Optimization Algorithms for Integrated Processes in Industry 4.0

Mário Leite
Department of Production and Systems
Centro ALGORITMI, Universidade do Minho
Braga, Portugal
maleite.cbc@gmail.com

Fernando Romero
Department of Production and Systems
Centro ALGORITMI, Universidade do Minho
Guimarães, Portugal
fromero@dps.uminho.pt

Cláudio Alves
Department of Production and Systems
Centro ALGORITMI, Universidade do Minho
Braga, Portugal
claudio@dps.uminho.pt

Telmo Pinto
Universidade de Coimbra, CEMMPRE, FCTUC
Coimbra, Portugal
Centro ALGORITMI, Universidade do Minho
Braga, Portugal
telmo.pinto@dem.uc.pt

2020 IEEE International Conference on Technology Management, Operations and Decisions (ICTMOD) | 978-1-7281-5950-8/20/$31.00 ©2020 IEEE | DOI: 10.1109/ICTMOD49425.2020.9380614

***Abstract* — Evidence of an increasingly dynamic market forces companies to look for new ways to respond, given that traditional supply chain management systems are increasingly more vulnerable in their needs. In this sense, we have seen a paradigm shift at the industrial level with the emergence of new concepts from Industry 4.0 to improve productivity and process efficiency. However, their implementation in companies can be an expensive and time-consuming process, particularly for small and medium-sized enterprises. This work presents a perspective for optimization algorithms in the context of Industry 4.0. With new methods and models, simultaneously integrating traditional supply chain processes, it is possible to find good solutions (globally optimal), in real time and with an investment cost more proportional to the reality of each company. It may, therefore, be an alternative to mitigate the discrepancy between companies of quite different sizes.**

Keywords — Industry 4.0; Supply chain; Optimization algorithms; Optimization of integrated processes.

I. Introduction

Increasingly specific customer and government requirements, coupled with economic and financial uncertainties in the markets, compel companies to look for new strategies to be able to respond adequately to the needs. The highly variable and diverse demand for products with tight delivery times combined with competitive cost is evidence of a progressively more dynamic market [1,2].

Companies must ensure consumer satisfaction, maintaining profit margins strategically defined so that they can be competitive in the market. Thus, production solutions and strategies must be more flexible to better adapt to circumstances, preserving or improving the functionalities and qualities of products while maintaining, or even reducing, costs [3].

However, traditional supply chain management systems are insufficient to guarantee the necessary adaptability. There are several problems intensified by this type of systems, reflected in the difficulty in managing the uncertainties that lead to overstocking or stock failures, which lead to high waste or non-compliance with due dates, respectively. For the authors in [4], traditional supply chains are becoming more expensive, complex, and, at the same time, more vulnerable.

In this sense, in recent years, there has been a paradigm shift at the industrial level. In 2013, a strategic plan by the German government determined a major step forward in relation to the third industrial revolution, by boosting digitalization and connectivity between elements and objects in the supply chain. In Germany, having in mind what was the advance to the fourth industrial revolution, they called this process with the comprehensive term “Industrie 4.0” [5,6,7].

The implementation of Industry 4.0 in companies is a lengthy and continuous process that may involve a large economic investment and qualified human resources that not all companies are available to do in the short term, especially small and medium-sized enterprises (SMEs). These companies, despite knowing the potential benefits that may occur in the long-term, still reveal some fears about their implementation, highlighting the need for specialized personnel, in order to develop a comprehensive strategy capable of dealing with new opportunities and maintaining their competitiveness [8,9,10]. For [11], the technological gap between companies of different sizes, with this predicted industrial revolution, may be intensified by the unpreparedness of some companies, which, given the interconnection of the existing economy, can slow the evolution of even the largest and most capable companies (usually companies with high production volumes) that supply or are supplied by other companies with lesser technological development [9].

