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CYBER–PHYSICAL SYSTEMS EXPRESSION IN INDUSTRY 4.0 CONTEXT

Abstract. The changing business environment has influenced new innovation development, which is currently described as the upcoming 4 industrial revolution. The development of Internet of Things, Big Data concepts increased the productivity of various businesses and influenced the appearance of new business models. A more advanced concept of technologies in recent years has been analysed in the context of advanced production. The appearance of cyber–physical systems and possible implementation in various other industries than production is even more stimulating the realization of the ideal Industry 4.0 concept. Therefore, it is important to identify how exactly cyber–physical systems is stimulating Industry 4.0 and to provide insights for future research. The authors of this paper provide the motivation for Industry 4.0, describes the concept of cyber–physical systems and their new implications. In the end the authors provides new and future business models. This publication is contributing to the understandment of the new competitiveness environment strategies. The authors amplifies the necessity to continue research focusing on cyber–physical systems implementation in supply chain management context, because supply chain management has only a limited amount of implications and research regarding the cyber–physical systems.

Keywords: Cyber–physical systems, Industry 4.0, competitiveness, business models, supply chain management

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ВИРАЖЕННЯ КІБЕРФІЗИЧНИХ СИСТЕМ У КОНТЕКСТІ ІНДУСТРІЇ 4.0

Анотація. Зміна ділового середовища вплинула на новий інноваційний розвиток, яке в даний час характеризується як майбутня промислова революція 4.0. Розвиток Інтернет–речей, концепцій Big Data підвищив продуктивність різних бізнесів і вплинув на появу нових бізнес–моделей. Просунута концепція технологій в останні роки була проаналізована в контексті передового виробництва. Поява кібер–фізичних систем та можлива реалізація в інших ніж виробництво секторах економіки ще більше стимулює реалізацію ідеалу концепції індустрії 4.0. Тому важливо точно визначити, наскільки кібер–фізичні системи стимулюють Індустрію 4.0 і та дають уявлення про майбутні дослідження. Автори цієї статті пропонують мотивацію для індустрії 4.0, описують концепцію кібер–фізичних систем та їх нові наслідки. В результаті автори представляють нові та майбутні бізнес–моделі. Ця публікація сприяє розумінню нових стратегій середовища конкурентоспроможності. Автори підкреслюють необхідність продовження досліджень, присвячених впровадженню кібер–фізичних систем у контексті управління ланцюгами постачання, оскільки управління ланцюжком постачань має лише обмежене число наслідків та досліджень щодо кібер–фізичних систем.

Ключові слова: кібер–фізичні системи, індустрія 4.0, конкурентоспроможність, бізнес–моделі, управління ланцюгами постачання

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ВЫРАЖЕНИЯ КИБЕРФИЗИЧНИХ СИСТЕМ В КОНТЕКСТЕ ИНДУСТРИИ 4.0

Аннотация. Изменение деловой среды повлияло на новое инновационное развитие, которое в настоящее время характеризуется как будущая промышленная революция 4.0. Развитие Интернет–вещей, концепций Big Data повысило производительность различных бизнесов и повлияло на появление новых бизнес–моделей. Продвинутая концепция технологий в последние годы была проанализирована в контексте передового производства. Появление кибер–физических систем и возможная реализация в других чем производство секторах экономики еще больше стимулирует реализацию идеала концепции индустрии 4.0. Поэтому важно точно определить, насколько кибер–физические системы стимулируют Индустрию 4.0 и и дают представление о будущих исследования. Авторы этой статьи предлагают мотивации для индустрии 4.0, описывающие концепцию кибер–физических систем и их новые последствия. В результате авторы представляют новые и будущие бизнес–модели. Эта публикация способствует пониманию новых стратегий среды конкурентоспособности. Авторы подчеркивают необходимость продолжения исследований, посвященных внедрению кибер–физических систем в контексте управления цепочками поставок, поскольку управление цепочкой поставок имеет лишь ограниченное число последствий и исследований в сфере кибер–физических систем.

Ключевые слова: кибер–физические системы, индустрия 4.0, конкурентоспособность, бизнес–модели, управление цепочками поставок

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Introduction. Changing business environment and models Globalization, appearance of new products and services in the world markets has drastically effected the competitiveness environment. Today consumer demand for high quality products with high variety and delivery directly to their doorsteps. The appearance of internet allowed consumers to receive information about products and services from the entire globe and expect delivery from different continents. Because of this the production process, logistics and services are required to optimize their operations and reduce costs to a minimum at the same time maximizing output. These trends requires companies to change their operational and tactical level strategies to cope with these challenges.

