changes brought by the digital transition result in shifts in the methods of innovation operations, innovation potential and innovation activity. New technology helps to significantly improve production efficiencies and margins in relation to costs. Automated and robotic technologies only require limited human engagement associated with exclusively control and setup functions [Gubán, et al. 2019, Kasa. 2020]. Technologies such as augmented reality and virtual reality provide even better visibility in terms of data representation. Big data draws a more comprehensive analytical picture. Humans become the principal intellectual agent of the production chain and come to perform exclusively intellectual tasks [Benavente, Dutta, Wunsch-Vincent. 2012]. This transformation is driven by changes in HR approaches. Opinions of line staff are increasingly taken into account in strategic elaborations; a reorientation occurs toward the lower management level. To develop the innovation potential of employees, continuous trainings are conducted, specifically in digital technology [Nikonova. 2019 Fawad, Tasweer, Afshan. 2020- Spiro. 2018]. Organisational structure and management are also changing constantly. Platforms

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are established to support joint efforts between several businesses and the state on the most complicated and expensive projects. Such platforms are known as clusters [Mariev, Nagieva, Simonova. 2020- Mariev O, Nagieva K, Simonova V. 2020- Sazonova, Kuzmenko, Terekhov. 2020]. New tools are adapted for attracting ideas and investment projects: hackathons, business accelerators [Leshchukh. 2019- Leshchukh. 2019- Pearson. 2020].

Innovative management and innovative facilities today play a crucial role for businesses, which brings about the need to provide for continuous assessments of the levels of innovation operations, innovation potential and innovation activity at an enterprise, which calls for approaches suitable for the new technological wave [Pearson. 2020, Mills-et al. 2019]. The development of a new methodology will open the way for objective assessments of an enterprise's innovation performance and the level of resource accumulation for running innovation operations and would contribute to proper alignment of the innovation strategy [Walcher, Wöhrl. 2018, Walcher, Wöhrl. 2018].

The state needs to conduct assessments of enterprises' innovation positions as it makes decisions to provide funding, grants and subsidies.

Investors need assessments of innovation levels to ensure maximum dividends on their contributed capital.

That is why it becomes crucial to develop new methods to assess innovation operations, innovation potential and innovation activity in the changing environment of the digital economy, taking into account the occurring changes in technology and management.

The object of this study is innovation operations, innovation potential and innovation activity of an industrial enterprise.

The subject relates to the methods of assessment of innovation operations, innovation potential and innovation activity of an industrial enterprise.

The aim of this paper is to describe and develop a methodology of measuring innovation operations, innovation potential and innovation activities of an industrial enterprise.

METHODS

The study refers to previously developed assessment methods for innovation operations, innovation potential and innovation activity of enterprises and regions. Such methods were proposed by Russian and foreign researchers.

Russian researchers are specifically M. A. Tobien, A. O. Tobien, N. E. Tsukanova, V. Iu. Koniukhov, D. V. Gaiazova, Iu.V. Babanova, V. P. Gorshenin, O. Iu. Efimova, E.N. Kartashova, V. M. Trofimov, N.V. Maksimova, Z. E. Shaporova, V. N. Riapukhina, E. V. Mukaseev, M. V. Gililov, I. G. Kukukina, S. V. Eremeeva, V. E. Kaup, G.P. Beliakov, A. S. Dubinin, V. M. Momot, E. N. Ilchenko.

Foreign research includes works by Richard Kasa, Daniela Benavente, Soumitra Dutta, Sacha Wunsch-Vincent, Miklós, Gubán, as well as methods for measuring regional innovation profile such as the Global Innovation Index [Wunsch-Vincent 2018], the methodology of European Innovation Scoreboard [Hollanders. 2020], European Regional Innovation Scoreboard [Munenge. 2018], Portfolio Innovation Index [Portfolio Innovation Inde].