Therefore, the use of mechanisms or strategies that may have a lower cost and risk may be a safer alternative for the initial phase of implementation in smaller or less prepared companies. The authors in [12] point to optimization algorithms that integrate simultaneously different phases of the supply chain as a trend in search of more effective solutions. Thus, we study the development of optimization algorithms for problems with common objectives, seeking to jointly solve problems that traditionally are/were seen separately. The integrated optimization problems (with a joint vision) can guarantee better solutions, which otherwise could not be achieved, and may be a good alternative for the most basic decision support systems to be used in Industry 4.0, but which are expected to be equally effective.

In this work, in Section 2, a brief theoretical framework on industrial evolution is carried out with the main focus on the changes existing in the fourth industrial revolution. In Section 3, a perspective of optimization algorithms to be implemented in traditional supply chain processes in the context of Industry 4.0 is presented, especially suitable for small and medium-sized companies. Finally, the essential conclusions of the study are presented.

II. Emergence of Industry 4.0

In the past, at different times, we have seen changes that have transformed the industry. The First Industrial

Revolution, at the end of the 18th century, was marked by the use of mechanical processes driven by the force of water and steam energy. At the beginning of the 20th century, the beginning of mass production with assembly lines and using electrical energy marks the Second Industrial Revolution. In the 1970s, the Third Industrial Revolution emerged with the development of electronics and information technologies as a form of autonomous production [13].

In recent years, there has been a new paradigm shift in the industry driven by strategic government plans [14,15,16,17] so that the countries involved can increase their productivity and, principally and consequently, strengthen their economic capacity. In Germany, as a way of helping companies to follow the best path, several studies have been developed and action plans have been elaborated that are appropriate to the needs of each company [18,19], having as a principle a rigorous analysis of the current reality and the objectives to be achieved ("Where we have been, where we are going?" – [18]). It is in this context that the Fourth Industrial Revolution, also known as Industry 4.0, appears as a stimulus to technological advances through the high digitalization of manufacturing processes or forms of consumption, associating cyber-physical systems between elements and components (Fig. 1). In [20], cyber-physical systems (CPS) are the next generation of systems that need a high connection between computing, communication, and control technologies to properly represent the various physical systems.

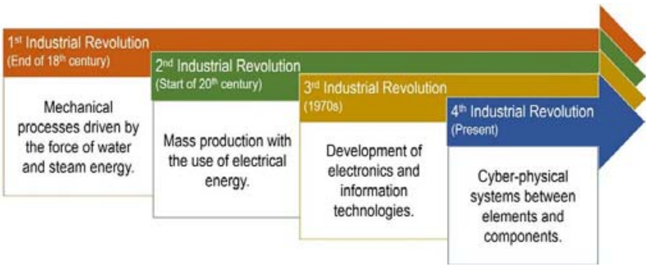

Fig. 1. Evolution of Industrial Revolutions.

The Industry 4.0 concept, as a landmark of the Fourth Industrial Revolution, appears in the literature with several definitions.

In [7], the authors refer to Industry 4.0 as a significant advance from the previous revolution without seeking to replace existing technologies. They also state that, instead, benefiting from the increase in the capacities of Information and Communication Technologies, in this process we seek to establish connections between these technologies and increase the interconnection between all objects.

In [21] Industry 4.0 is defined as an abstract concept in which the close integration between what is the physical world and the virtual world is sought. For their implementation, they indicate that it is necessary to work on new methods and models, on new technologies and demands, as a way to achieve two main themes: an intelligent factory and an intelligent manufacturing.

As referred in [6], the Industry 4.0 concept also consists of connecting the real world to the virtual world, through cyber-physical systems, to create value. Looking for efficient, more flexible, and decentralized production systems.

In [22], the Steering Committee of the Industrie 4.0 Platform as mentioned in [19], points to Industry 4.0 as a new level of organization with dynamic networks (interconnection of people, objects and systems) that allow control of the entire value chain, based on real-time updating of relevant information. Based on this data, it is possible to quickly define optimized solutions for different criteria (such as cost, availability, resources).

Some authors have a more simplified view, as in [23] who summarize Industry 4.0 only to an intelligent production network in which machines connect with products without human intervention. And others, as in [24], who consider Industry 4.0 the equivalent of a "Smart Factory".