Literature review and the problem statement. More and more research is being conducted, which analyses approaches to limit the negative effect of globalization and high demand for variety and low costs. The research mainly focuses on Industry 4.0 concept, which amplifies the necessity to automate business processes and utilize their assets in a more efficient manner and to allow mass customization [1]. The concept of Industry 4.0 has been developed in Germany since 2011, which amplified the necessary criteria to achieve for companies to maintain their competitiveness. These criteria involved mass customization, high quality and low production costs [2]. However, at that time there were only limited technologies allowing to achieve such criteria in production process. Concepts such as Internet of Things (IoT), Big Data and artificial intelligence moved towards the Industry 4.0 concept, however a more advanced concept of Cyber–physical systems (CPS) today can be considered as the main factor contributing to the development of Industry 4.0. "CPS are systems of collaborating computational entities which are in intensive connection with the surrounding physical world and its on–going processes, providing and using, at the same time, data–accessing and data–processing services available on the internet" [3]. Majority of researchers amplify the impact of CPS to advanced manufacturing in the context of Industry 4.0. „In particular, CPS is the core technology enabling the transition from Industry 3.0 to Industry 4.0 and is transforming global advanced manufacturing" [4]. Other research provides more application and benefits of CPS usage for production. For instance, "utilizing advanced information analytics, networked machines will be able to perform more efficiently, collaboratively and resiliently. Such trend is transforming manufacturing industry to the next generation, namely Industry 4.0" [5], [6]. Other researchers amplify the process control approaches with CPS. "CPS can radically improve functionally of monitoring systems and reduce the cost of its implementation" [7]. However, there are problems related with not only production processes, which reduces companies' competitiveness. Continually increasing demand for greater logistic performance and lower logistic costs, requires production enterprises to plan and control their order processing in a more efficient way [8]. Other research amplify CPS usage for service industry. "Many manufacturing systems are not ready to manage Big Data due to the lack of smart analytics tools. As more software and embedded intelligence are integrated in industrial products and systems, predictive technologies can further intertwine intelligent algorithms with electronics and tether–free intelligence to predict product performance degradation and autonomously manage and optimize product service needs" [9]. There is growing number of research related to CPS usage for other industries than production, however the least amount of research is related to transportation services, which is related with all the processes of customer service. The successful implementation of CPS in the supply chain sector could provide greater competitiveness advantage for companies. Personalised transport service addresses on–time access and multiple provider resource management, for capacity of transport operators in cities [10]. The novelty of the research is that CPS is the main factor contributing to the full realization of the Industry 4.0 concept. Moreover, the identification of the limited amount of research of CPS usage for other industry than production provides further research possibilities. Therefore, the goal of the paper is to define CPS concept in the context of Industry 4.0 in various industrial sectors such as transportation, services and so on. The research methodology consist of in depth literature analysis and analysis of possible CPS applications in industry to amplify the necessity to research CPS concept for more efficient organization management. To achieve this goal the following objectives will be accomplish:

1. To analyse the essential elements of Cyber–physical systems;
2. To identify cyber–physical systems possible applications for Industry 4.0;
3. To determine future trends of Industry 4.0 integration with Cyber–physical systems in industrial sectors.

Research results. Elements of CPS – integration, sensors, information and data processing, automation and control, networks, actors, adaptability A bibliometric analysis of CPS publications by title has been conducted in Clarivate analytics Web of Science data base. The results are represented in figure 1.

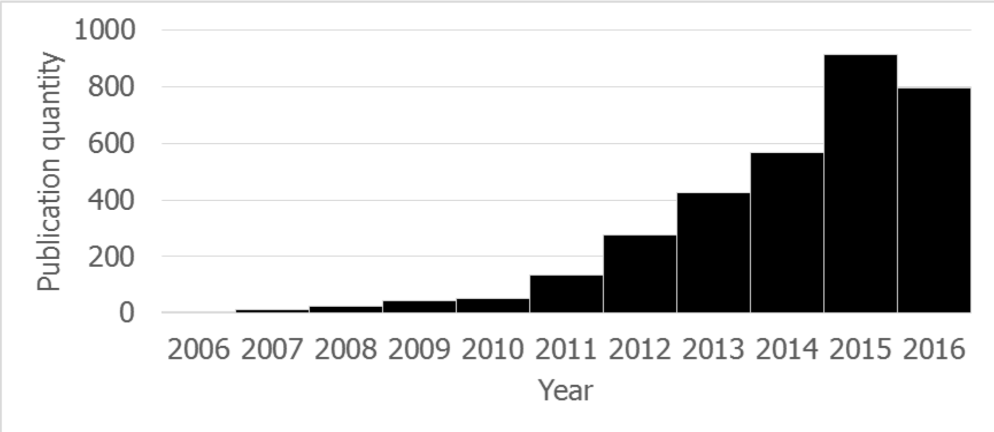

Figure 1. Bibliometric Analysis of Cyber–physical Systems
Source: compiled by the authors based on own researches

