CYBER-PHYSICAL PRODUCTION NETWORK PLANNING IN THE CONTEXT OF THE FOURTH INDUSTRIAL REVOLUTION

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Abstract

The Fourth Industrial Revolution means the universal digitization of all areas of the economy, including industry and logistics. New digital technologies enable real-time monitoring of production processes and obtain a high level of flexibility and productivity of cyber-physical systems (CPS). The idea of CPS means a set of intelligent devices, machines, and autonomous transport that communicate with each other using modern digital technologies capable of collecting, processing and exchanging vast amounts of data in real-time.

Nowadays, each company should be perceived as an intelligent module to be used in the cyber-physical network for producing and delivering a product to the customer. Therefore, enterprises should raise the level of technologies used and focus on open communication in the network. Modern enterprises can offer more complex, innovative products and services tailored to customers' needs, combining their potential into a cyber-physical network organization. The idea of such a cyber-physical production network means joint execution of production orders using digital communication technologies, the Industrial Internet of Things, Big Data and Cloud Computing technologies and fully automated production systems and processes of individual network partners.

The article aims to identify the critical problems of planning cyber-physical production networks of SMEs and to present the concept of planning temporary networks of enterprises capable of implementing personalized products in the Industry 4.0 environment. The proposed approach considers production flow variants considering logistic constraints. One of the significant advantages of the proposed approach is creating dynamic, temporary alliances of small and medium-sized enterprises that can be simultaneously involved in many different projects (networks).

Keywords: Cyber-physical production networks, SMEs, networks planning, production flow planning

1. INTRODUCTION

The fourth industrial revolution means the universal digitization of all areas of the economy, including modern industry. Nowadays, the widely understood automation of production processes and intelligent devices, machines and autonomous means of transport are used. The components of the current production systems communicate with each other using modern digital technologies capable of collecting, processing and exchanging vast amounts of data throughout the production process while reducing high labor costs. The idea of creating such cyber-physical systems was proposed by German experts and was called the Industry 4.0 concept. New technologies identified with the Industry 4.0 concept, such as the Internet of Things (IoT), Big Data and Cloud Computing, Augmented Reality, etc., enable real-time monitoring of production processes and obtain a high level of flexibility and productivity of cyber-physical production systems (CPS) [1,2]. The newly designed cyber-physical production systems must meet several essential features concerning the Industry 4.0 concept. These are, among others [3]:

- Interoperability is understood as the ability of systems and employees to communicate, exchange data and coordinate activities;

- Process and system virtualization combined with real-time monitoring of physical processes;
- Decentralization as a dispersion of resources to reduce risk and ensure flexibility and using know-how;
- Data analytics, which is collecting and processing vast amounts of data in real-time;
- Service orientation and modularity, resulting in a personalized approach to the customer, enabling high flexibility and resource productivity.

Modern enterprises are beginning to understand the need for changes, especially in the features mentioned above, the implementation of contemporary Industry 4.0 technologies and the broadly understood digitization of processes. What is needed is an entirely new, more modern and innovative approach to production and business management that will radically increase flexibility, productivity and customer orientation. Today's customers expect products that closely match their personal preferences, tastes, needs and lifestyle. Moreover, they want to influence the configuration of manufactured products directly and, at the same time, require prices similar to those offered in serial and mass production [4,5]. This means they need better customer orientation, product customization, and a servitization strategy for industrial companies.

Small and medium enterprises, which, unlike large enterprises with considerable development potential, require exceptional support during the implementation of the Industry 4.0 concept, are facing particular adaptation challenges. Therefore, there is a need for research leading to the development of new business models involving the involvement of the SME sector in the implementation of Industry 4.0 technology. The solution may be the networking of enterprises, growth of narrow specializations and servitization.

The article aims to identify the critical problems of planning cyber-physical production networks of SMEs and to present the concept of planning temporary networks of enterprises capable of implementing personalized products in the Industry 4.0 environment. The article presents selected results of literature analysis, a survey conducted on a selected group of 50 Polish industrial enterprises representing the SME sector. The proposed approach considers variants of the production flow, taking into account logistic constraints. One of the significant advantages of the proposed method is the creation of dynamic, temporary alliances of small and medium-sized enterprises that can be simultaneously involved in many different projects (networks).

