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# Application of the elements of the Industry 4.0 concept in chemical industry and comparison with other industrial areas in the Czech Republic

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*Information and Communication Technologies (ICT) is one of the most dynamic developed areas, opening new business models and impacting efficiency and productivity. The use of ICT technology and its outcomes in other economic areas and their overall social impact is desirable to be continually evaluated. Intensive ICT developments is named as Industry 4.0 or the fourth industrial revolution, including the deployment of integrated ICT solutions, digitization, automation, robotics, intensive use of the Internet, including the Internet of Things or the Internet of Services, cyber-physical systems and artificial intelligence systems, additive printing, and other tools. The aim of the article is to determine the basic elements of Industry 4.0 and assess their use and impact on society; such an assessment being carried out in selected companies of the chemical, food, and automotive industry of the Czech Republic. The above industries are using automated systems available already for years. The specific use of elements of Industry 4.0 is influenced by industry specifications, both by using these elements and gradually introducing them to be adapted for expected conditions. In the chemical industry, the elements of Industry 4.0 are used; especially, in the digitization of the assesment of the value chain from the design phase of the product up to its production, management, and logistics. There are used elements that contribute to increased productivity, production planning tools and supply optimization. For monitoring and controlling of operational safety production operations data, such as data distributed via the Internet of Things, are shared and analyzed. Similar situation is in the food industry, whereas in the automotive industry, it is possible to take advantage of digitalisation and robotization. Based on the analysis reported herein, the situation in selected enterprises of the chemical, food and automotive industries is evaluated, a number of elements of Industry 4.0 presented and the expected trends of further development in this area outlined.*

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## Introduction

The "Industry 4.0" concept can make a significant contribution to the intensive development of a number of areas of industry and services in the perspective of long time period. Over the next 10 years, the impact of the changes associated with putting Industry 4.0 into practice is expected to be very intense in many aspects. At least, 10 percent of jobs are expected to be lost and a significant impact on the activities performed is expected for 35 percent of jobs, but also new occupations and a number of jobs expected to be created. A distinct impact can be predicted not only for routine or physically demanding work positions that will be one day replaced by robots, but a similar effect can also be foreseen for administrative staff with the advent of automation of administrative processes [1–3].

There will also be a significant impact on the field of education, where the study plans should be modified already now as the existing students from all types of schools would be affected by the start of Industry 4.0 immediately after their graduation and first attemps to find employment in the labour market. A significant increase in demand for highly qualified employees is expected; especially, for those with technical and ICT knowledge, or a combination of both, which may lead to polarization in the labour market and greater wage differentiation [4,5]. A change in the business models and technical standards can be anticipated as well and the respective impacts will also be visible in the increased demands on the security of systems or the solution of legal framework. Industry 4.0 therefore brings significant societal change, not only in the industry, trade or services, but in all the economic processes, as the ICT tools will move the entire economy towards automated systems, digitization, higher levels of integration and, last but not least, higher productivity and innovation [6–8].

Industry 4.0 is a concept involving a number of elements and procedures, such as automation, digitalization, robotization, implementation of cyber-physical systems (CPS), utilization of the internet of things (IoT), the internet of services (IoS), the internet of people (IoP), cloud computing, machine learning, artificial intelligence (AI), big data (BD) and business intelligence (BI), additive manufacturing, augmented and virtual reality (AR and VR, respectively), smart factories, digital twins, digital economics, etc. [6,7].

The above-mentioned elements of Industry 4.0 and new processes are also being applied to varying degrees in the chemical industry. The use of such elements in chemical industry technologies is referred to as "Chemistry 4.0" or "Chemicals 4.0" [9,10]. It concerns general procedures within administrative or business activities (namely: automation of invoice processing, payment processes, communication with the customer, etc.), but also the specialized technological procedures typical for chemical industry.

Due to the characteristics of chemical processes, one does not expect an extensive use known from mechanical production, such as the production of additives and machine learning. However, in the area of maintenance of production infrastructure, the increasing control in the production or a possibility of more detailed predictions in the individual processes, the use of IoT, CPS, digitization, analysis using BI, AI, etc. should be considered [9–13].

The aim of this paper is to look into the practice of chemical industry companies and to assess how much they are familiar with this trend, how much they utilise the basic elements of the Industry 4.0 concept in their practice compared to the situation in other industries.

## Literature Review

The latest trends associated with the use of ICT technologies were first referred to as Industry 4.0 in 2011 in Germany [6]. Subsequently, the changes thus termed began to be reflected in the strategic documents of the most developed countries. This is how the first phase of the advent of Industry 4.0 has been introduced – *via* the preparation of socio-economic system, the direction of research to apply the elements of Industry 4.0 in practice, and by expansion of companies that applied Industry 4.0 solutions [14].