The results clearly show that the CPS concept started to be analysed from 2006 with only 1 publication. The research of CPS grew exponentially from 2011 when the concept of Industry 4.0 was started being promoted more intensively. Since Industry 4.0 concept started developed due to the necessity to increase quality and provide mass customization, therefore the research mainly focused on advanced manufacturing concepts. A more precise description and essential elements of CPS based on previous research has been summarized by the authors and represented in figure 2 [11], [1], [4], [12], [3]. The CPS base level begins from sensors, which are used to gather information from the physical world. These sensors have been widely used in IoT concept in previous literature. "IoT is an integrated part of Future Internet. According to the agreed protocol, any article can be connected and talk to each other. This can be achieved through a vast number of methods and technologies, including radio frequency identification, near field communication, infrared sensors, and many more" [13]. The next level of CPS is controllers or more specifically Programmable logic controller, which are used to distribute the sensors information correctly. Due to the variety of sensors the data velocity, variety and volume can be difficult to handle [14], therefore Programmable logic controller are used to control the flow of information. In some cases, it might be wise to collect information with intervals to reduce the load of the network. The network is the next level of CPS, which gathers, stores and distributes the information to High–performance Computers. Currently researchers focus on algorithms and simulations when analysing CPS concept. The ability to conduct business process simulations in the digital environment allows evaluating multiple scenarios without any failures to loose quality and reduces the risk to make mistakes in the real–world environment. Therefore, simulations allow maintaining zero defect rate, reducing production costs dramatically and even optimizing various business processes. One of the research groups amplifying these benefits is Warwick Manufacturing Group, which is based in UK. "Much has been published about potential benefits of the adoption of CPS in manufacturing industry. However, less has been said about how such automation systems might be effectively configured and supported through their lifecycles and how application modelling, visualization, and reuse of such systems might be best achieved" [15]. When conducting simulations it is essential to maintain the robustness of the system. „As CPS become more common in our society and directly interact with humans, it must be assured that they robustly behave as intended, which has a particular bearing when artificial intelligence (AI) is utilized" [16]. When evaluating multiple scenarios usually a stochastic approach is used based on previous data, therefore there are limitations when implementing CPS. To choose the best results during simulations and choose them periodically it is needed to run multiple times the same scenario. This problem is related to the populistic approach of the gathered data, therefore might be difficult to correctly compare current and past scenarios' results due to this variability. It is possible to limit the deviation of the simulation by using High–performance computing approaches, however still than the process involves a trade–off between time, accuracy, robustness, CPS infrastructure development costs and management costs which manly composes of energy sources due to cooling.

