Concepts Related to Industry 4.0 in Research Papers in the Field of Economics

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1. Introduction

In a constantly changing world, a huge revolution has occurred in technological progress. Like any progress, it has a big impact on every sphere of life. Industry 4.0 is another revolution we are dealing with. It does not concern whether we want to buy a new machine or collect data. It is a process that continues, changing the world as much as steam or electricity did.

Therefore, an attempt was made at work to analysis of issues related to industry 4.0 in research papers in the field of economics is the main goal of the paper. The authors are going to analyse abstracts of research papers related to the field of economics and published by authors from 36 European countries and registered in Scopus database in the period 2011-2020. The main steps of the research were to prepare data set with abstracts from this article and to identify of concepts appearing in abstracts related to economics, computer science and industry 4.0. The ontology-based approach will be used for identification of concepts related to computer science, economics and industry 4.0.

2. Theoretical Background and Literature Review

Industry 4.0 means a new level of organization and control of the entire product life cycle. This cycle is oriented towards more and more individualized customer wishes and covers all stages - from the initial concept, development and production order, through the execution and delivery of the product to the customer, to recycling (Kiraga, 2016). The concept of Industry 4.0 entails necessary changes in the operational processes of companies and forces changes in doing business in the field of relations with clients, work environment, production, technology etc. The fourth industrial revolution is driven primarily by the increase in the amount of available data and its analysis using artificial intelligence.

The emergence artificial intelligence (AI) is affecting more and more sectors. For instance, AI is expected to affect global productivity, equality and inclusion, environmental outcomes, and several other areas, both in the short and long term (Vinuesa et al., 2020). AI rests on technologies like machine learning, deep neural networks, big data, internet of things and cloud computing (Wagner, 2020). AI can be also used to analyse complex and high-dimensional dynamic economic models (Maliar Maliar, & Winant, 2019). AI is used in trade and logistics, e.g. to design efficient warehouse facilities. It also shapes the way customers interact with businesses through smart websites and bots, and these tools are increasingly integrated into everyday work.

Another technology that has revolutionized the industry and has received significant attention in recent years is blockchain technology. The four main kinds of blockchain applications are money transfer and payments, property registries, contractual agreements, and identity confirmation (Swan, 2017). Blockchain facilitates the management of an innovative supply chain. The technology allows companies to record every transaction and process - from production to sale, storage and shipping - in decentralized blocks. Thus, reduce the risk of delays, human error and related costs (Bhardwaj, 2019).

New computational technologies play an important role in the development of the economy according to the Industry 4.0 concept. This is due to the need to process huge amounts of data, known as big data. Conscious use of big data can bring many benefits to the entire economy. They include: production of new goods (including those made to order), optimization of business processes, better management of the organization, more targeted marketing that uses customer feedback in product design, more efficient use of resources, reducing energy consumption.

Technology based on virtual reality can help organizations improve operational efficiency and individual productivity, according to the report. Virtual reality experiments are framed field experiments, which allow testing the effect of contextual cues on economic behaviour under the strict control of the experimenter (Innocenti, 2017).

The biopharmaceutical sector is faced with such challenge of Industry 4.0 as personalized medicine also being under pressure to make production faster and cheaper. In this regard using digital and automated technologies are used as the key technologies to develop these biotechnologies according to the new industry revolution requirements.

Macdonald (Macdonald, 2020) also underlines the short-term difficulties of biomanufacturing which are trying to overcome traditional models of production. For example, adoptive cellular therapy demands the new technologies (Marks, 2017). In general, pharmaceutical sector with new biotechnologies has a great potential of long-term benefits.

Robotics is another cutting-edge technology of Industry 4.0 impacting on traditional manufacturing system (Mourtzis, Fotia, Boli, & Vlachou, 2019). Thus, adaptive robots have new advantages thanks to other technologies as artificial intelligence, big data and embedded systems (Bayram & İnce, 2018). Notwithstanding the specificity of robotics (such as replacement of human labour) (Pfeiffer, 2018), these technologies allowing manufacturing goods with better quality, less time and costs (Goel & Gupta 2020).

3D printing or additive manufacturing adds new power to manufacturing industry giving ability to fabricate items with complex characteristics (Goh, Sing, & Yeong, 2020). However, the implementation of additive manufacturing is faced with some barriers such as productivity limitations, new requirements for production processes and skills of workers (Korner et al., 2020).

