Formation of models of industrial cooperation management of machine-building enterprises in the transition to a digital manufacturing

Galina Belyakova¹, Gennady Belyakov² and Darya Fokina³, ⁴

¹ Department of Economics and Business Process Management Institute of Business Process Management and Economics, Siberian Federal University, Svobodny pr. 79, Krasnoyarsk, 660041, Russian Federation
² Department of organization and management of high-tech industries, Reshetnev Siberian State University of Science and Technology, 31 Ave named newspaper "Krasnoyarsk Worker", Krasnoyarsk, 660014, Russian Federation
³ Department of Customs Registration, Reshetnev Siberian State University of Science and Technology, 31 Ave named newspaper "Krasnoyarsk Worker", Krasnoyarsk, 660014, Russian Federation
⁴ E-mail: darya_fokina@mail.ru

Abstract. This paper considers the necessity to form models for managing the industrial cooperation of engineering industry enterprises in the transition to a digital manufacturing. A new production processes model, the so-called digital manufacturing, offers enterprises a wide range of modified tools for stimulation of industrial cooperation relations. The research focused on formation management processes of industrial cooperation among machine builders, and the studying tasks and main stages of the management of industrial cooperation. New models should take into account not only the new opportunities of the digital manufacturing, but also the specifics of machine-building enterprises and the features of their products.

1. Introduction

Some time ago, machine-building enterprises solved problems of increasing the efficiency of their own systems, which did not go beyond “walls of the factory”. The enterprise's management system had to solve tasks of only a part of the production process, limited to the resources of the enterprise itself. Recently, in the machine building industry, including enterprise as the production of machinery and equipment, the production of electrical and optical equipment, vehicles and devices, enterprises merged into vertically integrated corporate structures and increase production cooperation networks. Enterprises production cooperation stage of shaping led to a new tasks of production's cooperation management - control of the establishment of new cooperation relations and the allocation of corporate opportunities and potentials. The necessity to raise the efficiency enterprise’s management based on the implementation of the Digital manufacturing – the new concept of industrial production. In the world market, the level of digitalization characterizes the competitiveness of industries. Conducted research have shown that in order to increase the efficiency of production cooperation management,
machine-building enterprises need to apply to digital manufacturing models using modern instruments and technologies.

Behind the scenes of the world’s leading industrial and manufacturing companies, a profound digital transformation is now underway. The concept of "digital economy" was proposed by Nicholas Negroponte [1]. He called the advantages of the “new” type of economy: the lack of physical weight of products replaced by information volume, lower resource costs for the production of electronic goods, several times smaller area occupied by products (usually electronic media), as well as instant global movement through the Internet [2].

Like the Industrial Revolution impacted manufacturing, digital transformation is now responsible for changing in the machine building industry. Industrial manufacturers are joining their counterparts — and are moving to a digital world. Not since Henry Ford introduced mass production at machine building enterprises, there were not revolutions to this scale [3]. The changes of the Digital manufacturing industrial revolution were made possible by the powerful development of computing and digital technology. Driven by tech innovation, the future of machine-building enterprises will not be like current practices. To succeed, tomorrow's organizations will need new business models grounded in predictive analytics. They'll incorporate fast data to enable informed, real-time decisions. [4].

Modern engineering enterprises, interrelating in production cooperation, are not limited to the “walls of the factory” and geographic location of the partners. The complexity of products manufactured by machine building enterprises have increased over the past decades requires, and this factor requires introducing fundamentally new approaches to managing and controlling production processes. Cooperative relations sometimes arise between enterprises which are implemented with greater speed, at many levels of cooperation at the same time and often at considerable distances of objects from each other. New management models should ensure the smooth interaction of all participants in industrial cooperation, synchronization of plans and high speed of management decision making.

Leaders in machine-building industry are digitising essential functions within operations processes, as well as with their horizontal partners along the value chain. In addition, they are enhancing their product portfolio with digital functionalities and introducing innovative, data-based services. So, industrial cooperation’s management today is the implementation of systematic actions aimed at solving problems of optimizing the production process. Among the tasks of the management of industrial cooperation of enterprises are the following:

- Assessment of the resource potential of participants in industrial cooperation
- Formation of a portfolio of production orders for all participants in the cooperation;
- Identification and assessment of risks during production for all participants in the cooperation process;
- Planning the production of orders throughout the network of cooperation in real time, taking into account the identified risks
- Expansion of production capacity at the same time at many plants that are part of complex networks of cooperation;
- Redistribution of production of individual units and assemblies of products between enterprises;
- Selection of competence centres for the production of certain types of products;
- Development of various options for production plans for the release of products synchronously for all enterprises of the cooperation network;
- Monitoring the state of production and support processes for all orders for all levels of cooperation in real time.
The practical implementation of management functions and the selection of optimal options for solving problems are carried out using a system of management tools and methods. At the same time, certain instruments of coordinated impact are used, which ensure the achievement of the goals set. The system of instruments and methods aimed to stimulate the process of industrial cooperation can be represented as a digital mode. The optimization of production processes, achieved with the help of models of industrial cooperation management, will allow all enterprises involved in the cooperation process to achieve the planned results.