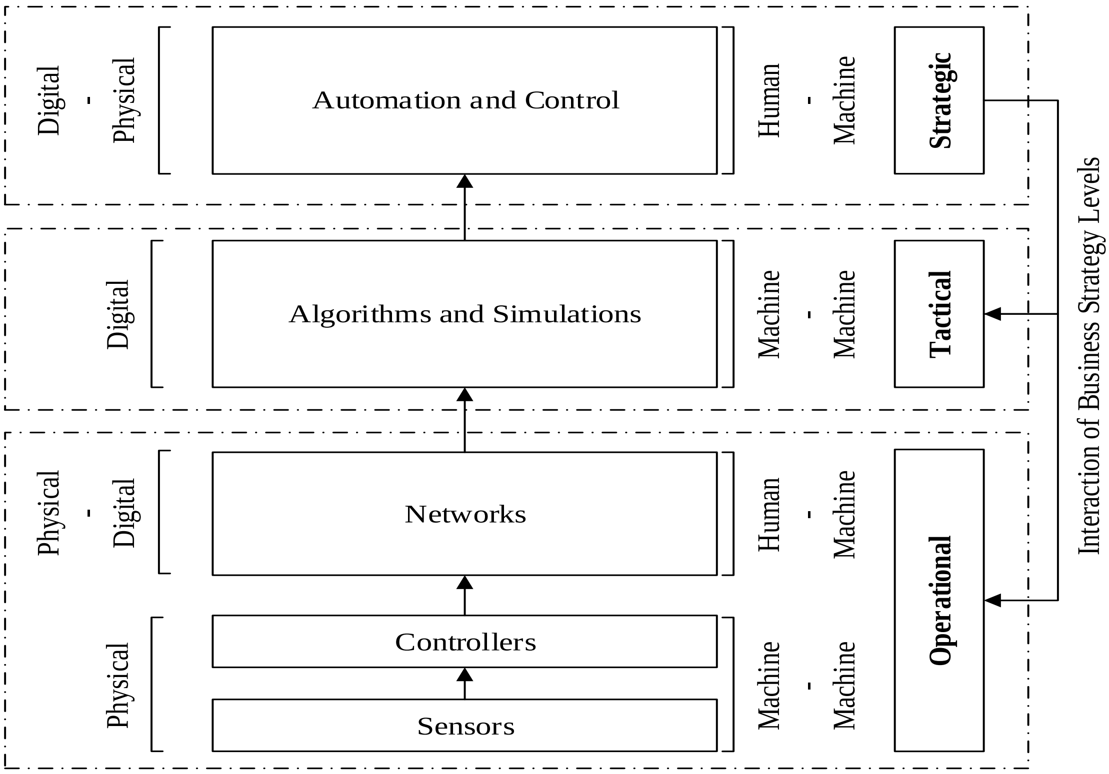

Figure 2. Elements of Cyber–physical Systems
Source: compiled by the authors based on own researches

After the simulations in the digital world, the decisions than are transmitted to the automation and control element of CPS. In this element, the system revaluates the recommendations of the algorithms to better adapt them to the strategic level of the company. The final decision than is directed to the tactical and operational levels, which causes the system to function without human interference. Than the systems develops adaptive abilities, which is caused due to the loop of information between the physical world to the digital and then back again to the physical world. This information exchange without Human–Machine Interaction, Machine–Machine interaction and Machine–Human interaction would not be possible.

The identification of the main elements of CPS is based mainly on advanced manufacturing concept. The implementation of CPS in to other type of processes is also possible; however the difference is the management aspect of the CPS and not the elements. A comprehensive CPS architecture has been developed by Lee et al. (2015) [5]. The architecture consists of 5 levels such as Connection, Conversion, Cyber, and Cognition and configure. The levels describe possible applications in the advanced manufacturing concept by using CPS. However, the architecture implementation in the service industry could also provide new type or applications that are more efficient.

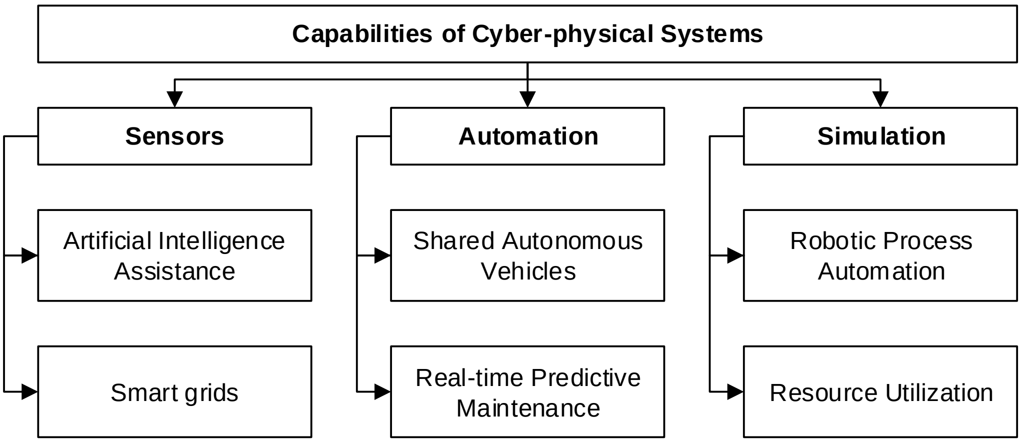

Figure 3. Cyber–physical Systems Usage Applications in Source: compiled by the authors based on own researches

The main adaption of the architecture to the service industry is related to the missing link of human importance in technological based approaches. „Technically driven approaches tend to neglect that the organizational dimension plays an important role for the application of CPS as well, particularly in a professional context“ [17]. When correctly involving professionals in the strategic level development and then combining the strategic level with operation and tactical more value–added services can be achieved.