We can verify that the concept of Industry 4.0 is a set of complex organizational structures or methodologies (at the intra- and inter-organizational level [13]), using more sophisticated resources to make faster and more efficient decisions, with the purpose of optimizing specific or even global objectives.

A. Main Changes

Industry 4.0 emerges in order to improve the productivity and efficiency of industrial production by taking advantage of new and better digital capabilities. The reorganization of traditional factories into more complex but at the same time more sophisticated, more computerized and intelligent systems promote advantageous situations and increase the benefits of their industries [4,13,21].

Smart factories cover systems, from the most complex to the most elementary, highly connected, with 24/7 availability, with high autonomous/independent and self-learning capabilities, allowing for greater efficiency, better adaptability, and ergonomics. It is expected that all decisions made will be supported by (production) data obtained through the different existing technologies [25]. Smart factories also seek to include and integrate more information from customers and business partners in order to improve their value chain. In [26], horizontal and vertical integration is considered one of the pillars of possible technologies in Industry 4.0. The first integration is internal with the exchange of information between areas in the same company and the second is external with the exchange between business partners. For [27] the linking between the physical and virtual worlds and the vertical and horizontal integration of processes are even the core of Industry 4.0.

This (r)evolution significantly increases the capacity and efficiency of inventory and transport management. What would be done by manual collections and, therefore, more susceptible to human errors, can now be updated automatically (quickly and online) through the use of small high technology devices. In this way, it is possible to obtain even more detailed information, with the possibility of synchronizing even with data from other companies (external data), in real-time. Better monitoring is also possible in the transport and distribution phases, which increases the transparency of logistics operations. The control of this phase, provides relevant information for the entire supply chain, both for processes prior to transportation, such as production, or for later phases where processes of return and customer satisfaction can be optimized [4,13,28].

In this way, Industry 4.0 guarantees greater flexibility to changes (achieving a better reaction to changes in demand and more or less unexpected failures in the supply chain). It improves and/or helps companies in their decision making, which leads to cost savings and also to reductions in delivery times. In addition, it allows the development of more personalized systems, of small batches, with specific options defined by each customer [13].

The improvement of industrial systems, in addition to aspects related to production efficiency, is able to guarantee more safety, better use of energy and, consequently, greater care for environmental sustainability [29].

III. New Methods and Models for Traditional Processes

A. New needs for traditional processes

The new systems incorporate, or should incorporate, the ability to easily collect and send relevant data and information between processes. In an Industry 4.0 environment, the tracking, monitoring, and synchronization of information of a process is expected to be available to the entire system, more or less automatically. Thus, higher transparency is achieved and the physical part (of the factory) is approached in detail with the cyber-computational part (digital) [5,7], obtaining data that is potentially more reliable and more representative of reality.

Each day, immense information about logistical processes is produced, even that which was once difficult to obtain. However, if this data set is not worked out and used for the benefit of the company, resources and time that are used in the collection and storing of such information is wasted. In [30] it is referred that one of the challenges of Industry 4.0 is the analysis and use of data so that it provides significant value in decision making.

Information collected throughout the supply chain, which is increasingly dynamic, must be oriented so that it can help to decide, as well as alert to previously unknown problems and issues, through appropriate approaches and tools [31]. Although the abundant crossing of information can allow a higher rigor in what are the data inputs for the optimization algorithms, it is still necessary to develop new and better optimization methods in order to obtain more effective solutions. For that purpose, formal methods and systems are decisive to explore the potential of Industry 4.0 [5].

Optimization algorithms, supported by previously collected data, continue to be one of the most important approaches of decision support systems that seek to obtain optimal solutions. Thus, and according to [12], one of the tendencies aimed at obtaining more flexible solutions comes from the development of methods that simultaneously integrate different supply chain processes. For [5, 32], the paradigm shift in relation to traditional business models, with the integration of heterogeneous processes in common structures (with unified time horizons), provides obvious benefits.