Creating models of production processes that allow to transfer any production processes from the real physical world into the virtual world of models, as well as the development and adoption of management decisions based on the algorithms in place and the transfer of control actions back is called “digital manufacturing” [5]. Digital manufacturing based on the theory of systems, and it is one of the levels of development of production control systems. Changes in the environmental factors of enterprises of the engineering industry lead to the need to create new management models, including models for managing industrial cooperation.

Digital manufacturing is based on using integrated, computer-based systems. Usually there are comprised simulations, 3D visualizations, analytics and collaboration tools to create product and manufacturing process definitions simultaneously. Digital manufacturing evolved from manufacturing initiatives such as design for manufacturability (DFM), computer-integrated manufacturing (CIM), flexible manufacturing and lean manufacturing that highlight the need for collaborative product and process design [5].

Digital manufacturing is a key point of integration between product lifecycle management (PLM) and shop floor applications and equipment, enabling the exchange of product-related information between design and manufacturing enterprises. This alignment allows manufacturing companies to achieve time-to-market and volume goals, as well as realize cost savings by reducing expensive downstream changes. “Digital manufacturing” is a complex concept, which has three main features:

- Computerization of workplaces and production equipment.
- Use of modern software, production management and resource management.
- Creation of a unified information space, covering issues of preparation, planning, organization and control of the production process for all enterprises belonging to industrial cooperation.

In digital manufacturing, instruments and techniques are provided to support the principles of optimizing all processes by predicting and analyzing the needs and efficiency of setting up production lines. Using these tools in a collaborative environment, process engineers can identify bottlenecks and inefficient processes, as well as develop corrective actions, thereby eliminating waste and losses and actively implementing lean manufacturing principles [6].

Digitising of organization, the emphasis in management must be placed on planning the entire supply chain and controlling the production of all suppliers at all levels of the cooperation network.

There are special management tasks related to the maintenance of production in the framework of industrial cooperation, which have to be addressed by cooperation's partners, and leading enterprises together with enterprises of the cooperation network [7]. Currently, the existing control technology in solving the above tasks has the following limitations:

- Formation of planned volumes and terms of production (plans and schedules for production preparation, testing, shipment, deliveries) - independently by own planning services of each industrial enterprise.
- Coordination of volumes and dates between the levels of a cooperation network occurs discretely, with the sequential transfer of planned volumes and production dates between enterprises - members of a common cooperation network.
- The parent organization (holding) does not have up-to-date information on the availability of production capacity and the status of orders at each of the enterprises of the cooperative
network and, therefore, it is unable to reliably and in real time assess the expected lead times for orders, the level of risks and the additional resources performance of tasks.

- The collection of the actual state of order fulfillment in the same technology of sequential information transfer leads to the fact that problems are mainly identified at the final stages of the transfer of components between enterprises, i.e. at the moment when it is too late to make corrective management decisions, or their value multiplies.

When management technology does not use digitising, it can’t provide an adequate level of synchronization between the plans of all levels of the cooperation network and the timeliness of making management decisions on deviations. As a result, the probability of delay in the delivery of finished products significantly increases and the cost of corrective measures increases.

It turns out that no optimization of individual manufacturing enterprises in principle will solve the problem when the final product will not be released due to the breakdown of the delivery time of individual components. This indicates the need to create a centralized management system with the ability to predict based on the current state of implementation of the plan at each enterprise within the overall technological production cycle.

One of the way to solve the whole set of problems in the field of management is proposed to consider an organizational management system that implements a model based on the presentation of products as a set of elements - resource consumers and enterprises participating in a cooperation network as owners of the resource potential and a method of automatically building, adjusting and monitoring network schedules for the production of products across all levels of a cooperation network.