2. CONDITIONS FOR THE DEVELOPMENT OF CYBER-PHYSICAL NETWORKS IN THE CONTEXT OF CUSTOMIZATION AND SERVITIZATION OF PRODUCTION.

The digitization of processes, the combination of Industry 4.0 technology and intelligent facilities in modern production and logistics systems caused a change of paradigms in industrial production and better orientation to customer needs (servitization and customization). Cyber-physical production systems supported by modern intelligent logistics solutions allow offering customers highly personalized products at low prices. Personalization is a challenge for enterprises, both large smart factories and small and medium enterprises. This requires an entirely different production organization, the priority of which is to shorten the time of customer order fulfilment and low cost, which will be similar to serial production. Therefore, high flexibility and productivity of logistics and production systems are required. The solution is the servitization which in the case of industrial production processes means the reorientation of enterprises consisting in expanding their offer with services of resources of manufacturing systems (Product-Service Systems). By using the potential of Industry 4.0 technology, servitization becomes an opportunity to build a competitive advantage in the industrial production sector, especially for small and medium enterprises [6].

The modernization of the industry through the servitization of production allows the company to move up the value chain [7] and develop narrow specializations and establish permanent or temporary network relationships. Changes in the production organization strategy, the use of new and intelligent technologies, often replacing hired employees, provide the opportunity to develop production system services and offer customers highly personalized products.

Nowadays, a significant competitive advantage of enterprises is the ability to meet individual customer requirements (product personalization) through a high level of product customization. According to Kaplan and Haenlein, mass customization is a strategy that creates value through the company's interaction with the customer during the product design, production and assembly stages to create customized products with production costs and prices similar to mass-produced products [8]. Nowadays, customization requires a personalized approach to the customer, thus high flexibility and efficient organization of production planning and implementation of production processes. The problem of meeting customers' growing expectations is all the more challenging to solve the more complex the product is. This requires a significant increase in flexibility, productivity and a reduction of manufacturing costs. Significant increase in production efficiency becomes possible through, inter alia, changing the strategy of modern enterprises and focusing on a high level of product personalization, servitization of industrial production and designing intelligent supply chains through the use of material, production and employee resources in cyber-physical systems of cooperating intelligent enterprise resources [9]. Significant support for achieving a high level of customization and shaping relations with the client in developing network forms of cooperation. The client becomes a partner in designing and creating a product.

According to the Industry 4.0 concept, each company is perceived as an intelligent module to be used in the cyber-physical system of producing and delivering a product to the customer, where the key role is played by the level of technologies used, the level of highly qualified staff employed and openness to unlimited communication. The idea of a cyber-physical production network means joint execution of production orders using digital communication technologies, Industrial Internet of Things (IIoT) technology and fully automated production systems and processes of individual network partners. Communication takes place via the Internet, and the necessary data is collected and processed using Cloud Computing technology [10].

The use of modern Industry 4.0 technologies provides all network partners with access to the necessary information in real-time, regardless of their geographic location. This enables the development of a partnership, which consists of combining the required resources, competencies, and know-how to better respond to the client's constantly growing needs and expectations. It effectively gains a competitive advantage in the market [11]. Using specialized network partners' resource potential and competencies for joint production projects also increases the flexibility and speed of introducing new products to the market. There are many obvious benefits to companies participating in the network, but the network formation process causes many problems, especially in the SME sector.