Traditional systems that analyze supply chain processes individually, most often through hierarchical approaches, may not guarantee, intrinsically, good solutions, especially taking into account the large data set they now have at their disposal and the ease with which information can be cross-checked. The importance of finding opportunities in new digital capabilities in production must be emphasized [33] but without neglecting the need to continue to understand and improve traditional production systems. The increase in the complexity of the processes, with the possibility of having a real-time perspective of all processes, requires new methods and new planning technologies in order to take advantage of the potential of existing information [34]. The use of optimization algorithms that are based on an integrated analytical perspective can be a way to address such challenges in a more economical but nevertheless efficient way.

B. Optimization algorithms in integrated processes

The analysis of supply chain processes in an integrated way can enable optimal global solutions and mitigate unexpected situations in advance. This hypothesis is depicted in Fig. 2, which represents an example of a possible decision support system based on methods and models that consider in an integrated way two processes belonging to the production phase of the supply chain, but which have different time horizons. In this case, the optimization algorithm seeks to solve, simultaneously, a problem that consists of two parts (production scheduling and planning, short and medium-term, respectively). The time horizon will be unified on the horizon of the longest phase (in this case, planning). In this way, it will be possible to identify, for example, whether the decisions of the previous phases are effectively the best. In other words, it seeks to verify whether the (intermediate) decisions foreseen for the scheduling part positively affect the final decisions, in the production planning part.

A more improved decision support system, eventually and ideally, may include a data mining component to more effectively work with large amounts of data and information (if any, as not all companies have sufficient data collection points [35]). In this way, it can increase the predictive capacity and recognition of patterns that are difficult to analyze. However, it is not always easy and so it is expected that the optimization algorithms component will be able to obtain solutions, in a self-sufficient way, with the preparation of data happening through conventional resources and, thus, be a more economical and equally efficient and advantageous system.

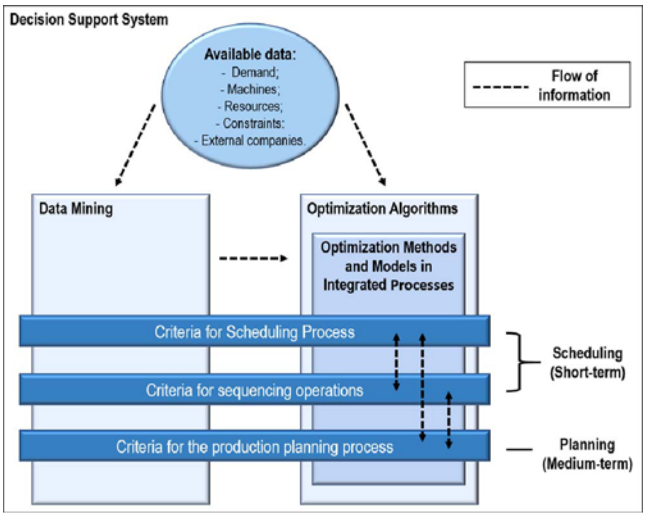

Fig. 2. Example illustration of a decision support system.

Despite the importance of advanced data analysis, investing in more sophisticated optimization algorithms may be a sufficient and good alternative to reduce the costs inherent in implementing the concepts involved in Industry 4.0 systems. This decision may be particularly suitable for resource constrained small and medium-sized enterprises (SMEs) and for companies that are in an early stage of the digitalization process. According to [36], less developed companies risk being unable to keep up with changes and becoming less competitive in the market when compared to the research and development conditions of large companies which may have easier access to financial and other investment assets and, therefore, it is necessary that each company defines its own implementation strategy within its own financial and time possibilities. Therefore, companies should be advised not to focus on technologies that could prove to be strategically wrong for them, given their internal capabilities [37].

The problems of supply chain processes, seen separately or in an integrated way, have a computational time that increases exponentially as the size of the problem increases. In other words, they are complex problems in which the developed algorithm may take time to find an optimal solution. However, decision managers want tools that enable quick responses (preferably in real-time) [38]. In this sense, it may be convenient to develop optimization algorithms based on heuristic methods that find good solutions in a substantially shorter computational time. Thus, these decision support systems will make it easier to face failures, defects, and unforeseen circumstances, with re-optimizations if necessary [39].

