

The production route selection algorithm in virtual manufacturing networks

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Abstract. The increasing requirements and competition in the global market are challenges for the companies profitability in production and supply chain management. This situation became the basis for construction of virtual organizations, which are created in response to temporary needs. The problem of the production flow planning in virtual manufacturing networks is considered. In the paper the algorithm of the production route selection from the set of admissible routes, which meets the technology and resource requirements and in the context of the criterion of minimum cost is proposed.

1. Introduction

The increasing customers' requirements as well as increasing competition in the global market are challenges for the companies operational productivity and profitability in production and supply chain management. Manufacturers are forced to dynamically respond to the situation by reducing product life cycles, increasing level of innovation and a multitude of new solutions. This situation became the basis for construction of virtual organizations, which are created in response to temporary needs, and which could bring profits to each member by increasing the degree of efficiency of available production resources. Therefore the producers are looking for more and more effective methods of supporting process of planning and control of production flow[1, 2, 3, 4, 5, 6, 7].

In this paper, we address the problem of the production flow planning in virtual manufacturing networks. The algorithm of the production route selection from the set of admissible routes, which meets the technology and resource requirements and in the context of the criterion of minimum cost is proposed. The resulting production plans allow the companies belonging to a virtual network organization to produce a product taking into account the existing constraints and requirements of the customer. The proposed approach in the paper is based on the methods and formalism from the game theory to the formulation of the decision-making situation. The input to the algorithm are data of the designated variants of production routes together with data on costs of cost of resource utilization of individual virtual network members.

The number of available strategies corresponds to the product variations of routes for all production processes. In subsequent steps of the algorithm, for the designated set of strategies, the costs of production and transportation are calculated. These costs are the basis to determining the value of the function of payoff in the next step and based on them, in turn, the payoff matrix. This step completes setting all required parameters of the production game. The determined values are also input data seeking solutions of production game in the pure strategies.



Application of proposed algorithm in the planning process should allow to increase the level of flexibility in the use of available capacity of production resources, which make it possible to increase the level of competitiveness of small and medium companies in a dynamic market.

The paper is organized as follows. Section 2 is devoted to presenting the Virtual Manufacturing Network concept. Section 3 is devoted to aspects of establishing a virtual production network. The production route selection algorithm based on game theory method is presented in Section 4. Finally, Section 5 presents our conclusions.

2. Virtual Manufacturing Network

Along with technological progress, there was a need to integrate activities influencing the execution of a production order and activities that enable better organization of multi-assortment production.

With growing customer expectations, products, terms, etc., companies are increasingly unable to cope with production alone. The need to perform complex orders or use of spare capacity, cause that manufacturers increasingly are seeking their chances in a set of organizations involved in the virtual organization. The Virtual Organization (VO) is defined as [8, 9] “An alliance for integrating competences and resources from several independent real companies, that are geographically dispersed. This integration is possible throughout the layout of an information systems infrastructure to satisfy customer’s requirements, or to seize a business opportunity without having to form a new legal entity”.

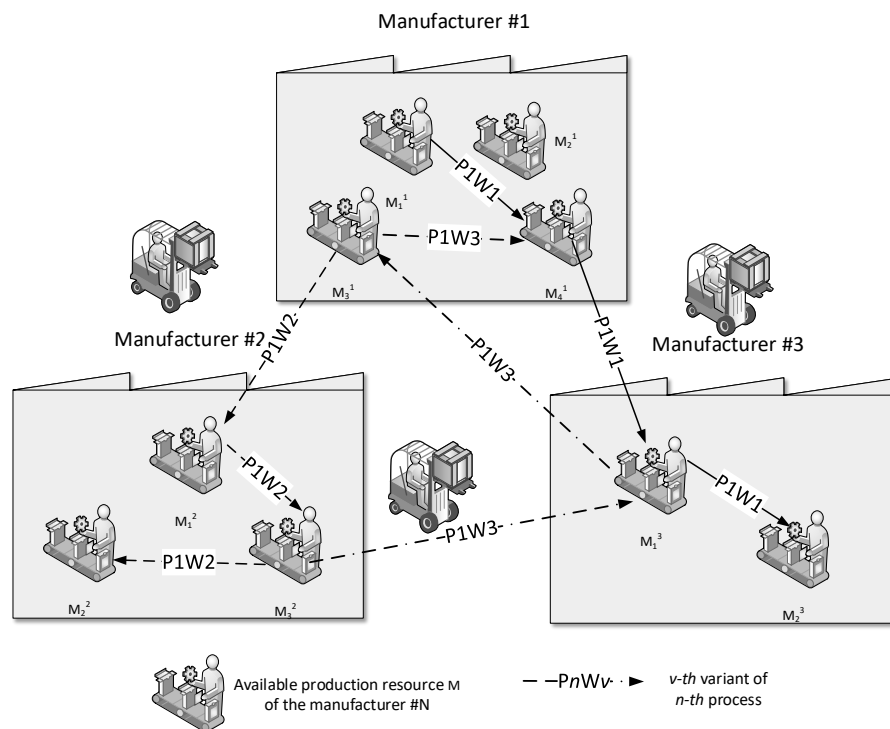


Figure 1. Virtual Manufacturing Network.