A survey conducted on a selected group of 50 Polish enterprises from the SME sector related to industrial production was used to identify the critical problems in forming cyber-physical networks of enterprises. The selection of the research sample was deliberate. The questionnaire, as a research tool, was developed and addressed only to enterprises interested in implementing the Industry 4.0 concept. The study was conducted using the Computer-Assisted Web Interview method. The main purpose of the survey was to demonstrate the need to develop a concept for rapid prototyping of cyber-physical production networks. Over 92 % of the surveyed companies declare the implementation of Industry 4.0 technology in the near future, but at the same time say the lack of a strictly defined implementation schedule. Among the expressed concerns raised by the respondents, a low level of cyber-security (79 % of respondents) and high investment costs (78 % of respondents) should be distinguished. Over 75 % of enterprises declare that the expected return on investment in new Industry 4.0 technologies is too low.

Another problem is the lack of qualified staff who can support the implementation of new technologies (67 % of respondents). Moreover, enterprises are afraid of disloyal network partners (45 % respondents) and declare difficulties in finding a network partner 41 % respondents). From the point of view of the concept of the methodology of planning SMEs' cyber-physical networks, enterprises' expectations regarding the development and implementation of the following solutions are declared. The enterprises need:

- e-business platforms supporting the process of network creation (80 % of respondents);

- a business model describing functioning SMEs within cyber-physical networks (72 % of respondents);
- a training system on the implementation of Industry 4.0 in the SME sector (67 % of respondents);
- European support programs for implementing Industry 4.0 technologies in the SME sector (55 % of respondents).

3. CONCEPT OF CYBER-PHYSICAL NETWORKS PLANNING

The integration of small and medium enterprises and their resources within the implementation of joint ventures oriented to the needs of today's customers is a chance for the SME sector. In the proposed concept of an e-business platform, the main task is, on the one hand, to establish relationships with the customer expecting a personalized product (order) and, on the other hand, to integrate the resources of small and medium enterprises and the organizing of a cyber-physical network for the new order execution (**Figure 1**). Therefore, the platform is an interface between the customer and the product's producer (temporary enterprise network). The customer can design and/or configure an individualized product online through the proposed offering of both products and production resource services.

