BASICS OF THE MANAGEMENT SYSTEM FOR TRANSFORMATIONS OF PRODUCTION PLANNING AND CONTROL PROCESSES

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Abstract: Intensive development of technologies, in particular of the spinotronics, nanotechnology, robotics, and ICT, shapes the new generation production systems. Their distinctive feature is the flexibility associated with production intelligence. It is required from all processes, including the production planning and control processes (PPCP). The article is of conceptual character. It was prepared based on literature research. It encompasses issues related to Next Generation Manufacturing Systems, including Intelligent Manufacturing Systems in particular, covering solutions for PPCP. The article was also built upon the results of research on the level of automation of Polish manufacturing enterprises. The research results in the development of general assumptions of an informatic management system for the transformation of PPCP for technologically advanced and organizational production systems. The system has a modular structure resulting from its functions, which include identifying the need for transformation, its goals and vision, planning, design, implementation and evaluation of transformation. It takes the technical, organizational, socio-psychological and economic aspects of transformation into account. Choosing the right solutions for PPCP purposes allows for flexible adaptation to the requirements and needs of the environment. Its essential part is the knowledge database, thanks to which it is possible to shape the system's intelligence.

Paper type: Conceptual paper

Published online: 19 October 2018
Vol. 8, No. 4, pp. 317–328
DOI: 10.21008/j.2083-4950.2018.8.4.3

ISSN 2083-4942 (Print)
ISSN 2083-4950 (Online)
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Keywords: *Intelligent Manufacturing Systems, production, production planning and control*

1. INTRODUCTION

Dynamic changes in the environment have shaped new customer-producer relations. The key role in these relations is played by mass customization, imposing the requirement of universal production of individualized products on the manufacturer, fully adapted to the needs and expectations of customers. This was achievable mainly due to robotization, virtualization, ICT technologies, and new organizational solutions. The new customer-producer relations have required flexibility and intelligence from manufacturers, which can be met by the Intelligent Manufacturing Systems (IMS) as part of the concept of Next Generation Manufacturing Systems (NGMS) and Industry 4.0 which connects to the basic technologies: IoT, Cyber-Physical Systems CPS and the concept of big data as well as machine learning, digitalization, wireless sensor networks, MES (Gudanowska, 2017). IMS function thanks to the mapping of human intelligence and its interaction with the substantive resources of production systems (IMS, 2005). NGMS are information companies in which computer-aided information processing determines their effecttiveness (Badurek, 2015). IMS integrate manufacturing and services to meet the industrial requirements. For this purpose they integrate communication process, computing process and control process (Chen et al., 2018). IMS require the use of new models, new forms and methodologies for the transformation of the traditional production system into a smart system (Zhong et al., 2017). By IMS there is a dynamic configuration of production structures to meet customer needs, whilst the production processes require monitoring and control in real time (Koren, Wang & Gu, 2017). Technological solutions can ensure that through the use of Artificial Intelligence AI, for example, a task planning system can be made available to other users through problem-solving and decision-making services on an internet platform (Barbosa et al., 2015).

The requirements of intelligent analysis and decision-making as well as continuous learning in IMS are set for all the processes that they implement, including production planning and control processes (PPCP). Their task is to plan and supervise the implementation of individualized customer needs, and at the same time, to ensure the efficient flow of materials and information in dynamically changing products value stream integrated into the organization's network. To implement tasks, they use new or evolving algorithms and behavioral schemas, adapted to, among others, changing product features, planning environment, applied forms of production organization, the place and role of the production unit in the organization network. PPCPs have to undergo constant transformations to meet the requirements of production intelligence linked with the flexibility that is posed to future-oriented production systems.