The following features are characteristic for Industry 4.0. The primary feature is integration, namely higher-order integration, compared to the previous practice. Tomek and Vávrová [8] talk about horizontal, vertical and diagonal integration. Another feature is interoperability, which allows people and smart factories to electronically connect and communicate with each other based on CPSs. Virtualization of the production process makes it possible to interconnect physical systems with virtual models. In addition to integration, decentralization is yet another feature of Industry 4.0, and CPSs are, to some extent, able of making decisions by themselves. An important feature is also the shift towards real-time or nearly real-time decision-making, thanks to a comprehensive online connection. And, finally, the last important feature is the modularity and flexibility of these solutions and their ability to modify with respect to changing requirements [15].

Digitalization, i.e. a digital model of the product and the production process, offers a possibility of maximum interconnection of the entities entering or influencing such a process and the product life cycle. Digital Enterprise (Digital Factory, e-Plant, e-Factory, Smart Factory) is a term for enterprises that use CPSs for monitoring physical processes. If businesses want to utilize all benefits of digitization, they must ensure the complete data integrity of all the processes involved. Based on this, a digital enterprise can then be created [16].

**Digital twins** are a virtual image of production in smart factories used to simulate and optimize the products or production technologies. A digital twin is designed to be able to obtain input data from its twin's sensors from the real world, with IoT being intensively used here. This technology makes it possible to simulate an object in the real time, identify potential problems, and monitor continuous performance [17].

**CPSs** are sophisticated information systems to control physical processes through integration into physical devices. They represent systems of computational elements and of physical systems that cooperate with each other and where computational elements are able to control physical subjects [12].

**Automation** has been used for a long time, and is currently associated with expanding the decision-making capabilities of control units. The term refers to the introduction of automatic control units designed to control both technological equipment and processes. This approach reduces the need to involve people in the work process when performing certain activities and hence, it is very closely linked to the concept of robotics, machinery learning and AI. Automation concerns production processes, but it is also a part of software applications that provide certain activities previously performed by employees; e.g., in business or administrative activities [18].

**Robotization** has also been known for a long time, and now there is a noticeable shift from the individual single-purpose robots to more universal, independent and intelligent robotic systems that are connected, thanks to digitization, into integrated structures in the form of a smart factory [19].

**IoT** stands for an Industry 4.0 element that uses the connection of real things to the Internet. The IoT is understood as an Internet interface through which the individual CPSs are able to communicate with each other. The term is generally used to refer to connecting things in public space, in companies, and at home. The term the **Industrial Internet of Things** (IIoT) then denotes interconnections in an industrial environment. Within IIoT, every production device, product, semi-finished product or transport device will be connected to the Internet without active human participation via sensors and chips. It is therefore a physical connection of the individual components enabling their direct communication and cooperation [12]. The transition to 5G networks is expected to contribute to the massive expansion, which, once implemented, will significantly increase the average data transfer rate (up to 20GB/second) and enrich up to one million devices on an area of 1 $km^2$ [20,21]. **IoS** is closely related to cloud computing where services of various kinds are offered via the Internet – applications, cloud storage or platforms for own development.

In the case of **IoP**, a person is involved in communication or use of services via the Internet (in a corporate environment, one can control production systems and technologies via Internet access, utilize remote connection to the work environment, work communication, etc.). Newly, all these areas are summarized by the term the **Internet of Everything** (IoE), which connects together the things, processes, data and people via the Internet on a global scale [22].

Another enriching technology that expands the list of tools within Industry 4.0 is **additive manufacturing** that uses 3D-printing from various materials (thermoplastics, gypsum composite, steel powder, low-melting alloys [23]). Using this type of production, three-dimensional solid objects are created via digital input by stratifying the individual continuous layers of a material.

**AR and VR** expands the real world with additional information or images or creates real or unreal worlds or systems. In the corporate environment, it is possible to visualize remote environments, actual or planned technological equipment, unavailable internal spaces of technological equipment, planned products, etc. [24]. The respective areas of use are almost unlimited: infrastructure monitoring and management, marketing and sales (demonstration of a product, technology, space to the customer), education, training of workers in working with new technology, simulating extreme conditions, and practicing the corresponding reactions, etc. [11].

An integral part or consequence of Industry 4.0 is the creation and concentration of data from various elements, internal and external sources. There is a lot of space for their processing with the aid of **analytical tools (Big Data, BI)**, but also other uses in the field of machine learning, AI, automation, etc. [25, 26].