Possible applications of CPS usage for service industry are represented in figure 3. For example, by gathering personalized information of consumers personalized insights for improved customer service could be achieved. An artificial intelligence assistance system might provide recommendations for purchases, leisure or other activities in real–time. This application might also provide useful insights regarding product purchasing, which might be used for new product development. Other industries such as energy sector might benefit from advanced smart grids, which could relocate power to more efficient usage and storage. From the other side, the CPS could provide high level of predictive maintenance services to energy industry also and not only in advanced manufacturing concept. “By integrating Industry 4.0 and CPS, smart devices are able to access and analyse abundant data of themselves as well as other items and thereby automatically react to current health condition” [12]. CPS could also be implemented in supply chain management to utilize more efficacy vehicles, which concept is called shared autonomous vehicles. The problem is that current vehicles are not utilized effectively, because a lot of the time the transports are not used due to malfunctions due to legislation requirements for drivers to rest. CPS usage in managing transport fleets could utilize the resources in a more efficient manner. Lastly, this approach might be also used for other processes, which are repetitive, and worth automating. This process is called Robotic Process Automation, which could reduce manual work and provide more efficient resource utilization in various areas.

Innovative business models are appearing after every industrial revolution. Internet, IoT, Big Data, CPS and further development towards Industry 4.0 are causing even more rapid growth of new business models. In some cases, these technologies are reinventing past business models in others cases, are creating new business models. „We are currently experiencing the fourth Industrial Revolution in terms of CPS. These systems are industrial automation systems that enable much innovative functionality through their networking and their access to the cyber world, thus changing our everyday lives significantly. In this context, new business models, work processes and development methods that are currently unimaginable will arise. These changes will also strongly influence the society and people. Family life, globalization, markets, etc. will have to be redefined“ [18]. Due to these developments, various businesses have arisen or a laying ground work for new disruptive industries.

Currently main research is being done in the advanced manufacturing concept. For example, BASF is using Industry 4.0 applications in its deployment of connected systems and advanced analytics models for predictive asset management, process management and control, and virtual plant commissioning [19]. Okuma Corporation and Hitachi announced that they have embarked on collaborative creation aiming to establish an advanced high–efficiency production model that supports mass customization making use of IoT and set up an experimental model. The target of this demonstration experiment is to increase productivity by twice and to reduce production lead time by 50% [20]. These developments are more oriented to operational management mainly as resource planning. However, other technologies like flexible manufacturing systems integrated with CPS can be used for decision support in production process, which provides companies continuous efficiency growth and reduces breakdowns. Other approaches, which also involve CPS are called additive manufacturing technologies. Additive manufacturing applications allows building products layer–by–layer trough adding material. The implementation of CPS in this process could provide great potential. For example, customers could order personalized products, which would be manufactured on the spot with additive manufacturing technologies. CPS in this case would allow high flexibility and customization. Lastly, CPS allows human – computer interaction in real–time during production processes. “Remote robot control becomes relevant not only in rescue operations but also in cyber and/or cloud manufacturing environments where distant operations can be done quickly and economically” [21]. The advances in production process are increasing productivity and decreases defect rate and lead–time.

However, to fully automate the whole processes integration of production and logistics must be also research. For instance, a robotics company “Symbotic” has developed a system to automate warehouse jobs formerly done by humans. The system cut labour costs by 80% and reduced warehouse size by 25% [22]. Technological innovation will affect not only warehousing, but also the transportation sector. One of the largest distribution company DHL indicated that self–driven vehicles will be able to travel 24/7 without requiring driver rest time and, compared with today’s driving, could achieve overall cost reductions in the region of 40% per kilometre [23]. Because of increasing rate of assets utilization, it is important to share the equipment between multiple organizations; otherwise autonomous vehicles might be utilized not to the fullest potential. CPS in this context is essential, because it allows integration and control of all the processes. However, CPS usage in context of supply chain management has only a limited amount of research.