The aim of this article is to present the basics for the IT system of managing PPCP transformations in advanced organizational and technological production systems. The method of PPCP implementation has a significant impact on the effectiveness of the production process and the functioning of the production system. The need for PPCP transformation is caused by the diversity and variability of both PPCP tasks and systems, meta-algorithms and meta-rules of procedure that support these tasks. In addition, the dynamic volatility of market conditions and customer expectations, network connectivity and reconfigurability of production unit connections which affect geopolitical and social conditions as well as intensive development of technology, knowledge and organizational solutions, create the need for constant changes and effective transformation process. This requires current information on the status and directions of changes in the environment and the production process so that the need for transformation can be identified, appropriate solutions for the implementation of PPCSP tasks and planning can be selected and transformation can be implemented. In addition, acquiring the knowledge from the transformations carried out will enable the shaping of an intelligent system of managing them, and as a result, will contribute to self-designing, self-planning and self-implementation of PPCP transformation which is necessary in NGMS.

2. PPCP TRANSFORMATIONS

2.1. Methods and systems supporting PPCP in IMS

The development of methods supporting PPCP, similarly to the development of production systems, is influenced by new technologies, including ICT, spinotronics, nanotechnology, robotization, AI and knowledge development as well as new organizational solutions. The organizational methods include, above all, kanban and the drum-buffer-rope DBR method compatible with the Theory of Constraints. The kanban method implements the idea of pull and allows to harmoniously coordinate the pace of work and material flow with the client's needs. Kanban brings information about the need to perform tasks (moving or processing of material and information) upstream, to the (temporarily) operating processes that are covered in kanban loops. According to the DBR method, the constraint of the production system extracts (PULLs) the materials from the upstream processes, and then after the processing pushes them (PUSH) to the downstream processes. The location and size of constraint and assembly time buffers (Goldratt & Cox, 2000) are crucial to be determined for the efficient functioning of the production process.

Systems and methods using AI include: expert systems SE, fuzzy logic and bio-algorithms. An important element of expert systems is the knowledge database with its declarative (knowledge that) and procedural (knowledge how) part. Numerous applications of the SE can be indicated in the PPCP area. These include GENESYS system for production scheduling (Metaxiotis, Psarras & Askounis, 2002), SESA system for machine demand planning (Masmoudi, Chtourou & Maalej, 2007) or MHESA (material handling equipment) for planning the need for means of transport and warehouse equipment (Chan, 2002).

Fuzzy logic uses computational intelligence and acts as an extension of traditional binary (zero-one) logic. It allows to build a model of generating signals controlling the system using a smaller amount of data on the system condition.

Bio-algorithms, on the other hand, fit into the trend of transferring the behaviour of living organisms and natural mechanisms to the area of management, including production from the point of view of the organization's network. They enable super-heuristic optimization in the decision-making process as well as self-learning and self-adaptation to new conditions. These include Evolutionary Algorithms EA (Genetic Algorithms GA, Evolutionary Programming EA, Evolution Strategies ES), Swarm-based Optimization Algorithms, Memetic Algorithms MA or Artificial Immune Systems AIS. Numerous applications of bio-algorithms can be found in the PPCP area. Genetic Algorithms were applied to schedule works (human resources) in expert cloud (Navimipour, Rahmani & Navin, 2014), increasing the effectiveness of cloud computing. They were also used to build Multi-Site Aggregate Production Planning APP in the conditions of uncertainty of demand, machine failures and the need for reprocessing (Rabbani, Manavizadeh & Aghozi, 2015) and Advanced Overlapping Production Planning for planning of production capacities, resource allocation and production orders in a multi-product environment, multi-machine, multi-cost and multi-location supply chain (Wang & Shih, 2011). Ant Colony Optimization (ACO) found application, among others, in scheduling problems (Filo, 2011) and Sequence-Dependent Disassembly Line Balancing SDDLBP for solving the issue of disassembly planning, covering even distribution of work between the minimum number of positions and acquiring elements with higher demand in the first place (Kalayci & Gupta, 2013). Combinations of individual methods and systems also find their application. An example here is the use of fuzzy logic and Evolutionary Algorithms to develop a fuzzy-evolutionary algorithm for coordinating material flow in a multi-silo supply chain (Ibrahimov et al., 2012).

The examples presented above illustrate the diversity of solutions supporting PPCP. Meta-algorithms and meta-heuristics present the general framework of conduct, whilst their selection, combination and refinement depend on the type of PPCP tasks to be carried out, the organization and operating conditions of the production system. Each of the solutions also entails the need to properly adapt the organization and principles of the production process. The intensive development of technology and knowledge overlaps with these factors, causing the need for PPCP transformation.

