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RAPID PROTOTYPING OF VIRTUAL PRODUCTION NETWORKS IN SMES

Abstract

Nowadays many companies, especially small and medium-sized enterprises (SMEs), specialize in a limited field of production. It requires forming virtual production networks of cooperating enterprises to manufacture better, faster and cheaper. Apart from that, some production orders cannot be realized, because there may not be a company of sufficient production potential. In this case the virtual production networks of cooperating companies can realize these production orders. These networks have larger production capacity and many different resources. Therefore it can realize many more production orders than only one of them. Such organization allows for executing high quality product. The maintenance costs of production capacity and used resources are not so high. The productivity is higher in all production systems in the network. The average costs of these systems are smaller and companies are more competitive.

I. INTRODUCTION

Nowadays, one may observe development of cooperation between enterprises carrying out common production orders in virtual production networks. There are two main reasons of this development. The first one is a high degree of enterprises specialization in a limited field of production. The second one is the fact, that there is much more potential of advanced computer and telecommunication systems like global networking or groupware systems [8]. An idea of manufacturing in a network means joint manufacturing, while enterprises offer essential production capacity to manufacture products according to production orders. This solution allows for executing production orders by a group of specialized enterprises, whereas one of them could not have realized a given production order because of lack of production potential [9].

The contemporary networks result from enterprises cooperation. These companies would like to take advantage of synergy effect. It improves global manufacturing. It allows for: shortening delivery time, reducing stocks in a whole supply chain, reducing costs of production

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order execution, increasing effectiveness of customer's service, etc. The structure of logistic chain extends horizontally in comparison to classical logistic chain. In a theory it is possible to form a huge network of suppliers; manufacturers and distributors in which everyone optimizes its own business activity according to costs, stocks and workload of the system [2].

Contemporary functioning of delivery chains is not sufficient enough, because there is a need to respond quickly to frequent changes. The effectiveness of virtual production network reduces lack of flexibility of contractor's selection and long-standing contracts with contractors. So the need for matching to changes is the main reason of using an adaptive management [3] which can match planned production order to characteristic feature of enterprises formed network, logistic infrastructure, customer's demand, etc. The virtual production networks means organizations in which resources of cooperating enterprises are joined together in order to realize a common undertaking, thanks to which deriving more benefits than functioning in a traditional way [1], [10]. A virtual manufacturing company normally consists of geographically dispersed master company's branches sub-contractors, joint ventures and partners [11].

In the last past years database systems in the Internet have been formed, which gather information about production capacity in SMEs. These systems help to find partner to cooperate. Unfortunately businessmen are not interested in these solutions. The main reason for that, is lack of data-introducing rules and aversion to delivering confidential information about enterprise such as production costs, etc. to such an easy accessible system like Internet.

It is easy to notice that problem of using SMEs abilities is still vital. Because of that, there is a need to work out a method of quick prototyping of virtual production networks in SMEs. It concerns enterprises which are able to make a new production undertaking (production order) on time, according to production capacity and given transportation system of the set of enterprises.

It is not easy to set acceptable variants of virtual production networks because it is a problem of a big complexity. The known and applied methods (like optimization and simulation methods) are very time-consuming, work-consuming and therefore expensive [9]. It is not possible to set acceptable solutions in on-line mode to use them. Therefore, one should do research, implement methods and computer systems which can set quickly acceptable variants of planned production order execution with consideration to resources and financial and logistic limitations.

