USE OF DIGITIZATION IN CHEMICAL ENTERPRISES

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Abstract

Industrial transformation and especially the digitization of business processes is a prerequisite for maintaining competitiveness, across industries. However, the use of digitization Key Enabling Technologies (KETs) differs in the mechanical, process, and hybrid industries. The chemical industry, as a typical representative of process production, differs significantly, especially in the possibilities of product monitoring or in the operation of production equipment. No significant impact of digitization on raw material purchasing, logistics, research, and development processes is expected. Perceived benefits, on the other hand, are expected in production, sales & marketing, and administration processes. To confirm these starting points and verify the state and perception of the importance of digitization in the Czech Republic among chemical production companies, research was carried out in selected chemical companies. Areas and processes in which digitization is already developing have been identified, as well as obstacles and barriers to a faster transformation of the chemical industry according to the Industry 4.0 concept.

Introduction

With the mass development of Industry 4.0 technologies, there has been a revolutionary transformation of industrial production in the last decade. Many mechanical industries adopt technologies of individualized production according to customer requirements, while maintaining a production speed comparable to mass production [1]. Digitally monitored and controlled production technologies are the basis for maintaining the speed of individualized production while increasing quality and minimizing losses and poor-quality production. [2] The list of technologies that form the basis of a digitally controlled production system is based on the digitized form (cyber layer) of the real production process (physical layer) and thus creates a Cyber-Physical System (CPS or Digital Twin) [3], which collects data using sensors, connects via the Internet of Things creates Big Data files, which are used to analyze and adjust the optimal production process. For large amounts of data, companies use Big Data Analysis, Artificial Intelligence (AI) and Cloud Computing (CC) [4]. Other Key Enabling Technologies (KETs) are used in production (3D print, autonomous and collaborative robots, Machine Learning (ML), machine-as-a-service, RFID Tags, RTLS Systems, and other) [5], in research and development (simulations, modelling) [6] and in service processes (augmented and virtual reality, wearables, predictive maintenance, etc.) [7, 8]. The use of these KETs is growing rapidly, but not at the same pace in all industrial areas. Especially for mechanical production, it is not difficult to use Artificial Intelligence elements to adapt production according to customer requirements for almost every individual product [1, 9]. The product is clearly traceable during the production process and the production equipment can be modified quickly and relatively easily. The production process is based mainly on modifiable processes of pressing, machining, welding, assembling, or surface treatment, in which there is no conversion of substances, but in principle to mechanical modifications and component addition [10]. Using sensors, data collection during production, connection of the production system via the Internet of Things and remote control with elements of Artificial Intelligence, it is relatively easy to control production processes in real time [11].

However, in chemical and other process productions, the production process is more complex, usually based on chemical transformation [12]. During production, materials change their nature, input substances disappear, the resulting product has different physical and chemical properties, and production must respect specific chemical balance conditions with a number of reaction conditions related to temperature, pressure, density, humidity, viscosity, chemical reaction speed or concentration [13]. The equipment and reactors built are usually adapted to a single production process and their service life and payback period are extremely long [14, 15]. Despite these limitations, it is desirable that process productions should be digitally monitored and Cyber-Physical Systems should be created for them to achieve production efficiency, product quality, or Its differentiation, if technologically possible [16].

Although the digitization of business processes in mechanical production (especially for the automotive industry, electronics, consumer goods) is currently a common practice not only for production itself, but also for logistics, sales & marketing, purchasing, R&D, and administration, in chemical and other process production we identify obvious implementation delays [17]. Nevertheless, the leading companies in the chemical industry in the EU, as

well as consulting companies Deloitte, KPMG, Ernst & Young, PwC give maximum support to the implementation of KETs and promote digitization as a key tool for maintaining competitiveness and sustainability [15, 18, 19, 20, 21]. And while it may not be possible to achieve a higher degree of product diversification for the production process itself, its digitization will allow higher productivity, efficiency and quality [22]. According to Deloitte, there is great potential to significantly improve R&D, logistics, sales & marketing, and administration processes [18].

Although large chemical corporations show a strong interest in introducing KET and digitizing, implementation is not easy and fast for them either [17]. All the more, digital transformation is more difficult for other medium and smaller manufacturers (SMEs) [23]. High financial and personnel demands for implementation, adoption, maintenance and cyber security can significantly hinder digitization and there is a risk of significant lags in the digital transformation for process productions.

As a result of our theoretical study and assumptions we formulate three research goals to confirm:

Goal 1: To verify the state and perception of the importance of digitization in the Czech Republic in chemical production companies with regard to the competitiveness and sustainability of the company.

Goal 2: To identify the benefits, limits, and barriers related with individual KETs in chemical production.

Goal 3: To confirm the specifics of KETs implementation and digitization in chemical companies and process productions.

Research methodology

Academic researches and studies from relevant fields of research, Industry 4.0 technologies and digitization KETs are used to address the validity of theoretical problems and assumptions concerning expected benefits and limits of digitization and KETs implementation. Previously realized analysis suggests that the chemical industry shows significant specifics in monitoring the product during the production process and specific production conditions do not allow to diversify production - the equipment used is designed to meet the requirements of individual productions.