Industrial revolution is based on cyber physical systems generating new features and benefits making system of production more flexible, visible, creating new planning methods (Fakhri et al., 2020). Internet emerged the new way of automation of the industrial processes as Internet of Things (IoT) (Aazam, Zeadally, & Harras, 2018). It’s worth to underline that IoT requires other technologies of Industry 4.0 such as robots, appliances, big data analysis and new business models (Wan et al., 2016).

Using of technologies of Industry 4.0 put new requirements to energy capture, storage and transmission. Thus, smart factories based on technologies of Industrial Internet reduce energy consumption (Mohamed, Al-Jaroodi, & Lazarova-Molnar, 2019).

In general, Industry 4.0 combines core technologies such as Internet of Things, Big Data and Cyber-Physical Systems to increase the operational efficiency, productivity and automatization (da Silva, da Costa, Crovato, & da Rosa Righi, 2020). All these technologies are connected with each other and they give rise to general and specific problems. Thus, new computational technologies and Internet of Things should to manage the problems of cyber security (Gasimov & Aliyeva, 2020).

3. Research Design, Methodology and Data Analysis

The analysis of appearance and significance of concepts related to the fourth industrial revolution in research papers prepared in the area of economics in the period 2011-2020 is the main goal of the analysis. During the study, abstracts of all papers registered in the Scopus database from 2011 to 2020 were used.

The research process was composed of the following steps:

1. selection of ontologies appropriate for description of economics, computer science and industry 4.0 areas,
2. identification of concepts in abstracts of research papers,
3. evaluation of significance of concepts related to Industry 4.0 area,
4. analysis of relationships between concepts related to Industry 4.0 and concepts related to computer science and to economics.

a. Selection of ontologies for description of economics, computer science and industry 4.0 areas

The approach used for research process has ontology-based character. It means, that the scope and the structure of scientific areas were defined in formal way with the use of ontologies. In the case of economics, the JEL classification system was used (https://www.aeaweb.org/econlit/jelCodes.php). For computer science area, the CSO ontology was used (https://cso.kmi.open.ac.uk/home). Concepts related to Industry 4.0 scope were defined by authors with the use of main groups of concepts:

- 3d graphics,
- 3d printers,
- agent based approach,
- augmented reality,
- biometrics,
- blockchain,
- cloud computing,
- control systems,
- cyber security,
- data analytics,
- embedded systems,
- human machine interface,
- “Industry 4.0” concept (indicates that phrase “industry 4.0” or “fourth industrial revolution” appeared in the text),
- internet of things,
- mobile systems,
- ontology based approach,
- robotics,
- sensors,
- wearables.

Every group of concepts from the above list was defined as a set of concepts choosing from the CSO ontology. Therefore the description of Industry 4.0 area had a form of the sub-ontology of the CSO ontology.

b. Identification of concepts in abstracts

During the next stage of the research process, the analysis of abstracts was carried out. During this stage, 124,460 abstracts from the Scopus database were browsed and the following numbers of concepts were identified:

- 1,283,253 concepts related to economics,
- 288,898 concepts related to computer science,
- 3,763 concepts related to the fourth industrial revolution field.

Concepts related to Industry 4.0 appeared in 3456 abstracts.

The system used for concepts' identification was prepared by authors in R language and has an ability to annotate parts of text document with ontology concepts according to rules defined in the form of patterns which can be assigned to every concept. The detailed description of the system used for concepts' identification can be found in (Kovaleva, Lula, & Tuchowski, 2020).

c. Analysis the significance of concepts related to Industry 4.0 area

Having Industry 4.0 concepts identified, their importance was evaluated. Two approaches were used for achieving this goal:

- the analysis of concepts' frequency (concepts: *agent-based approach*, *data analytics*, *internet of things*, *control systems* and *cyber security* were found as the most important),
- the analysis of concepts' centrality (in this case *data analytics*, *internet of things*, *control systems* and *sensors* were evaluated as the most significant).

d. Analysis of relationships between concepts related to Industry 4.0 and concepts related to computer science

The next step of the research was focused of analysis relationships between concepts belonging to Industry 4.0 area and concepts related to computer science and economics. Using the information about co-occurrence of these two groups of concepts in abstracts, a bipartite graph model was built. It allowed to find the most frequent relations observed in the corpus of abstracts. The results showed that:

- *internet of things* (concept related to industry 4.0 area) is strongly connected with the following topics from the CSO ontology: *computer systems*, *Internet*, *networks*, *software engineering*,
- *data analytics* (as an Industry 4.0 concept) is related to: *computer systems*, *artificial intelligence*, *data mining*, *hardware* and *computer aided design*,
- *agent-based approach* (Industry 4.0 concept) is connected with *artificial intelligence* from computer science area.