IV. CONCLUSIONS

Given the needs for companies to be, or become, more competitive, in a very dynamic market, they join efforts, sometimes encouraged by government support, to implement innovative strategies related to the fourth industrial revolution. Rapid technological advances, which enhance the use of more global and sophisticated digitalization, have helped to increase the responsiveness of industries. However, not all companies have the same capabilities and possibilities for making an effective implementation.

In the literature, the concepts and definitions of Industry 4.0 mostly emphasize the possibility of achieving better structures that relate to the physical and computational parts between components. In other words, it is possible to collect and share a large amount of relevant information that should be used appropriately to obtain better solutions.

This study, more than addressing the mechanisms of data collection and sharing, intended to highlight the importance of developing and improving optimization algorithms in a decision support system. Thus, optimization algorithms with integrated processes are proposed in the context of Industry 4.0, which can be a good alternative for smaller companies with lower investment conditions.

These optimization algorithms, with methods and models that simultaneously integrate traditional supply chain processes, have clear advantages. These enable globally optimal (more effective) solutions, mitigate gaps between processes (unexpected situations that would eventually be detected too late), allow to manage resources of different process together, and can be less expensive.

As we are talking about problems of high computational demand, and since they have exponential growth, it may be recommended to develop algorithms based on heuristic methods. In this way, the computational time required to find a valid solution decreases significantly and it is possible to obtain solutions in real-time (which is especially important for cases of successive adjustments with re-optimizations).

These systems thus allow small and medium-sized enterprises to mitigate large differences in relation to larger enterprises, with less investment.

ACKNOWLEDGMENT

This work has been supported by FCT - Fundação para a Ciência e Tecnologia within the R&D Units Project Scope: UIDB/00319/2020 and by FEDER funds through the program COMPETE – Programa Operacional Factores de Competitividade – and by national funds through FCT – Fundação para a Ciência e a Tecnologia –, under the project UIDB/00285/2020.

REFERENCES

[1] Baldea, M., & Harjunkoski, I. (2014). Integrated production scheduling and process control: A systematic review. Computers and Chemical Engineering, 71, 377–390. https://doi.org/10.1016/j.compchemeng.2014.09.002

[2] Wu, L., Yue, X., Jin, A., & Yen, D. (2016). Smart supply chain management: a review and implications for future research. International Journal of Logistics Management, The, Vol. 27 No. 2, pp. 395-417. https://doi.org/10.1108/IJLM-02-2014-0035

[3] Pfeffer, J., Graube, M., Reipschlaeger, P., Arndt, S., Urbas, L., Dachselt, R., & Stelzer, R. (2015). Towards collaborative plant control using a distributed information and interaction space. In 2015 IEEE 20th Conference on Emerging Technologies & Factory Automation (ETFA) (pp. 1-4). IEEE.

[4] Abdel-Basset, M., Manogaran, G., & Mohamed, M. (2018). Internet of Things (IoT) and its impact on supply chain: A framework for building smart, secure and efficient systems. Future Generation Computer Systems, 86, 614-628.

[5] Da Xu, L., Xu, E. L., & Li, L. (2018). Industry 4.0: state of the art and future trends. International Journal of Production Research, 56(8), 2941–2962. https://doi.org/10.1080/00207543.2018.1444806R. Nicole, "Title of paper with only first word capitalized," J. Name Stand. Abbrev., in press.

[6] Hatterscheid, E., & Schlüter, F. (2018). Towards a decision support approach for selecting physical objects in collaborative supply chain processes for cyber physical system-transformation. In 2018 5th International Conference on Industrial Engineering and Applications (ICIEA) (pp. 1-5). IEEE.

[7] Trappey, A., Trappey, C., Fan, C., Hsu, A., Li, X., & Lee, I. (2017). IoT patent roadmap for smart logistic service provision in the context of Industry 4.0. Journal of the Chinese Institute of Engineers, 40(7), 593-602.