With the increase of the above-mentioned elements, with the increasing volume of data, it is necessary to address the issue of **cyber security** as a matter of priority. The system security must be understood comprehensively and systemically, from the data and communication level at the lowest level, through the infrastructure reliability and security, up to the global system security at the level of companies and entire supply chains. All this while maintaining the information privacy of individuals and ensuring the protection of intellectual property [25].

In the chemical industry (**Chemistry 4.0**), it is possible to apply Industry 4.0 elements in generally applicable procedures, such as supporting economic and business operations to increase productivity, creating smart factories, improving the efficiency and flexibility of supply chains, and increasing the performance of existing assets.

However, the use of tools in the actual chemical-technological processes is also anticipated. An important area for which solutions are being developed is the maintenance of an extensive chemical-technological infrastructure and predictive maintenance management. Furthermore, the Industry 4.0 elements are applicable for reduction of energy requirements in chemical production, a reduction of waste, safety risks, and the elimination of routine or health-threatening activities [26–28]. A progress in digitization can be expected, too; e.g. by using digital twins in the form of digital images of technologies, products, production processes that can be modified, optimized, monitored, and controlled in real time, but also used for training; e.g., in operator-controlled simulations. With the expanded volume of production-characterizing data, a more intensive use of data analysis, BI, AI and self-decision algorithms can be an anticipated result [9,11,12].

However, the expected onset of these technologies will be rather gradual due to the high investment intensity of the chemico-technological infrastructure [13]. The high investment intensity of the introduction of Industry 4.0 elements in chemical industry is also confirmed by Kneißel [10]. Based on research in Germany in 2016, when listing and surveying the limits of the introduction of Industry 4.0 in chemical industry, he also mentions the lack of qualified workers, insufficient know-how, as well as unwillingness to accept technological innovations in the companies gathered in his study.

Economic development in the chemical industry in the Czech Republic in the last 10 years has been affected by the financial crisis and the subsequent economic growth; see [29,30] for more details. In the period 2015–2019, the economic growth brought greater investment activity. At the same time, however, it led to overpressure in the labour market and a shortage of workers, both skilled and, in 2018–2019, unskilled ones [3]. With the commencement of Industry 4.0 during this period, state support was gradually conceived, a number of conceptual and program documents approved, which has led to sort the Czech Republic among the countries that actively respond to this development, support it, and helped to define legal and other conditions [31]. The expected impact of the actual coronavirus pandemic, which will significantly affect the economic situation in the Czech Republic, the European Union, but also in the entire global economy, will probably slow down the advent of new technologies, but it will certainly not stop. On the contrary, some of these technologies can help to overcome the unexpected situations.

## Research Methods

The use of Industry 4.0 was assessed in four selected chemical industry companies and compared with the situation in two other companies – one in the food industry and second in the automotive industry. The study was carried out in a survey in the form of a questionnaire, which was prepared on the basis of a literature review. The respondents were employees who had implemented the new innovations in companies, or managers of the production activities. The questionnaire had ben distributed either personally to the individual respondents directly in companies, or the persons selected had been asked to answer the questions in a form and to send the filled-up material by e-mail. In order to avoid possible misunderstandings, the Industry 4.0 concept have also been briefly explained in the questionnaire. The whole survey took place in the period from April to May 2019.

## Results of research

In accordance with the companies' request for maintaining anonymity, they were marked with letters A–F. Their basic characteristics are as follows:

- **Company A** – operates in the chemical industry. It is a manufacturing and trading company, active mainly in the field of explosives and services related to the application of energetic materials for civilian and military use. The company has a significant position on the market in the Czech Republic and is a major exporter to EU countries.
- **Company B** – operates in chemical industry. It focuses on the production of chemical products for household, such as washing powders, detergents, fabric softeners, cosmetics, etc. It is a production plant within an international company with global operations.
- **Company C** – operates in chemical industry. It is engaged in the production of household chemicals, cosmetics and cleaners for professional use. Its main interest is the Czech market.
- **Company D** – operates in chemical industry. It focuses on the production of chemical products for household, cleaners, detergents, cosmetics. Again, it is active preferably on the Czech market.
- **Company E** – operates in the food industry. Its production is focused on beverages – coffee, tea; both in a wide range of products. It is a branch within an international company with global impact.
- **Company F** – operates in the automotive industry. It is a major producer with three regional plants in the Czech Republic; all being a part of an international group.