The principal basis of the proposed technology for the management of industrial cooperation:

- Transformation of industrial cooperation enterprises interacting with each other in the uniform production process, in which units have the resource potential to perform certain types of work and the construction of such model;
- Transformation of manufacturing products as a connected network of production-supply stages (technological delivery composition of a product), generated in an automated way on the basis of design documentation and containing total resource estimates of the duration and complexity of each stage at the respective enterprises, in accordance with the division scheme;
- Automated formation of cooperation schedules based on the technological supply composition and resource model of the cooperation network;
- Automated generation of all types of plans and schedules of purchases, shipments, own production of all enterprises of the network of industrial cooperation as derived from the schedule of cooperation;
- Automated collection and analysis of the current status of work, collected from all machine-building enterprises at all levels of the cooperation network in real time due to integration with the production systems of each enterprise.

The introduction of the proposed technology digital models will allow to machine-building enterprises:

- Ensure optimal utilization of the production capacity of the industrial cooperation network of enterprises, taking into account the timing of orders, scheduled repairs, as well as to ensure prompt change of plans or redistribution of equipment loading in the event of an unplanned outage. The management of plans at the level of the cooperation models will allow for the most efficient provision of the transfer of production to other enterprises, taking into account their current load when re-equipping the enterprise.
- Optimize the labor costs of a significant number of employees of holding enterprises to collect information on the current status of work and “manually” synchronize start-up and delivery
processes for hundreds of thousands of units of nomenclature positions, thereby freeing up
time to solve production management problems and make quality management decisions.

- Reduce the number of errors and delays in the preparation of documentary and financial
  support for work caused by the “human factor” through automated planning and monitoring of
  the work done on drafting contracts, contracting, advancing and fulfilling treasury obligations.

Moreover, these works are presented in the general cooperation model of management as an
integral part of the overall sequence of work carried out during the production and delivery stages,
with the definition of advance cycles for the automated formation of the timing of these works and
ensuring control of the necessary regulations for the implementation of these works.

Creating digital models of industrial cooperation management of machine-building enterprises in
the transition to a digital economy is the basis for to ensure a synergistic effect from the
implementation of various projects for the implementation of information management systems at
each individual enterprise of the holding.

Transition to digital models allows, among other things, to receive in real time the current
indicators of the state of production and orders for all enterprises of holdings.

Digital models provide the ability to prevent disruptions in the execution of orders by:

- Real-time monitoring of changes in the capacities of enterprises through automated analysis of
  the resource model of enterprises;
- Determination of critical deviations and initiation of re-planning of the general delivery
  schedule at early stages of deadlines;
- Automated analysis of the dynamics of control points for each project / contract / order and
  the ability to make the necessary management decisions.

"Digital cooperative production" as the name of the model of management of industrial cooperation
of enterprises based on the digital presentation of information about processes and objects should have
the following main steps:

- Formation of the resource model of the network of industrial cooperation enterprises and
  transformation of this model digital space.
- Formation of a digital model of technological supply chains of components and raw materials
  for all participants of industrial cooperation system.
- Analysis and ranking of production risks for all participants in the cooperation process.
- Formation of schedules for mutual deliveries of industrial cooperation enterprises
- Combining production plans and schedules of all enterprises of industrial cooperation in a
  single digital system.
- Analysis of the status of planned orders throughout the network of industrial cooperation
- Comparison of the obtained results with planned indicators, assessment of identified
  deviations.

When creating models of cooperation’s management systems, for example, when creating a digital
model of industrial cooperative production management, it is necessary to additionally solve the
problem of establishing connections between control parts of control systems of connected subnets of
a common network.

A special role in this is played by the introduction of the modern industry development concept
Industry 4.0 and the formation of an effective industrial policy [8] based on the creation of
innovatively active clusters, the formation of development institutions, the development of
infrastructure projects as system integrators and communicators of industrial economics, the formation
of strategies and programs for the innovative development of enterprises and organizations.
Instruments for creating and developing are used by various countries' associations, for example, Eurasian Economic Union and European Union [9].

The research undertaken by the authors allowed concluding that digitalization of industrial enterprises taking place at the present time determines changes of models of industrial cooperation management. Each of models has to take in to account certain advantages and disadvantages for organization of cooperation of enterprises in specific projects it is necessary to thoroughly develop and fix in a contract the interaction model every time in order to take the advantage for participants and manage risks. More owe, when enterprises form the models for management cooperation interaction it is recommended to use digital manufacturing instruments and technologies. In the model's forming it is also important to take into account external and internal informational infrastructure of cooperating enterprises, its composition, functional capabilities and architecture. This will enable cooperating not only at the management but also at the technological level which will promote its efficiency and productivity.

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