Russian methodologies are different in making a clear distinction between innovation potential and innovation activity in measurements of innovation operations, though both of former define the functional relationship of the latter, while foreign methods address an object's innovation profile, determining its innovation potential and innovation activity only as constituents.

Both Russian and foreign authors have thoroughly developed mathematical methods for calculating an ultimate integral score of innovation operations taking into account all significant factors and extremes. The difference between the methods lies in the use of different data preparation and normalisation techniques and in applying different mathematical approaches to derive the ultimate score of innovation operations.

E. g., the ultimate score of innovation operations is calculated as the arithmetic mean of its constituents according to the following formula (1):

$$I = \frac{i_1 + i_2 + \cdots + i_n}{n} \quad (1)$$

where I is the ultimate integral score; $i_1, i_2, \dots, i_n$ are the values of group scores; n is the number of group scores.

Another approach is to use the n-th root method to calculate the integral score of innovation operations according to (2):

$$I = \sqrt[n]{i_1 * i_2 * \dots * i_n} \quad (2)$$

where I is the ultimate integral score of innovation operations; $i_1, i_2, \dots, i_n$ are the values of group scores; n is the number of group scores.

Both Russian and foreign methods derive the ultimate integral score only including basic criteria associated with degree-level staff numbers, percentage of funding allocated to innovation, equipment or staff trainings. Such basic criteria are insufficient in the digital economy, as many new techniques and management approaches emerge, which are integral to innovation operations. The traditional assessment methodology has to be expanded with new criteria characterising the degree of the enterprise's readiness to engage in innovation operations in the context of digitalisation and the pace of digital adoption.

The research addresses the problem of developing new criteria of innovation operations, innovation potential and innovation activity and building a system to

assess and derive an integral score by applying mathematical tools.

RESULTS

A principal distinction of the methodology is the dual measurement of innovation operations. The first approach refers to the functional relationship between an enterprise's innovation operations and innovation potential and innovation activity as shown in formula (3):

$$IO = f\{IP; IA;\} \quad (3)$$

where IO is innovation operations; IP is innovation potential; IA is innovation activity.

i.e., innovation performance is in a functional relationship with innovation potential and innovation activity, which, following a mathematical sequence, produce an integral score of innovation operations.

This method of assessment requires an abundance of input data, while the output, beyond the ultimate integral score, also comprises group scores characterising the development of partner networks, goodwill levels, staff development and levels of commitment to staff, equipment, R&D, levels of adoption of innovation technology, innovation-supportive organisational structures, open innovation and HR innovation. This provides a comprehensive assessment of the enterprise and an identification of weaknesses and growth areas by respective scores. Where a group score is low, this implies the need to contribute funds to advance the respective line of business.

The second method relies on an initial assessment based on public data retrieved from the Internet, tax authorities or paid-for SPARK database. It takes limited time and a much narrower scope of criteria. A disadvantage of this method is that it does not produce group scores. Such initial assessment only serves to assess innovation operations in general without isolating specific lines of business requiring additional commitment. However, such assessment would not take any confidential input, data inquiries or much time. This method can be used by competitors and investors for strategic decision-making.

Table 1 lists the proposed criteria of innovation potential and innovation activity in the digital economy, as well as the criteria for the initial assessment of innovation operations.

The method for assessing innovation activity comprises 38 criteria, including 21 relating to innovation potential and 17 relating to innovation activity. The assessment of innovation potential development comprises nine groups of criteria. Innovation activity assessments comprise seven groups of criteria. A major group of new criteria reflects the adoption of new technology, HR innovation, innovation in organisational structure, open innovation. Traditional criteria are those in groups such as Staff, R&D, Equipment, Goodwill levels.