Virtual Manufacturing Network (VMN) (figure 1) is a flexible configuration of the various production companies combined into one virtual production system for execution of a production order. It is designed to continuously adapt to emerging needs. Their dynamics are related to the ability to configure and re-configure a number of different manufacturers that can participate in the network at the same time. The RRS: Reusable, Reconfigurable and Scalable its main characteristics of VMN [7, 8]. The complexity of the production order and the capabilities of each manufacturer affect the nature of the network. Compared with traditional organization, in a virtual organization it is difficult to

distinguish a rigid internal structure. The main feature of virtual organizations is the dynamic, variable operational pattern, which depends on the current number of network participants, the duration of collaboration between them, and the specificity of the production order to execute. Both traditional and virtual organizations strive to achieve their intended goals with different constraints and opportunities. They are also capable of renewing their resources, while in the virtual manufacturing network, the renewal of resources is independent of the individual manufacturers in the established network [8, 9, 10, 11, 12].

Depending on the production order specification and available production capabilities the virtual network is created, in which the number of different manufacturers temporarily collaborate. Each of the production orders may be different, executed by a different number of manufacturers. The basis for creating VMN is the production order and the possible answers to several questions, such as:

- what spare production capacities do they have and when?
- which of the producers would have cooperated?
- whether it is possible the formation of a network?
- will they meet their requirements?
- which production routes to use for production?

3. Establishing a virtual production network

Establishing a virtual organization is a complex process in which entities must be involved on many levels of each enterprise that operates as a single, independent organization before they join the network. Creating such a structure can be done in two ways [12, 13]:

- transforming the existing, traditional company hierarchy into a more modern, flexible structure; larger companies are being transformed into a network of small, independent organizations that are easier to manage,
- the way associated with the integrator; the integrator manages the process of establishing a network of several companies and assists the co-operation on a specific production order; the integrator is responsible for the distribution of tasks between manufacturers and is responsible for the structure of the created network.

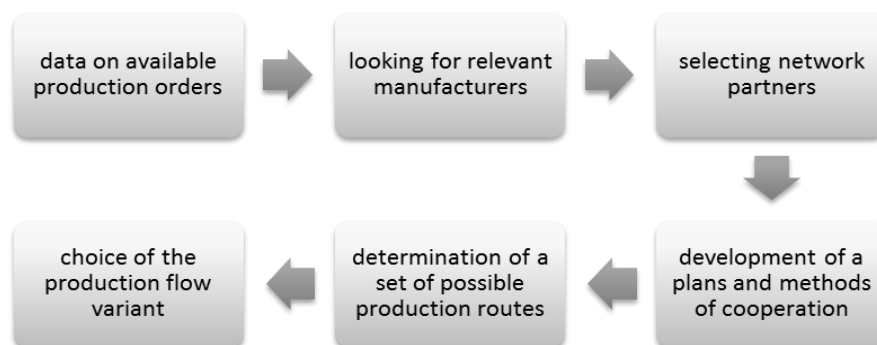


Figure 2. Basic actions taken by the integrator.

The integrator is responsible for a range of tasks, including planning and controlling network activities and accounting orders with network members and recipients. The integrator is also responsible for solving the following problems: disruptions and changes occurring in the network, such as the withdrawal of the participant, late delivery on the supplier side, which affects the execution of the entire production order.

Implementation of the establishing a virtual organization process may consist of the following stages (figure 2.) [11, 12, 13]:

- obtaining an production orders and looking for relevant companies that would meet the criteria,
- selecting network partners, taking into account the suitability of the project and the ability to work together; an important element of the cooperation is the trust between the selected companies,
- development of a plans and methods of cooperation, allocation of resources, selection of production routes, etc.,
- estimation of the total cost of cooperation, delivery methods that significantly affect the cost,
- establish the key conditions of co-operation and the procedures for cooperation contacts.

Initially decisions affect the nature of the cooperation between enterprises during the entire order. Having data on the production order i.e. number of production processes, specification of customer requirements and technological documentation, manufacturers who have spare capacity in their planning period and who wish to participate in the virtual production network are selected (moreover, they must meet certain criteria, among others, including the availability of a specific group of production resources, geographical distance, etc.).

Participation in the virtual manufacturing network brings with it the possibility of exploiting market opportunities such as ability to share spare production capacity, knowledge, etc. The production order is made using split production. On the other hand, participation in a virtual manufacturing network also raises questions and concerns related to the functioning of a single organization in a larger whole. In this context, it is crucial to plan activities related to the execution of orders.