Coordinating and synchronizing of the flow of materials and information in the product value stream is enabled by ICT technologies. Types of information systems performing varied functions in the PPCP area are presented in Table 1.

Table 1. IT systems supporting the implementation of PPCP tasks; own elaboration

System	Examples of application in the PPCP area
Online Transaction Processing OLTP	on-line access to information for users and clients, cloud computing, taking orders
Enterprise Resource Planning ERP	includes a business model, database on product structure, production process, routes, etc., algorithms of conduct for production plans building, planning and management of production capacity, demand management, production process control
Advanced Planning System APS	contains advanced algorithms supporting the implementation of PPCP tasks, enables simulation of plans
Manufacturing Execution System MES	combines information systems with the physical layer of the production process, enables obtaining in real-time data on the course of the production process, its parameters, results, and their collection
Supervisory Control and Data Acquisition SCADA	directly supervises and controls technical equipment which realizes technological processes, provides information on the current state of technical equipment

According to the research results, only a small part of Polish enterprises use IT systems for operational management and production control, which is mainly identified with the implementation of the MES class system. The introduction of Industry 4.0 is declared by 6% of enterprises (www.astor.com.pl/industry4). The issue of next generation systems is therefore also valid from industrial practice perspective.

The PPCP transformation management system will extend the scope of functionality of the presented IT systems. It also constitutes an attempt to adapt to the needs of automation of communication based on Cyber-Physical Systems. For the purposes of intelligent production, it will allow to select appropriate systems and methods enabling to perform the PPCP tasks and to make necessary transformations in the area of planning and control production processes and the interdependent production process.

2.2. Assumptions of the PPCP transformation management system

The effectiveness of production systems depends to a large extent on the correctness of the planning and control production processes. In the face of dynamic changes of the environment and the development of production systems, it is necessary to effectively manage the transformation of production planning and control processes. It is linked with reacting to new operating conditions and selection of appropriate methods for performing the PPCP tasks as well as the transformation implement-tation plans, respectively. As already mentioned, intelligent, technologically advan-ced production systems require support from the IT system. The general assumptions of the system are presented in Table 2.

Table 2. Assumptions of the transformation management system for production planning and control processes; own elaboration

Assumption	Description
The system has a modular structure	The modularity of the construction stems from the need to implement various functions in the PPCP transformation process. These functions include: (1) identification of the need for transformation, (2) defining the vision and goals, (3) planning, design and implementation of transformations, (4) evaluation of transformation efficiency. Realization of individual functions is enabled by appropriate algorithms that can be improved. These functions take the complexity and multilevel nature of PPCP into account. They include activities related both to the current control of the production process, as well as performance management, demand and construction of production plans for a longer time period. The functional structure of the system is related with interconnected modules. Planning and implementation of transformations requires collaboration (sometimes multiple) of individual modules, e.g. a prospective evaluation of transformation efficiency can be implemented for the planning stages, design and the planning of transformation implementation for the selection of the best transformation option, whilst retrospective for the evaluation of implemented transformation.
The system requires consideration of transformation from production process perspective	The production process can be treated as an internal customer of production planning and control processes. Due to the interrelations and dependencies between the production process itself and the planning and control processes of production, the transformation in the PPCP area cannot be evaluated by isolating them from the consequences occurring in the production process area. In turn, transformations in the area of the production process generate the need for PPCP transformation. Therefore, the system takes the place and role of PPCP in the organization's network into account.