[8] Schröder, C. (2017), The Challenges of Industry 4.0 for Small and Medium-Sized Enterprises, Friedrich-Ebert-Stiftung, Bonn, Online. 14 Sep 2020. Available in: http://library.fes.de/pdf-files/wiso/12683.pdf (accessed September 19, 2018)

[9] Ghobakhloo, M., & Fathi, M. (2020). Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing. Journal of Manufacturing Technology Management, 31(1), 1–30. https://doi.org/10.1108/JMTM-11-2018-0417

[10] Tortorella, G. L., & Fettermann, D. (2018). Implementation of Industry 4.0 and lean production in Brazilian manufacturing companies. International Journal of Production Research, 56(8), 2975–2987. https://doi.org/10.1080/00207543.2017.1391420

[11] Sommer, L. (2015). Industrial revolution - Industry 4.0: Are German manufacturing SMEs the first victims of this revolution? Journal of Industrial Engineering and Management, 8(5), 1512–1532. https://doi.org/10.3926/jiem.1470

[12] Stank, T., Autry, C., Daugherty, P., & Closs, D. (2015). Reimagining the 10 megatrends that will revolutionize supply chain logistics. Transportation Journal, 54(1), 7-32.

[13] Shafiq, S. I., Sanin, C., Szczerbicki, E., & Toro, C. (2015). Virtual engineering object/virtual engineering process: a specialized form of cyber physical system for Industrie 4.0. Procedia Computer Science, 60, 1146-1155.

[14] Europe 2020. (2010). A strategy for smart, sustainable and inclusive growth. vols. Europe 2020. Brussels: European Commission, 2010. Online. 20 Mar 2020. Available in: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:2020:FIN:EN:PDF

[15] Holdren, J. P., Power, T., Tassey, G., Ratcliff, A., & Christodoulou, L. (2012). "A National strategic plan for advanced manufacturing", Online. 20 Mar 2020. Available in: https://www.energy.gov/sites/prod/files/2013/11/f4/nstc_feb2012.pdf

[16] Lasi, H., Fettke, P., Kemper, H.-G., Feld, T., & Hoffmann, M. (2014). Industry 4.0. Business & Information Systems Engineering, 6(4), 239–242. https://doi.org/10.1007/s12599-014-0334-4

[17] Zhou, J. (2015). Intelligent Manufacturing — Main Direction of "Made in China 2025". China Mechanical Engineering, 26(17): 2273-2284.

[18] Willliam, M. D. (2014). Industrie 4.0-Smart Manufacturing For The Future. Berlin: Germany Trade & Invest. Gesellschaft für Außenwirtschaft und Standortmarketing, Berlin, 2014, 4f.

[19] Lichtblau, K., Stich, V., Bertenrath, R., Blum, M., Bleider, M., Millack, A., Schmitt, K., Schmitz, E., & Schröter, M. (2015). IMPULS - Industrie 4.0 - Readiness, Impuls-Stiftung des VDMA, Aachen-Köln.

[20] Lee, E. A. (2008). Cyber Physical Systems: Design Challenges. 11th IEEE International Symposium on Object and Component-Oriented Real-Time Distributed Computing (ISORC), Orlando, FL, 2008, pp. 363-369.

[21] Wan, J., Cai, H., & Zhou, K. (2015). Industrie 4.0: Enabling technologies. In Proceedings of 2015 International Conference on Intelligent Computing and Internet of Things (pp 135–140). IEEE.

[22] Platform Industrie 4.0. 2015. Industrie 4.0 implementation strategy, Platform Industrie 4.0 results report. Plattform Industrie 4.0, 2015, Umsetzungsstrategie Industrie 4.0, Ergebnisbericht der Plattform Industrie 4.0.

[23] Ivanov, D., Dolgui, A., Sokolov, B., Werner, F., & Ivanova, M. (2016). A dynamic model and an algorithm for short-term supply chain scheduling in the smart factory industry 4.0. International Journal of Production Research, 54(2), 386-402.