4. Production flow planning in VMN

Production flow planning in virtual manufacturing network is a complex problem. The network integrator must have information about the complexity of the production order. Then, with data on manufacturers, selects the appropriate number (taking into account the qualitative aspect) to accomplish the task. Planning is related to access to information which manufacturers have spare capacity with appropriate parameters to carry out the order and at what time, so as to be able to generate alternative routes.

The process of production flow planning in dynamic production networks, allowing for the selection of alternative production routes, should allow for the choice of the partners, the appropriate use of the free resources of the network members, the selection of the appropriate routes and the delivery of components in due time.

The choice of network members in this context is reduced to the definition of a set of alternative route routes available to allow the execution of a production order. The next step is to choose the final solution for the production flow plan, followed by the individual stages of the production process. For this purpose the algorithm based on the methods and formalism from the game theory to the formulation of the decision-making situation is proposed. The decision-making situation is considered as a non-cooperative, 2-person, non-zero-sum game with complete information. The proposed model of decision-making problem is therefore related to the production flow planning problem.

4.1. Model of decision-making problem in VMN

The virtual manufacturing net is defined as [14, 15, 16]:

$$VS=(S, PP, C) \quad (1)$$

where:

S – the production system,

PP – the production order,

C – the costs of the order.

The production system is defined as:

$$S=(M, T, R) \quad (2)$$

where:

$M = \{M_i^\varepsilon, i = 1, 2, \dots, m_\varepsilon; \varepsilon = 1, 2, \dots, R\}$ – production resources owned by ε^{th} manufacturer,

T – a set of means of transport serving between producers,

R – the number of manufacturer in the network,

The production order is defined as:

$$PP=(P, MP, N) \quad (3)$$

where:

$P=\{P_j, N_j, j = 1, 2, \dots, n\}$, – production processes,

$MP = \{MP_j^w, j = 1, 2, \dots, n; w = 1, 2, \dots, v_j\}$ – production processes matrix:

n – the number of manufacturing processes,

w – version of the process route, v_j – the number of routes version for the j^{th} process,

N_j – batch size,

The cost of production order is defined as:

$$C = C^P + C^T \quad (4)$$

where:

C^P – the unit production cost,

C^T – the unit costs of transport

For the above-defined models of production systems, production orders and unit costs, players and functions of the objective are defined:

$N=\{N_g, g = 1, 2\}$ – set of players corresponding to each of the objective function $f(\sigma)$,

f_P : minimizing the production cost:

$$f_P(\sigma) = \sum_{j=1}^h \sum_{h=1}^{H_j^{\sigma_j}} (C_{(mp_{1h}), (mp_{2h})}^P * mp_{3h}) \rightarrow \min \quad (5)$$

f_T : minimizing transportation costs between producers:

$$f_T(\sigma) = \sum_{j=1}^h \sum_{h=1}^{(H_j^{\sigma_j}-1)} (C_{(mp_{1h}), (mp_{1(h+1)})}^T * N_j) \rightarrow \min \quad (6)$$

where:

σ_j - the selected production route variant.

4.2. The Production Route Selection Algorithm

A decision support algorithm for finding and selecting production route from the set of available alternative routes for the proposed approach to production flow planning based on game theory methods has been developed (figure 3). All required input data and parameters for determining the solution concept of the production game in pure strategies are the results from the algorithm.