The system has a layered structure	The layers of the system structure stems from the complexity of production systems. One can distinguish: (1) the level of individual positions or their groups, (2) the level of internal stream of values (associated with an autonomous intelligent production unit, e.g. holon), (3) level of the whole value stream (resulting from the possibility of cooperation between independent entities within the network of connections, e.g. holarchic structures, i.e. autonomous and cooperating modules corresponding with software agents (Zawadzka, Badurek & Łopatowska, 2012b)). Transformations in the area of one layer may translate into transformations in the remaining layers, where they can both run bottom-up and top-down, e.g. transformation of the internal value stream in the PPCP area causes the need for transformation in the area of positions and the whole value stream (this need is caused, for example, by transformations in relations and rules of cooperation in the flow of matter and information in client-supplier relations in the organization's network). Each of the layers engages relevant system modules in the transformation process.
The system takes the multifaceted nature of transformation into account	PPCP transformations concern various aspects of the functioning of production systems. The system should therefore take the following into account: (1) technical aspects resulting from new technological solutions (e.g. in the ICT sphere) and new technical resources (e.g. drivers), (2) organizational aspects resulting from the application of new organizational solutions (e.g. algorithms of conduct for PPCP tasks, spatial and geographical distribution of processes implemented by specific production units, rules of collaboration), in the PPCP area and the interrelated production process, (3) socio-psychological aspects – transformations also apply to people involved in processes and are linked with the new work conditionings (e.g. telework, multi-project, remote communication). In addition, globalization and network connectivity cause linguistic, socio-cultural, political and economic-legal differences and create uncertainty related to mental distances (Spector, 2012) (4) economic aspects – transformations can bring effects of a technical, organizational, social, information or market nature. However, their final form is of an economic character, which determines the further development of production systems.

The knowledge database integrates the system and is the source of its intelligence	The modules of the PPCP transformation management system use a common knowledge database. It collects data, among others, on the state of the production process and PPCP, planned and realized transformations, which with the help of appropriate rules of conduct are transformed into information. These, in turn, shape knowledge, which is the source of the system's intelligence. It takes place according to the following pattern (Zawadzka, Badurek & Łopatowska, 2012b): data → information → knowledge → intelligence. The knowledge database consists of two basic parts: (1) procedural including procedures and algorithms of conduct for both the implementation of production planning and control tasks (e.g. kanban method activities, scheduling tasks in accordance with the DBR method) as well as for the process of their transformation (e.g. rules and algorithms of conduct for identifying the need for transformation, its planning and implementation), and lastly self-development and self-improvement, (2) data on the state of PPCP, production process, production units, environmental space, planned and realized transformations.
The system collaborates with other IT systems	The system works with ERP, APS, MES, OLTP and SCADA class systems, acquiring necessary data and models, algorithms and procedures. These include: a general model of business processes, procedures and algorithms of conduct in the area of production planning and control processes (e.g. advanced algorithms of the APS system) and production, as well as data on the current state of the production process and PPCP. They supply both the procedural part of the knowledge database and the section containing the data.
Is characterized with self-learning and self-improvement features	The knowledge database includes data mining processes for Data Science and machine learning. The knowledge database uses solutions to acquire knowledge from planned and realized PPCP transformations. They allow, on the basis of cause-and-effect connection, to search for links between factors triggering transformations, transformation plans, the manner of their implementation and obtained effects. This enables the improvement of algorithms of conduct for individual system functions as well as for those included in the procedural part of the knowledge database. At the same time, it enables the improvement of the effectiveness of PPCP transformation management. In addition, it is possible to improve the algorithms for the realization of PPCP tasks (e.g. adaptation functions in bio-algorithms). This creates an opportunity to shape the intelligence of the production system.
There is a possibility to control the system parameters	It is possible to control the system's parameters in the scope of e.g. an acceptable level of transformation efficiency assessment of, transformation implementation parameters (e.g. time, costs) or significance of factors triggering transformations. This enables the construction of multi-option transformation plans.

The basic structure and interaction with other IT systems is shown in Figure 1.

Intelligent manufacturing systems require high integration of human-machine cooperation in the area of production processes as well as planning and control processes. This allows the ecosystem of various production elements to be shaped so that the organizational, management and technical levels can be seamlessly combined (Zhong, Klotz & Newman, 2017) in order to meet individual client needs. Smart Factory helps people and machines to interact in a conscious context.