Table 1. Criteria of innovation potential, innovation activity and innovation safety of an enterprise

Innovation operations	
Innovation potential	**Innovation activity**
Partner network: - Number of partner highereducation institutions - Number of partner companies in R&D Goodwill levels: - Intellectual property ratio Staff - Share of degree-level staff, including staff engaged in intellectual work Equipment: - Upgraded equipment rate – share of equipment aged under 5 years - Capital/labour ratio - Share of innovative production equipment R&D: - Relative share of non-industrial staff in R&D - Relative share of R&D spending in the total costs Innovation technology - Number of digital systems constituting the enterprise's digital platform - Percentage share of 3D printers in the equipment fleet of the enterprise - Percentage of equipment with augmented reality - Product automation coefficient - Degree of robotisation and digitalisation at the enterprise Innovation-supportive organisational structure - Percentage of non-industrial staff working on internal projects Open innovation - Percentage of spending on open innovation - Number of hackathons per year - Number of accelerators per year - Number of ideas proceeding from hackathons for further development - Number of finalists in accelerators HR innovation - Percentage of funding committed to digital trainings for the staff - Percentage of staff with KPIs	Partner network: - Share of projects to develop new technology, technical and technological solutions advanced in joint efforts with partner universities - Share of projects advanced in joint efforts with partners in the small business sector Goodwill levels: - Percentage of appreciation of the company's goodwill Equipment: - Fixed asset renewal coefficient R&D: - Share of adopted intellectual property items - Economic performance of R&D Innovation technology - Percentage of enterprise description in the digital twin model - Percentage of production operations accomplished on a 3D printer - Percentage of digital data stored in cloud services - Percentage of staff equipped with mobile platforms - Percentage of designs transferred to virtual reality - Percentage of tokenisation of the enterprise Innovation-supportive organisational structure - Percentage of intrapreneurship projects in total company projects HR innovation - Percentage of staff unrelated directly with production processes working remotely - Percentage of staff after complete digital training - Percentage of attainment of KPIs - Net profit in relation to salary
Innovation operations (quick calculation) • Relative share of innovation in products (monetary, not items, as this refers to real sales) • Economic performance of innovation • Effectiveness (available market capacity)	

Data on each of the criteria require preparation given the diversity of formats. We use normalisation to relative values with ideal values determined by expertise according to formula 4.

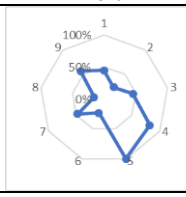
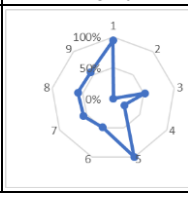
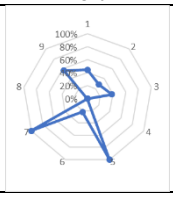
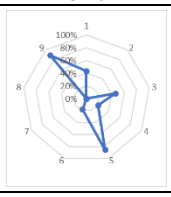
$$i_j = \frac{i_j}{i_j^{ideal}} \quad (4)$$

where i_j is an actual value; i_j^{ideal} is the ideal value.

Extreme values outside the three-sigma range in normal distribution are taken at a maximum value, i. e., one.

When all values are normalised to relative levels, significance coefficients are assigned to each item based on their level of influence on the number of implemented innovations. We use two significance

Table 2. Table of values of enterprise innovation operations

	Hyundai Motor Manufacturing RUS, PLC	NTZ RUS, PLC	Karfidov Lab, PLC	Ryegrass, PLC	Germes-Servis, PLC
	Group scores of innovation operations				
Partner network	71%	44%	94%	44%	43%
Goodwill levels	2%	23%	0%	28%	0%
Staff	38%	45%	53%	38%	46%
Equipment	-13%	82%	21%	0%	21%
R&D	13%	100%	100%	100%	86%
Innovation technology	45%	23%	49%	22%	18%
Innovation-supportive organizational structure	33%	48%	56%	100%	0%
Open innovation	57%	16%	58%	0%	0%
Safety (environmental, labour safety)	95%	56%	56%	56%	89%
Integral score	38%	49%	54%	43%	34%
Diagram					

coefficients. The first one assigns elevated values to innovation activity vs. innovation potential indicators. The values of innovation activity are multiplied by 1, while innovation potential values, by 0.5. Such an approach is justified, as innovation activity describes actual measures taken for enterprise development, while innovation potential only characterises accumulated resources applicable for development.