The questioning scenario deals with detailed assessment of the companies' approach to Industry 4.0 in two ways – in general and with the individual elements of this concept. For an overview of usage of each element of Industry 4.0, see Table 1. Answer *Yes* symbolizes significant implementation, or usage of the Industry 4.0 element and *No* means that the company has not implemented and/or used the Industry 4.0 element. The table also presents their assessments of the Industry 4.0 impacts on the company in human resource management area and their view to the future in this area. All the companies pay attention to Industry 4.0, but the rate and level of utilization of Industry 4.0 features varies significantly; the size of the company, international connections and the investment intensity of complex solutions also playing a role.

Company A is at the beginning of the implementation of Industry 4.0 elements, is developing a long-term concept of further progress in this area. Company A focuses on expanding of human resources, and organizes Industry 4.0 training for employees. While, given its focus on energetic materials, placing great importance on ensuring cyber security of prepared solutions. The company A plans to introduce automation and robotics, with particular emphasis on reducing manual work in hazardous environments.

Company B is a leader in the implementation of Industry 4.0 in the chemical industry; it has been recognized in the international field for its readiness for the upcoming changes and introduction of new technologies with their intensive integration. [32]. This company is continuously working on the creation of a smart factory while introducing the elements of Industry 4.0 both into the production itself and into other activities in the company. It uses automation, has implemented a number of robots in production (collaborative robots, robotic arms), uses 3D-printing to produce spare parts and parts for testing. It also works on the use of IIoT and even in its case, emphasis on security is one of the priorities. Social impacts have already been seen in this company, there are job losses for manual and unskilled types of work, but on the other hand, new ICT-related jobs are being created into more extent. There are also regular activities leading to the improvement in qualifications and training of employees to ensure that they can cope with the implemented technological changes.

Company C is also at the beginning, but it is interested in the topic and due to the high investment intensity of technology modification, it is gradually taking the strategy of introducing individual elements and modernization of production equipment within the Industry 4.0 concept. The already established elements include the individual automated lines, but the company foresees a further gradual automation of production. The social impact is manifested in the form of increasing requirements for the scope of qualifications of the sought-after workers.

For the time being, Company D uses the individual elements of Industry 4.0, such as autonomous robots to replace routine, repetitive work when handling products. Again, it plans to gradually expand these elements. It also uses 3D-printing to make prototypes. It also uses cloud storage, but this company also pays attention to cyber security in this context, solving it with a set of measures and technical means at the level of all elements of the ICT infrastructure. The social impacts are still minor, but some manual positions have already been made redundant and the requirements for qualifications are rising, especially in the field of working with data and other ICT skills.

Company E has been working on the implementation of the Industry 4.0 elements for a long time, using digitization tools to collect data from the production lines, thus monitoring the energy consumption, using 3D-printing and AR. The company is already using robots in the area of product assembling. It does not underestimate the area of security either, having built a partnership with an external professional company. In the near future, the management is also considering the use of AI for analytical activities.

Company F is already active in using a number of the Industry 4.0 elements. Indeed, this company is one of the leaders in this direction, employing them both to design new products (VR, 3D printing) and in production (digitization – e.g. digital twins, IIoT, automation, robotics – robotic supply trucks, collaborative robots, fully automated robots, autonomous robots, etc.) and other supporting activities, in business activities (IoS), in the education or training of employees (VR), but also in cooperation with partners in the supply chain. With such a massive use, security is also comprehensively addressed. The social impact is already well identifiable, routine work jobs disappearing, but at the same time the requirements for the qualified workers are increasing. The company assumes that the number of jobs resulting in such changes will be greater than the number of jobs that will be lost. The limiting factor for the company is not only the requirements for higher qualification, but also the high investment to incorporate these changes. However, as a whole, the company sees clearly a positive impact in implementing the Industry 4.0 elements.

**Table 1** Comparison of companies and their implementation of Industry 4.0

| Type of trend | Company A | Company B | Company C | Company D | Company E | Company F |
|---|---|---|---|---|---|---|
| Industry 4.0 awareness | Yes | Yes | Yes | Yes | Yes | Yes |
| Use in production | Yes | Yes | Yes | Yes | Yes | Yes |
| Digitalisation | Yes | Yes | Yes | No | Yes | Yes |
| Digital factory | No | Yes | No | No | No | Yes |
| Digital twins | No | Yes | No | No | No | Yes |
| Automatization | No | Yes | No | No | No | Yes |
| Robotization | Yes | Yes | No | Yes | Yes | Yes |
| IoT | No | Yes | No | No | No | Yes |
| IoS | No | Yes | No | No | No | Yes |
| Cloud computing | No | Yes | Yes | Yes | No | Yes |
| Cyber security | Yes | Yes | Yes | Yes | Yes | Yes |
| 3D Print | Yes | Yes | No | Yes | Yes | Yes |
| AR, VR | No | No | No | No | Yes | Yes |
| Job lost | No | Yes | No | Yes | – * | Yes |
| Job created | No | Yes | Yes | – | – | Yes |
| Qualification increase | Yes | Yes | Yes | Yes | – | Yes |
| Future plans for the use of Industry 4.0 elements | Yes | Yes | No | Yes | Yes | Yes |