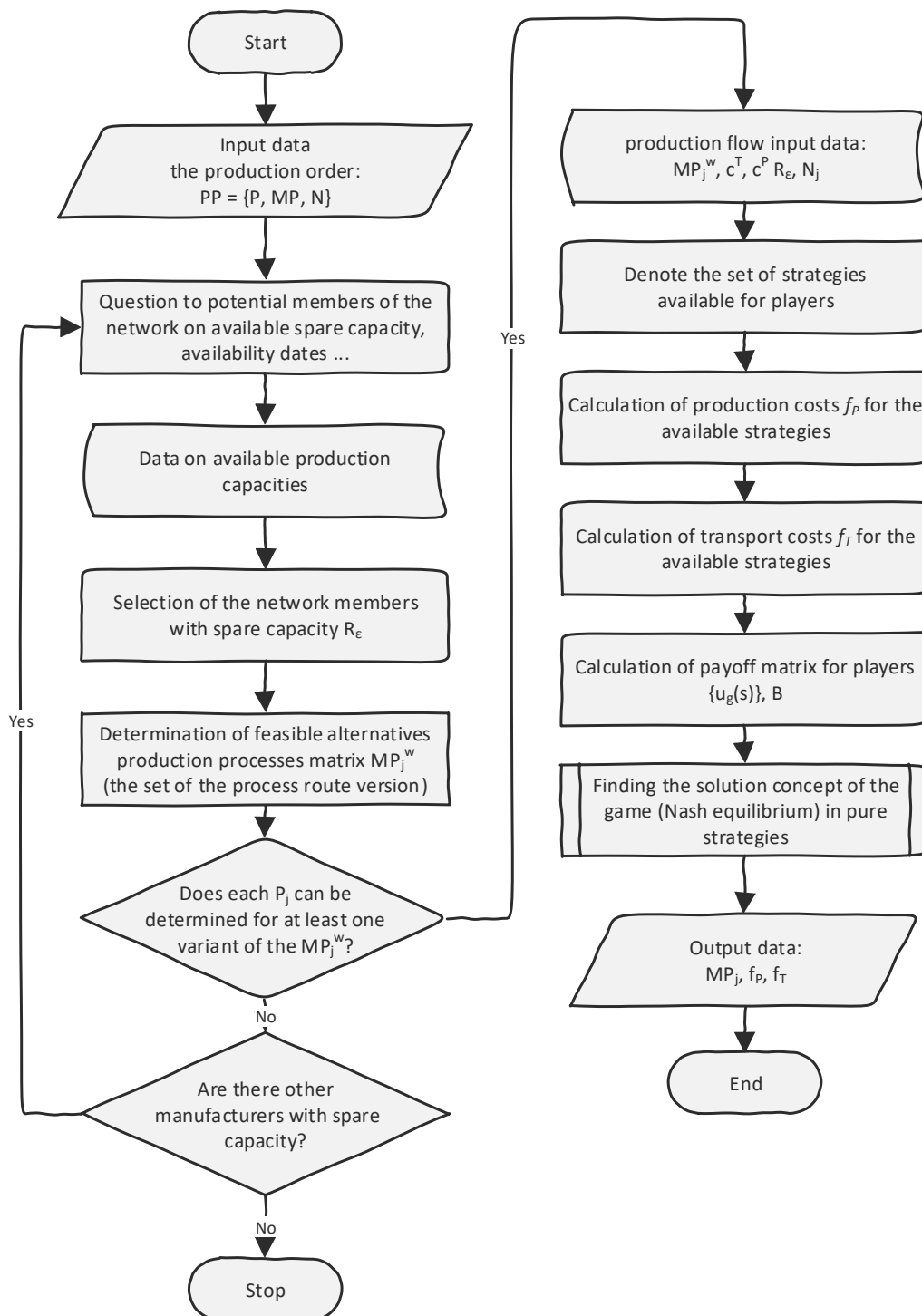


Figure 3. The Production Route Selection Algorithm form VMN.

It is assumed that data on a particular production order is available as an input data, i.e. data on the specification of the set of technological processes, the size of the production batch and the production order deadlines. Then, from potential VMN members, information on spare production capacity in subsequent planning periods (in quantitative and qualitative terms) and data on the cost of their use are obtained. The next step is to develop a set of possible technological route variants. Then it is checked

that at least one production route variant are possible for all production processes included in the production order.

The input data for the next steps are the data of the designated variants of the production routes variants, along with the production resources cost data for each member of the network. The next step is to identify possible strategies (as a set of possible technological route variants) for both players who represent the objective functions defined in chapter 4.1: minimizing production costs and minimizing transport costs. These strategies correspond to the feasible sets of production routes for all processes. In the next two steps, the costs of production and transport are calculated for the designated strategies. These costs are the basis for determining the value of the payoff function in the next step and, in turn, the payoff matrix. These values are also the input data required in the search for a solution of the production game in pure strategies. The integrator (decision maker) can make a choice of routes selection from the set of permissible routes (i.e. meeting the technological and resource requirements) based of these data.

5. Conclusions

Manufacturers ability to adapt to changing market conditions in a dynamically changing environment impact on the success of business operations. It depends on the level of flexibility, both in terms of technological resources and the methods and methods of planning. This forces efforts to find innovative planning and execution of production orders solutions that go beyond the traditional individual organization. The concept of virtual manufacturing networks is entirely consistent with this situation. However, with the possibility of using virtual networks, additional problems arise in the process of production flow planning. The decision maker (integrator) must carefully analyze the production capabilities of each manufacturer on the network and select the right production resources at the right time.

Presented in this paper algorithm is a complete solution to supporting the decision-making process of production route selection based on methods derived from game theory. However, the proposed route selection method has some limitations. These limitations result from specific game scenarios (lack of Nash equilibrium), forcing the planners to assist the decision-making process, who in such cases must arbitrarily decide on further steps. The subject of further work in this area will be related to the identification and analysis of such cases. Another area of research concerns the development of the definition of the decision-making model by elements related to the production auxiliary processes (taking into account the model of material handling and storage subsystems).

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