Also the specificity of concepts was evaluated. Measures of specificity calculated for individual concepts as well as the index for the whole model were rather low (the H_2' was equal to 0.056).

Very interesting conclusions may be formulated based on the results of cluster analysis of concepts belonging to industry 4.0 and two domain ontologies. To perform this analysis, the co-occurrence matrix of concepts from Industry 4.0 area and concepts from one domain ontology was decomposed with the use of SVD decomposition and next, the coordinates of all concept in a new, common space were calculated. After this transformation, the cluster analysis could be performed (thanks to the fact that vectors representing all concepts in a new space had the same length). The calculations were carried out with the use of Ward's method with Euclidean distance matrix. This analysis recognized a very well-defined cluster containing concepts related to Industry 4.0 (*agent-based approach*, *internet of things*, *data analysis*) and concepts from the CSO ontology (*artificial intelligence*, *computer systems*, *software engineering*, *networks* and *Internet*). The remaining concepts were assigned to the second cluster. It is very useful, that the results formed a dendrogram showing required level of details.

The same methodology was used for analysing relationships between Industry 4.0 concepts and concepts related to economics. The results indicated that the most relevant relationships can be observed between Industry 4.0 concepts: *agent-based approach, data analysis* and *internet of things* and economics concepts represented by JEL classes: *D* (microeconomics), *L* (industrial organization), *C* (mathematics and quantitative methods) and *O* (economics development, innovation, technological change and growth). The specificity index for the whole network is extremely low and is equal to 0.0058.

4. Results/Findings and Discussion

The following conclusions can be drawn from the studies carried out:

- ontology-based approach was positively verified as a method for annotating documents with large number of concepts having hierarchical or network-centric structure;
- the JEL classification system is the most popular system of concepts used for annotating research papers in the field of economics. However, JEL concepts have rather general character and are not convenient for identification of detailed topics;
- the CSO ontology covers the scope of computer science area; the number of concepts is incomparably higher than in the JEL ontology. It should be underlined that the CSO ontology has a network-like, not hierarchical, structure;
- ontology-based approach is very flexible and allows to define sub-ontologies containing choosing set of concepts;
- undirected and bipartite graphs are very useful for modelling and evaluation relationships between concepts within the same or belonging to two different ontologies;
- the SVD decomposition of the co-occurrence matrix calculated for concepts taken from two different ontologies used together with the methods of cluster analysis can be used for studying similarity of concepts from various ontologies.

5. Conclusion, Contribution and Implication

The authors are going to develop methodological and empirical part of their research and are going to include other domain ontologies (Universal Decimal Classification System, MeSH ontology) and design and implement linguistic tools for analysing document prepared in various languages.

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6. References

Aazam, M., Zeadally, S., & Harras, K. A. (2018). Deploying fog computing in industrial internet of things and industry 4.0. IEEE Transactions on Industrial Informatics, 14(10), 4674-4682. https://doi.org/10.1109/TII.2018.2855198

Bayram, B., & İnce, G. (2018). Advances in Robotics in the Era of Industry 4.0. In Bayram, B., & İnce, G., Industry 4.0: Managing the Digital Transformation (pp. 187-200). Springer International Publishing.

Bhardwaj, Ch. (2019) Beyond the Hype: The Real Impact of Blockchain on Economy [Blog]. https://appinventiv.com/blog/real-impact-of-blockchain-technology-on-economy/

da Silva, F. S. T., da Costa, C. A., Crovato, C. D. P., & da Rosa Righi, R. (2020). Looking at energy through the lens of Industry 4.0: A systematic literature review of concerns and challenges. Computers & Industrial Engineering, 106426. https://doi.org/10.1016/j.cie.2020.106426

Fakhri, A. B., Mohammed, S. L., Khan, I., Sadiq, A. S., Alkazemi, B., Pillai, P., & Choi, B. J. (2020). Industry 4.0: Architecture and equipment revolution. Computers, Materials & Continua. Retrieved from https://wlv.openrepository.com/bitstream/handle/2436/623464/Al_Shakarchi_Industry_Four_Point_Zero_2020.pdf?sequence=3&isAllowed=y

Gasimov, V., & Aliyeva S. (2020). Basic components of the digital business: cryptocurrency, blockchain, cloud technologies and internet of things. International Journal of 3D Printing Technologies and Digital Industry, 4(2), 97-105. https://doi.org/10.46519/ij3dptdi.734633

Goel, R., & Gupta, P. (2020). Robotics and industry 4.0. In Nayyar, A. & Kumar, A. (Ed.) A Roadmap to Industry 4.0: Smart Production, Sharp Business and Sustainable Development (pp. 157-169). Springer International Publishing.