The second coefficient is a regression coefficient normalised within the range of 0 to 1 describing the degree of influence of the respective indicator over the number of implemented innovations per year. Such degree of influence is analysed for each indicator. The indicator with maximum influence is isolated; it will thus have the maximum absolute value of regression coefficient. The maximum regression coefficient divided by itself produces one. All other absolute regression coefficients are divided by it and normalised to the range of 0 to 1. Regression coefficients are normalised within the said range and innovation indicators are multiplied by the respective values. Thus, we derive prepared values with significance degrees and limited to 1.

Based on the resulting values, group scores are calculated according to formula 5:

$$I_j = \frac{\sum_1^n i_j}{n} \quad (5)$$

where I_j is the value of the group score; i_j is the value of a constituent indicator in the group; n is the number of criteria in the group.

Group scores are used to derive the integral score of innovation operation calculated as an arithmetic mean according to formula 6:

$$I = \frac{\sum_1^m I_j}{m} \quad (6)$$

where I is the integral score of innovation operations; I_j is the value of a group score; m is the number of group scores.

Apart from the integral and group scores, ideal values are also calculated. Divisions of score values by ideal values produce clear percentage ratios characterising the enterprise's innovation performance. Percentage values are charted in the table of values.

Alongside the percentages, the table includes a graphic representation of the result as a raypath plot where each ray represents the respective value of a constituent of the integral score, i. e., the value of a group score. The total area of the figure corresponds to the integral score of innovation operations.

To test the method of assessment of innovation operations, consider the following calculations of the respective values for innovative technological companies in **Table 2**. The respective enterprises in these assessments are Karfidov Lab, PLC (karfidovlab) [Karfidov Lab company], Ryegrass, PLC [Ryegrass company], Germes-Servis, PLC (hydraulics international inc) [Ryegrass company], NTZ RUS, PLC [Hyundai manufacturing CIS company], Hyundai Motor Manufacturing Rus, PLC [Ltd NTZ RUS company].

Table 3. Table of values of enterprise innovation operations under the quick method of calculation

Hyundai Motor Manufacturing RUS, PLC	NTZ RUS, PLC	Karfidov Lab, PLC	Ryegrass, PLC	Germes-Servis, PLC
Integral score of innovation operations				
41%	56%	67%	60%	46%

Table 3 will include integral scores of the companies calculated according to the initial assessment methodology as an arithmetic mean of the three indicators.

Thus, the indicator of innovation operations can be calculated in two ways depending on time available for the analysis and available data.

CONCLUSION

Consider the findings of company assessments. Negative values mean the indicators have deteriorated vs. the same figure for the previous year. This may happen if the company sold fixed assets or energy consumption rose in unit costs. If the company has no available resources or shows no efforts in the said direction, the values are taken as zero. E. g., if the company does not advance open innovation, the value of open innovation equals zero. The values might be equal to one, if the company reaches or exceeds a maximum result in the respective area. An example is NTZ RUS, which bought fixed assets and registered considerable growth in the value of the innovative equipment fleet.

A comparison of the main and initial assessments indicates both methods identified Karfidov Lab, PLC as the company with the highest innovation operations score. Also, both methods produced a similar distribution of the companies by tens of percentiles, i. e., into three groups: Karfidov Lab, PLC in the first group, Ryegrass, PLC and NTZ RUS, PLC, in the second group, Germes-Servis, PLC and Hyundai Motor Manufacturing Rus, PLC in the third group.

However, there is a considerable discrepancy in the specific values of indicators by 3-16%. Also, misalignment is observed in the distribution of companies vs. other businesses, as well as their differences reaching 1-5%.

The main advantage of the methodologies is that they are applicable to innovation assessments in the digital economy. That means, they include modern criteria characterising digital technology and innovation in management and organisational structure.

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