*) – … no answer

## Important Findings and Recommendations

For all the research subjects, it is possible to identify common features related to the implementation of Industry 4.0 elements. If we focus on the assessed companies of the chemical industry, the survey shows a clear tendency to use elements of Industry 4.0, and it is also evident that companies are aware of the elements of Industry 4.0 and trying to apply them in various extent in the production processes. In particular, there is a profound inclination towards digitization and robotization, although complete solutions in the sense of smart factory, deployment of digital twin, IoT, IIoT or IoS are not yet commonly applied in the companies investigated.

Another common feature is a high emphasis on cyber security, which is absolutely essential for all research subjects, as well as the priority for education and training.

A surprising finding is the relatively high rate of use of 3D-printing, even in non-mechanical production; in the case of possible job losses, there is a surprisingly low level of concern about the consequences of Industry 4.0 implementation in the structure of jobs, which may be caused by a recent noticeable labour shortage in the Czech Republic. An interesting finding is the presence of a company that has not prepared any plans for the implementation of Industry 4.0 elements in the future, and also that one company does not use the currently common cloud-computing services.

On the other hand, VR and AR technologies are among the elements that have so far been applied to a limited extent, with none of the assessed companies using these technologies, regardless of the degree of progress in implementing the Industry 4.0 elements in the company.

Further research based on one-to-one interviews with business managers revealed the need and willingness to work more closely with research and innovation centres, and they would also appreciate more intensive research collaboration between practice and other research institutions. They would also welcome the opportunity to obtain and share information on the latest technological trends and to develop possible solutions for supporting the innovation and creativity in the search for new applications of Industry 4.0 elements, new processes, business models, etc. In this respect, it is expedient to use the National Centre for Industry 4.0 for finding suitable partners ready to share the experience or targeted advice [33].

In the field of employee training, the companies are looking for specialized partners and consultants to help employees learn about new trends, encourage their communication skills, engage them into transformations in the company and offer them a space to suggest how to use new technologies, how to modify the work procedures, and how to use remote communication or flexible forms of work.

At the same, they perceive the need to dispel concerns about the onset of the Industry 4.0 concept regarding job cuts, but also the management's distrust and fears of introducing and mastering new technologies, and, as a result of these concerns, address possible impacts on personnel management, the legal consequences of the changes and social or interpersonal impacts.

They agree on the need to openly present implemented procedures, objective information for employees, business partners, and customers about the implementation of the Industry 4.0 elements as they perceive space for interconnected solutions (horizontal, vertical, diagonal integration) and, in terms of reputation, such an approach increases positive business awareness [34].

## Conclusions

The results of the research show that all the companies pay attention to the Industry 4.0 concept and although they are in various stages of implementation, they have already applied some elements of Industry 4.0 into the production, agreeing on the need for a high level of security, need for education and training, in principle, regardless of the nature of the company's activities.

So far, the degree of implementation of digital and autonomous technologies differs between companies, the transformation into fully digitalized forms of production in the terms of digital twins, smart factories, autonomous management is not taking place yet, although plans are being formulated on how to implement the Industry 4.0 elements in a company.

However, the respondents mention the barriers and limits that hinder the faster deployment of the Industry 4.0 elements, which should be addressed in the future. These barriers include ignorance of available technologies and innovations, low level of cooperation with research, innovation and educational institutions, as well as perceived levels of mistrust among employees, management, but also other stakeholders, of technologically advanced elements of Industry 4.0.

The limitation of a report in this paper is a small number of companies assessed and only a basic screening of the presence or absence of the individual elements of Industry 4.0; however, its indisputable value lies in the obtaining of the first basic overview of the approach of companies to this issue. In the area of implementation of the Industry 4.0 elements, a wide range of topics can be considered for further research. It is a deeper assessment of use in the individual industrial areas, development of infrastructure and information platforms to support monitoring of the development of autonomous, digital and automated technologies over time, for their rapid implementation in commercial sphere. But, in addition to the technical aspects, a more detailed assessment is yet needed to investigate the social impact on employees, other participants in the supply chain, and the society as a whole.

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