Goh, G. D., Sing, S. L., & Yeong, W. Y. (2020). A review on machine learning in 3D printing: applications, potential, and challenges. Artificial Intelligence Review, 1-32. https://doi.org/10.1007/s10462-020-09876-9

Hernandez Korner, M. E., Lambán, M. P., Albajez, J. A., Santolaria, J., Ng Corrales, L. D. C., & Royo, J. (2020). Systematic Literature Review: Integration of Additive Manufacturing and Industry 4.0. Metals, 10(8), 1061. https://doi.org/10.3390/met10081061

https://appinventiv.com/blog/real-impact-of-blockchain-technology-on-economy/

https://cso.kmi.open.ac.uk/home

https://www.aeaweb.org/econlit/jelCodes.php

Innocenti, A. (2017). Virtual reality experiments in economics. Journal of Behavioral and Experimental Economics, 69, 71–77.

Kiraga, K. (2016). Przemysł 4.0: 4. Rewolucja przemysłowa według Festo. Autobusy: Technika, Eksploatacja, Systemy Transportowe, 17(12), 1603–1605.

Kovaleva, A.S., Lula, P., Tuchowski, J. (2020). Ontology-Based Measurement of Study Program Innovativeness in the Area of Economics and Management. In Babić, V., Nedelko, Z. (Ed.), Handbook of Research on Enhancing Innovation in Higher Education Institutions (pp. 381-407). IGI Global. http://dx.doi.org/10.4018/978-1-7998-2708-5.ch017

Macdonald, G. J. (2020). Biomanufacturing Makes Sense of the Industry 4.0 Concept. Genetic Engineering & Biotechnology News, 40(S3), S7-S10. https://doi.org/10.1089/gen.40.S3.03

Maliar, L., Maliar, S., & Winant, P. (2019). Will Artificial Intelligence Replace Computational Economists Any Time Soon? CEPR Discussion Papers, 14024.

Marks, L. (Ed.). (2017). Engineering Health: How Biotechnology Changed Medicine. Royal Society of Chemistry.

Mohamed, N., Al-Jaroodi, J., & Lazarova-Molnar, S. (2019). Leveraging the capabilities of industry 4.0 for improving energy efficiency in smart factories. IEEE Access, 7, 18008-18020. https://doi.org/10.1109/ACCESS.2019.2897045

Mourtzis, D., Fotia, S., Boli, N., & Vlachou, E. (2019). Modelling and quantification of industry 4.0 manufacturing complexity based on information theory: a robotics case study. International Journal of Production Research, 57(22), 6908-6921. https://doi.org/10.1080/00207543.2019.1571686

Narayanan, H., Luna, M. F., von Stosch, M., Cruz Bournazou, M. N., Polotti, G., Morbidelli, M., & Sokolov, M. (2020). Bioprocessing in the digital age: The role of process models. Biotechnology Journal, 15(1), e1900172. https://doi.org/10.1002/biot.201900172

Pfeiffer, S. (2018). Industry 4.0: Robotics and Contradictions. In Bilić, P., Primorac, J. & Valtýsson, B. (Ed.), Technologies of Labour and the Politics of Contradiction (pp. 19-36). Palgrave Macmillan.

Salkin, C., Oner, M., Ustundag, A., & Cevikcan, E. (2018). A conceptual framework for Industry 4.0. In Bayram, B., & İnce, G., Industry 4.0: Managing the Digital Transformation (pp. 3-23). Springer International Publishing.

Swan, M. (2017). Anticipating the Economic Benefits of Blockchain. Technology Innovation Management Review, 7(10), 6–13.

Vinuesa, R., Azizpour, H., Leite, I., Balaam, M., Dignum, V., Domisch, S. & Nerini, F. F. (2020). The role of artificial intelligence in achieving the Sustainable Development Goals. Nature Communications, 11(1). https://doi.org/10.1038/s41467-019-14108-y

Wagner, D. N. (2020). Economic patterns in a world with artificial intelligence. Evolutionary and Institutional Economics Review, 17, 111–131.

Wan, J., Tang, S., Shu, Z., Li, D., Wang, S., Imran, M., & Vasilakos, A. (2016). Software-Defined Industrial Internet of Things in the Context of Industry 4.0, in IEEE Sensors Journal, vol. 16, no. 20, pp. 7373-7380. https://doi.org/10.1109/JSEN.2016.2565621