A form of qualitative research with representatives of large chemical production companies was chosen for the research itself. The intention was to address representatives of multinational corporations with demonstrable experience with Industry 4.0 technologies and more advanced implementation of digitization. The pre-selection was made on the basis of press releases and awards received in the field of digitization and innovation, on the assumption that large multinational companies have sufficient resources for digitization solutions and are among the early adopters of KETs.

Based on theoretical basis qualitative research was carried out as structured one-to-one interviews with managers of three chemical companies producing basic chemicals. All surveyed companies can be considered leaders in national markets in the Czech Republic in terms of both market share and sales volume. Each of the surveyed companies has sufficient support from the group's management and the digitization process is thus not limited by a lack of resources or the will to change current processes.

The respondents were business managers, IT managers, production managers, and production technologist of the companies. The research was carried out in the period September 2021 - April 2022. Information obtained was processed using content analysis. The first set of questions inquired into the importance of digitization, perceived benefits for the company and other stakeholders and finding out the current state and degree of digitization in the company. The second set of questions investigated individual KETs, the degree of their implementation, benefits and limits in their use, as well as the reasons for their rejection or restriction. The third set of questions focused on the specifics of chemical production in relation to digitization.

Prior to the research, business representatives confirmed that digitalisation is considered an undeniable pillar of competitive advantage and therefore the anonymity of individual companies, including a more detailed specification of products and customers, had to be ensured. Despite the different assortment and form of individual production processes, mostly common perceived benefits and limits were identified and there was also a strong agreement on attitudes to the importance of digitization, as well as on procedures for implementing KETs.

Research findings

The first set of questions first confirmed that the assumption of more advanced digitization in large multinational companies was fully justified. Each of the companies has shown significant progress in digitizing its processes and implementing individual KETs. However, for none of the companies is the goal to achieve a completely digitized factory in the sense of an almost autonomous "Smart Factory" and therefore they do not consider digitization as a goal, but a means to achieve business goals.

All respondents, without exception, stated in the evaluation of the importance of digitization that in the first place it is considered as a necessary requirement to maintain competitiveness. In principle, it was important for each of the companies to primarily digitize the production process, create the most reliable "Digital Twin" and monitor the state and changes in the production process. Thanks to real-time process monitoring, the key benefit of increasing efficiency was mentioned in the second place, based on three perceived partial benefits: first mapping of processes, their control and immediate optimization; second saving materials and other resources; and finally increasing product quality.

Perceived benefits for employees are also considered important, as technologies not only reduce the need for insufficient workforce (benefits for employers), but also reduce the need for risky and demanding work (benefits for employees). Furthermore, the benefits for customers and consumers were mentioned to a lesser extent, for other stakeholders the benefits are considered to be minor.

However, the digitization process is not progressing smoothly. The need to consider and defend the meaningfulness of digitization is considered by all respondents to be the most important limits and barriers. The need for the owner of each solution and the reasonable rate of return on each investment decision based on the processed business case are mentioned. Only solutions with a demonstrable payback period within three years can be implemented usually, and it has once again been confirmed that digitization is not the ultimate goal, but a tool for improvement.

The historical context of each of the companies is problematic - for each of them, the production facilities were built in the last century and therefore the process of digitization is more difficult than in building a completely new facility. In addition, each production is unique and completely specific, all digitized solutions must be customized and adapted to the specifics of production. This also increases the financial complexity of each change adopted.

Problems related to IT security and the reluctance of people (management and employees) to accept change were considered to be limits and obstacles of lesser importance. Although the organization always shows some resistance and rigidity to change, these barriers can be overcome by proper communication and motivation. Last but not least, there were interesting restrictions on the sustainability of already digitized processes. The need to maintain digitized elements for years (sensors, software, hardware) is growing significantly, which places new demands on the structure of job positions, and in one of the companies the lack of competent staff has become a limiting factor that has slowed down the digitization process.

The second set of questions targeting individual KETs, examining the experience with the use of individual KETs, resulted in the classification of individual KETs into groups: the most frequently used (implemented by each of the surveyed companies), the second group included less used KETs (used by 1-2 companies) and the third groups of technologies that companies did not implement or did not evaluate as promising and viable after initial testing. Table I shows an overview of individual KETs according to the categories of their use.

Table I
KETs implementation and utilization

The most important KETs	Less used KETs	Not used or rejected KETs
Big Data/Analysis	3D print (prototypes)	Machine Learning/AI
Sensors	Virtual and Augmented Reality	Autonomous robots
Internet of Things	Digital Twin	Wearables
Cloud computing	Collaborative robots	Edge computing
Automatic robots	Predictive Maintenance	Cognitive computing
Cybersecurity	Machine as-a-service	Digital modelling

It follows from the individual groups that each of the companies used basic KETs to digitize their production process. The production lines are equipped with sensors, data is collected in real time using the Internet of Things and processed for other analytical purposes using Cloud Computing. Digitized system is secured on the basis of security protocols and firewalls, as disruption of production due to cyber threats or attacks would have a fatal impact on financial results and increases the risk of accidents and failures.