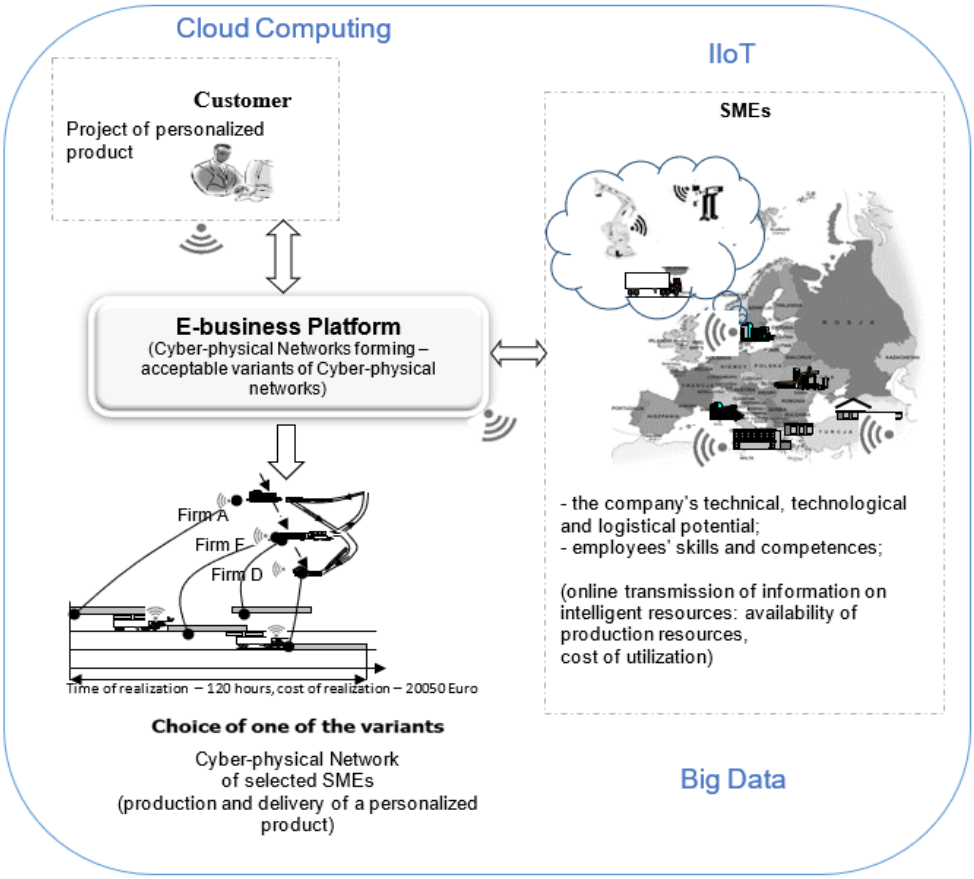

Figure 1 The concept of the e-business platform

The cyber-physical network planning methodology is based on the sequence of checking sufficient conditions. Based on the data provided by the resources of enterprises, an appropriate algorithm compares the generated order execution plan with the availability of resources offered by network partners. The proposed algorithm considers the limitations related to the availability of intelligent resources, the cost of their use, and logistic constraints considering the distance between partners and the cost of transporting components in the physical

flow of materials. The proposed cyber-physical networks planning methodology consisted of three phases presented in **Table 1**.

Table 1 Phases of the methodology of cyber-physical networks planning

Phases of networks planning	Responsible/ Communication	Description of activities
Application phase	Customer-Platform Online communication (designing of personalized product)	Developing a project for a personalized product and planning production operations related to the production and delivery of the product to the customer. In this phase, the customer contacts the e-business platform via the online e-commerce service and creates product specifications, selecting the available options and product variants regarding shape, size, color or additional product-specific features.
Declaration phase	Enterprises-Platform Online communication of resources of SMEs with Platform)	Enterprises provide real-time information on the availability of production resources and data related to the costs of their use. Real-time information transfer is possible thanks to the Industrial Internet of Things (IIoT), Cloud Computing, and Big Data.
Formation phase	Platform - Selected enterprises - Customer (online communication)	The network variants are shaped based on the selection of resources for production operations, considering the sequence of operations and logistics aspects related to the transport of all materials and components during the production process for each of the acceptable network variants. At the same time, the cost of the contract is determined, which is the basis for determining the price of the product. As a result of this phase, a set of production networks representing the set of resources of various companies is obtained. Each variant is characterized by the time and cost of product implementation. The customer selects the final variant of the network based on these two criteria. The price and delivery date accepted by the customer means creating a network and launching production stages in individual enterprises of the network.

4. CONCLUSION

Polish enterprises wanting to develop and then maintain a competitive advantage in the international market must systematically introduce innovations. The relatively low level of innovativeness of enterprises in Poland, both industrial and service, results mainly from the existing financial barriers, insufficient funding in the research and development sphere and a low degree of correlation between science and business [7, 12]. The condition for the development of network forms of cooperation is, therefore, the development of a business model for collaboration between enterprises supporting the development of cyber-physical production networks and the concept of e-business platforms that will allow the interaction of the network with the client,

the creation of temporary networks oriented to a joint venture production, operation of the enterprise in the network, load planning of geographically dispersed resources, production control and the method of the financial settlement of network partners [9].

The presented approach to creating cyber-physical production networks is a solution to small and medium enterprises' fundamental and current problems, with extremely limited potential to develop intelligent 4.0 factories. One of the significant advantages of the proposed network organization approach is creating dynamic, temporary alliances of enterprises that can be simultaneously involved in many different projects (networks). Thanks to this, enterprises can quickly establish cooperative ties and obtain a high level of use of available resources. The concept of organization of e-business platforms may be an excellent solution to many problems identified in the presented research, related to the adaptation of the small and medium-sized enterprise sector to the conditions of the fourth industrial revolution. The proposed platform concept will provide the possibility of intelligent resource communication, where enterprises will be able to automatically exchange, in real-time, information about available resources in the network for the needs of a given order. Further research will include the development of a prototype of an e-business platform equipped with algorithms for rapid prototyping of networks of distributed resources of small and medium-sized enterprises and the development of a business model of cooperation between enterprises within cyber-physical production networks.

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