[24] Broy, M. (2013). Challenges in modeling cyber-physical systems. Proceedings of the 12th International Conference on Information Processing in Sensor Networks - IPSN '13, 5. https://doi.org/10.1145/2461381.2461385

[25] Osterrieder, P., Budde, L., & Friedli, T. (2020). The smart factory as a key construct of industry 4.0: A systematic literature review. International Journal of Production Economics, 221, 107476. https://doi.org/10.1016/j.ijpe.2019.08.011

[26] Büchi, G., Cugno, M., & Castagnoli, R. (2020). Smart factory performance and Industry 4.0. Technological Forecasting and Social Change, 150, 119790. https://doi.org/10.1016/j.techfore.2019.119790

[27] Fatorachian, H., & Kazemi, H. (2018). A critical investigation of Industry 4.0 in manufacturing: theoretical operationalisation framework. Production Planning & Control, 29(8), 633–644. https://doi.org/10.1080/09537287.2018.1424960

[28] Weyer, S., Schmitt, M., Ohmer, M., & Gorecky, D. (2015). Towards industry 4.0 - Standardization as the crucial challenge for highly modular, multi-vendor production systems. IFAC-PapersOnLine, 28(3), 579–584. https://doi.org/10.1016/j.ifacol.2015.06.143

[29] Kinsy, M., Khan, O., Celanovic, I., Majstorovic, D., Celanovic, N., & Devadas, S. (2011). Time-predictable computer architecture for cyber-physical systems: Digital emulation of power electronics systems. Proceedings - Real-Time Systems Symposium, 305–316. https://doi.org/10.1109/RTSS.2011.35

[30] Li, H. X., & Xu, L. D. (2001). Feature space theory - A mathematical foundation for data mining. Knowledge-Based Systems, 14(5–6), 253–257. https://doi.org/10.1016/S0950-7051(01)00103-4

[31] Lee, J., Lapira, E., Bagheri, B., & Kao, H. an. (2013). Recent advances and trends in predictive manufacturing systems in big data environment. Manufacturing Letters, 1(1), 38–41. https://doi.org/10.1016/j.mfglet.2013.09.005

[32] Grossmann, I. (2005). Enterprise-wide optimization: A new frontier in process systems engineering. AIChE Journal, 51(7), 1846–1857. https://doi.org/10.1002/aic.10617

[33] Kinkel, S., Schemmann, B., & Lichtner, R. (2017). Critical Competencies for the Innovativeness of Value Creation Champions: Identifying Challenges and Work-integrated Solutions. Procedia Manufacturing, 9, 323–330. https://doi.org/10.1016/j.promfg.2017.04.021

[34] Prinz, C., Morlock, F., Freith, S., Kreggenfeld, N., Kreimeier, D., & Kuhlenkötter, B. (2016). Learning Factory Modules for Smart Factories in Industrie 4.0. Procedia CIRP, 54, 113–118. https://doi.org/10.1016/j.procir.2016.05.105

[35] Taurino, T., & Villa, A. (2019). A method for applying Industry 4.0 in Small Enterprises. IFAC-PapersOnLine, 52(13), 439–444. https://doi.org/10.1016/j.ifacol.2019.11.099

[36] Trstenjak, M., & Cosic, P. (2017). Process planning in Industry 4.0 environment. Procedia Manufacturing, 11, 1744-1750.

[37] Faller, C., & Feldmúller, D. (2015). Industry 4.0 learning factory for regional SMEs. Procedia CIRP, 32, 88–91. https://doi.org/10.1016/j.procir.2015.02.117

[38] Cheng, Y., Chen, K., Sun, H., Zhang, Y., & Tao, F. (2018). Data and knowledge mining with big data towards smart production. Journal of Industrial Information Integration, 9, 1-13.

[39] Leite, M., Pinto, T., & Alves, C. (2019). A real-time optimization algorithm for the integrated planning and scheduling problem towards the context of industry 4.0. FME Transactions, 47(4), 775–781. https://doi.org/10.5937/fmet1904775L