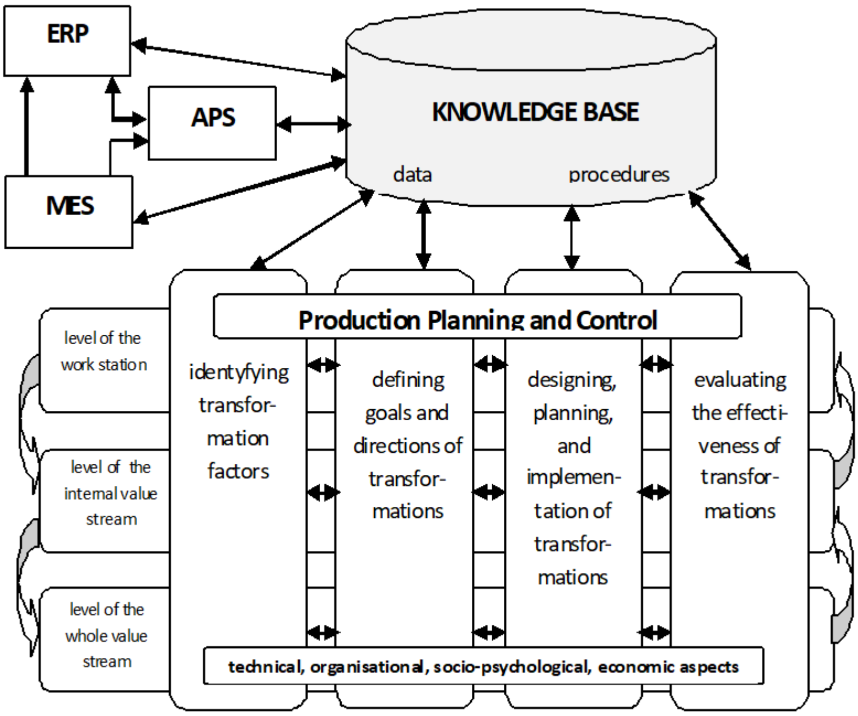

Fig. 1. Basic structure of the PPCP transformation management system; own elaboration

This also applies to the PPCP transformation management system, which apart from technical and organizational aspects and economic transformations takes socio-psychological aspects into account. The knowledge database, thanks to the use of Artificial Intelligence solutions, enables the implementation of typical IMS functions, which include reasoning, self-learning and self-improvement. Data Science enables acquiring knowledge from planned and realized transformations. Through the application of neural networks, random forest, decision trees or support vector machines, it is possible to identify hidden patterns in the data and on this basis to formulate general rules and algorithms of conduct (Szeliga, 2017).

The system, through the implementation of tasks, from identifying the need for transformation, defining its goals and vision, through planning, designing and implementation, to assessment of the transformation, enables the modification of planning and control production processes and interdependent production process into new expectations, the state of the environment and the production system. Performing individual tasks requires appropriate algorithms of conduct. For example, in literature (Łopatowska, 2012), one can find the assumptions of an algorithm for identifying the need for change. It requires the analysis of the state of the surrounding space, including technological and organizational, business and economic, competitive and cooperative space, or that of the customers, in order to detect the impulses of transformation. The ability to assess the effectiveness of transformation is also an important function of the system, both at the stage of its planning and design for the selection of the best option of the plan, and after its implementation, to obtain valuable knowledge.

3. CONCLUSION

Intelligent Manufacturing Systems require that the coordination of individual processes is based on self-learning and intelligence (Zawadzka, Badurek & Łopatowska, 2012a). In addition, decision-making models in the next generation production systems should acquire the necessary information and knowledge from a large amount of production data (Zheng et al., 2018). These requirements encompass a management system for the transformation of production planning and control processes. Its task is to acquire information from the environment, from the procedure of matter processing, which is the production cycle itself, and from planned and implemented transformations which are then to be transformed in a virtual environment into effective PPCP projects and related production processes. Thereby, they combine the virtual computing layer with physical processes.

The article presents the basics of the PPCP transformation management system. Its core element is the knowledge database, with its procedural and declarative parts. The result of the system activity is the choice of method and system supporting the implementation of specific PPCP tasks, adapted to the environment and customer requirements, plan and project of their implementation in the area of PPCP and the interdependent production process, as well as the evaluation of conducted transformations. This system fits into the needs of automation of communication based on future-oriented Cyber-Physical Systems. Further work should be focused on the formulation of the functional and structural concept of the system and the formulation of meta-algorithms for the conduct of its specific functions.

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