Two of the three companies use Digital Twin, 3D print technology, especially for prototyping and spare parts production. Sensor data is also used for predictive maintenance in two companies. To a lesser extent, the elements of Virtual and Augmented Reality are used, and if so, mostly for training or simple remote instructions for repairing equipment. Collaborative robots are also used to a lesser extent (as opposed to automatic ones, which are usually considered a common part of production equipment when handling a product or material). Machine as-a-service is used by only one of the companies and only for a small segment of the production line.
Machine Learning and Artificial Intelligence, digital modeling and autonomous robots have already been tested in some companies, but were no longer considered viable - a meaningful business case was not created and companies decided to step down from early adopters in these technologies.
The third set of questions focus on the specifics of process production in relation to digitization. Each of the respondents confirmed that chemical production has such strong specifics compared to mechanical production that every production process is completely unique. Due to the need to meet the technological criteria, it is not possible to achieve a higher degree of modularity / variability of production, and at the same time the high expertise and experience of the operating personnel is absolutely essential.
The risks associated with the failure of the human factor and the ability / necessity to avoid working in a hazardous environment are also significant.
In terms of the use of digitization in R&D of new products, differences in prototyping were mentioned, because in the chemical industry the prototype is not a physical product, but a laboratory sample that cannot be printed on a 3D printer but can be modeled using appropriate software, which none of the companies does not use.
All respondents agreed that with high demands on the consumption of materials and energy in chemical processes, digitization helps them to save these resources as much as possible and thus increase cost savings even in the conditions of unfavorable developments in the markets for materials and energy.

Discussion and result analysis

Despite the expected opportunity in logistics, R&D, sales & marketing, and administration processes, companies promote and implement digitization primarily in production processes. So far, they use various platforms for communication with customers and suppliers, from emails, telephones, personal meetings to e-shops. Significant digitized communication platforms are not used yet, which is not a surprise in B2B markets, however, for B2C markets these platforms should already be at least on the rise.
Due to the focus of process production, it is difficult to use many KETs that would be easy to use in mechanical production, such as 3D printing. The reason is the different nature of the chemical product, which is created not by shaping but by chemical transformation. Machine-as-a-service technology is not used; the primary reason is the robustness of production lines, which are traditionally investment-intensive and long-term. It is not customary in the industry to operate them in service mode.
Artificial Intelligence systems and Machine Learning are also poorly promoted due to the low standardization of the developed solutions. The principles of AI and Machine Learning must be tailored to the specific process, which prevents subsequent commercialization when selling to other entities. The design of the solution is thus too investment-intensive. Due to the relatively low need to move materials, intermediates and final products by hand, autonomous robots, wearables (exoskeletons) are not widely used either. The technology of the production process usually works with the flows of liquids, gases, bulk materials and transport must be solved in large volumes using conveyors, pipes, or gravity.
The research revealed that the reason for not introducing technologies is not inexperience or ambiguity in their application. All respondents showed a high level of familiarity with the possibilities of digitization and individual KETs. It was confirmed that the specifics of the built process production cause low variability of the resulting products. The proposed equipment with the used construction material does not allow to fundamentally change the production technology, to achieve individualized production is difficult or almost impossible for most chemical productions.

Conclusion

During the qualitative research, it was found that the digitization of production processes in particular is not underestimated in the chemical industry in the Czech Republic. However, one of the most fundamental findings is the relatively slow pace of transformation. Although the research was conducted in companies with sufficient resources, background and support, none of them proceeded to implement digitization with radical innovations. On the contrary, the pace of digitization is chosen gradually, in partial steps and only on the basis of meaningful business cases that are viable and financially advantageous with short payback period. The reason may be the historical context, where many productions have been in operation for decades and digitization would be

disproportionately demanding, but not impossible. Nevertheless, even at a slow pace, digitization is considered highly investment-intensive for these companies.
Related to this is the finding that none of the companies aims to transform into a so-called "smart factory", which would create a comprehensive view of all business processes from marketing and market development, customer contact, order confirmation, purchasing, production, expedition and administration. Again, the changes adopted are rather local and gradual.
Many advanced digitization technologies were identified in the surveyed companies and it was also confirmed that their implementation could not be carried out without the information and financial support of the corporate management. It is therefore worth considering whether it is possible to make the same progress for other companies in the Czech Republic that do not have a similar background, face current problems due to rising costs and therefore cannot consider launching large-scale renovations at high capital expenditures. Unfortunately, this has and will have a direct impact on future competitiveness, especially for SMEs. The direct threat will be the inability to achieve high efficiency, while maintaining the required quality and minimizing waste of resources.
In conclusion, it can be stated that the research confirmed both the limits in the introduction of digitization in process production, as well as certain delays that Czech chemical companies show in comparison with world and European leaders in the chemical industry. However, these companies have achieved especially in the production very advanced forms of digitization and implementation of KETs, which proves that digitization is feasible in the conditions of process production.

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