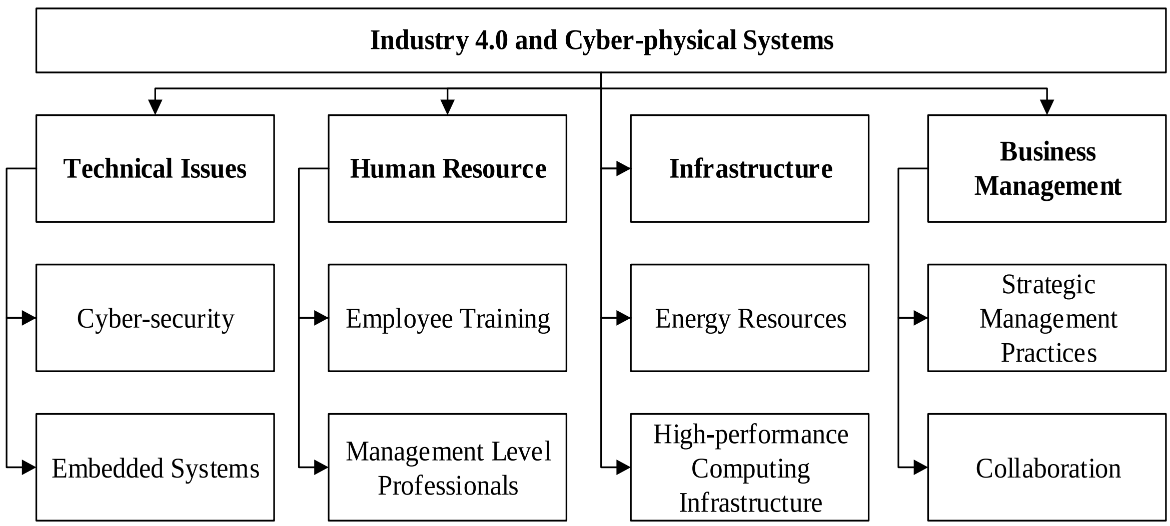

Figure 4. Trends and problematic areas of CPS and Industry 4.0 integration in industry
Source: compiled by the authors based on own researches

Growing usage of CPS in various sectors of Industry 4.0 is causing problems, which must be addressed in near future (see figure 4). For example, CPS implementation in production and supply chain management generates new problems in energy sector. Embedded systems requires constant energy sources, which would allow gathering, processing and utilizing information in an efficient way. Moreover, High–performance computing requires cooling equipment, which takes a lot of power. “It is estimated that 90% of power consumption during breaks in production is accounted for by machinery such as robots, extractors and laser sources and their cooling systems” [24]. Because of high demand for electricity, CPS enables to use smart grid systems to control the flow and storage of electricity more effectively. Smart grids are electric networks that employ advanced monitoring, control, and communication technologies to deliver reliable and secure energy supply, enhance operation efficiency for generators and distributors, and provide flexible choices. The next phase of Industry 4.0 concept growth involves service industry. The full automation without customer service and constant feedback would not be possible, therefore implementation of CPS together with artificial intelligence in the service industry is also a must. Artificial intelligence can be used to develop bots or assistance agents. Lastly, the usage of CPS in Industry 4.0 arises new problems, which solutions must be finding. One problem is related with employee training, because understandment and skills required to work with CPS requires technical knowledge. Today companies are already identifying this gap and focusing on providing solutions to the industry. The solutions currently focuses on technical employee training, however there are only a limited amount of focus on manager level professionals which could monitor and control all the business processes involving CPS. Moreover, CPS is very keen to cyber–attacks. A fully automated business could become a victim of hackers and involve huge financial loses and leakage of confidential information. Therefore, the cyber–security sector is growing rapidly. According to the Nasdaq report, global cyber security market was valued at USD 105.45 billion in 2015, is expected to reach USD 181.77 billion in 2021 and is anticipated to grow at a CAGR of 9.5% between 2016 and 2021 [25].

In summary, CPS are dramatically influencing further growth of Industry 4.0 concept. Further research towards CPS usage in supply chain management by considering human interaction and effective energy management are essential for the full realisation of Industry 4.0.

Conclusions. It is clearly visible that Cyber–physical systems (CPS) is one of the main factors influencing the growth of Industry 4.0 New applications of CPS in other industries than advanced production will provide disruptive changes. One of the key identification of CPS limited usage has been identified in supply chain management context. Further research is recommended to be focused on supply chain management, because it is integrating production processes with customer. It would be difficult to provide value added services without efficient distribution of resources and products. Moreover, the implementation of shared autonomous vehicles concept in current business models could provide even greater efficiency and maintain companies’ competitiveness. Possible recommendations of further CPS research in supply chain management should be related to practices and strategies development of how to implement CPS in business management. It is important to notice that without information through the whole supply chain efficient usage of CPS would be impossible. Therefore, it is recommended to focus research not only on technical aspects, but also consider social aspects such as collaboration, commitment and so on.

The authors of the paper amplifies that CPS will dramatically influence the development of Industry 4.0. However, there is only a limited amount of strategies and practices developed which uses CPS in to new business model development.

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