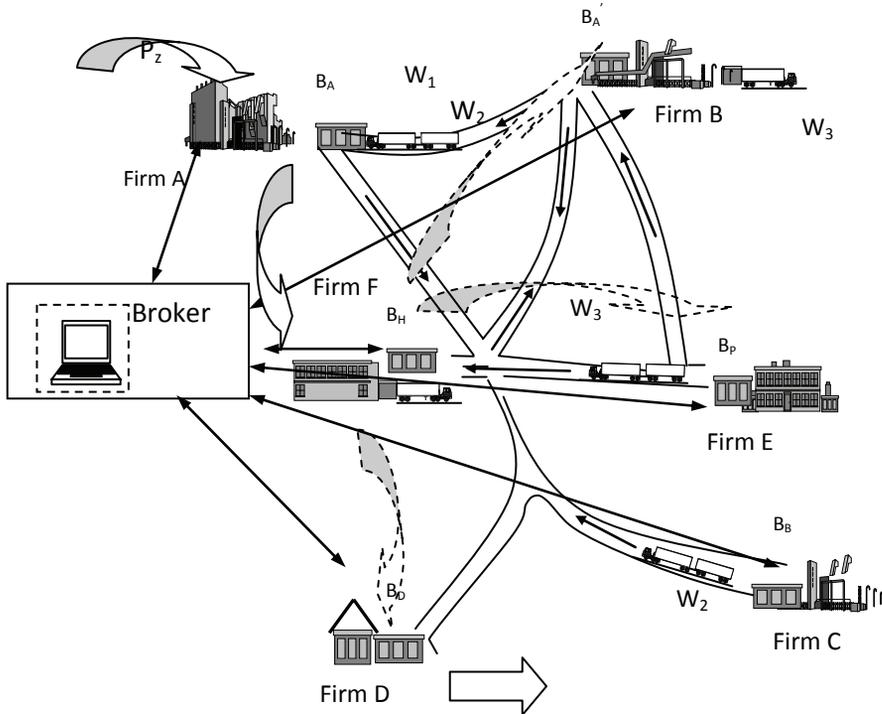
In this paper, problem solutions for possible execution production order in accordance with customer's requirements, production potential of cooperating enterprises and possibility of transport system is considered. It is supposed that there is a set of enterprises with known production capacity, defined products and services offers, know-how licenses, certificates, etc. and there is a production order specified in terms of quality and delivery time. This paper suggests using a new methodology of rapid prototyping in virtual production networks which is able to execute production order on time, according to logistic constraints. This methodology allows for reducing costs of production order execution.

It is suggested to use a broker. The broker is an independent enterprise which forms a virtual production networks and collects needed information about co-operators. The broker is not competitive neither as production enterprise nor transportation enterprise. It allows for secure keeping of the transferred information.

2. MODEL OF VIRTUAL PRODUCTION NETWORK

There is a set of SMEs manufacturing in specialized and limited field of production. These enterprises have certain production capacity. Given limitations are the following: production capacity (a kind of operations, time of availability, cost of using production resources), transportation routes, means of transport (quantity, capacity, time and cost of drive) and capacity of storehouses.

The very important component of the presented model is a transaction broker. The main target activity of this broker is connecting cooperating companies, which would be able to execute production order with known limitations. The broker organizes a set of enterprises that guarantees that production order execution is on time and with low production costs. The scheme of the presented model is illustrated on Fig. 1.



Legend:

Firm A, B, C, D, E, F - enterprises which are able to execute production order P_z ;

W_1, \dots, W_3 - means of transport;

\longleftrightarrow - information flow;

 - process material flow P_1 ;

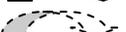
 - alternative process material flow P_1 .

Fig. 1: The model of virtual production network.

There is a planned production undertaking (production order), execution of which exceeds potential of single enterprise, according to its production capacity and possessed technology. The production order is specified by size of planned production, given time of execution and costs of realization (price). The way of production order realization is described by production process $Pz = (O_1, O_2, \dots, O_i)$, marked as a vector. The elements of this vector are characterized by partial operations which are executed in individual enterprises.

3. PROBLEM FORMULATION

In common case the following research problem is considered: is there a network of enterprises which can execute production undertaking on time and according to logistic constraints?

The solution of this problem requires answering the following questions:

- does structure of production capacity in time of cooperating enterprises allow for execution of a new production order?
- can a new production order be executed using existing transportation system?
- what is total cost of production order execution?

4. METHODOLOGY OF RAPID PROTOTYPING OF VIRTUAL PRODUCTION NETWORKS

The prototyping of virtual production networks is connected very often with a need of solving a very complex problem. It should select such enterprises which have production capacity and allow for quick execution undertaking and the logistic position allows for realization of assumed material flow. The important instrument of suggested conception of prototyping is a production capacity exchange platform which is represented by transaction broker. The broker has to select such enterprises which guarantee execution of production undertaking. The scheme of information flow to be used by broker is shown on fig. 2.

The suggested solution matches demands of described production undertaking and supplying which means better production possibilities of geographically dispersed enterprises [4]. Impermanent organizations which are able to realize common undertaking are to be involved. In practice, enterprises submit an offer of production capacity and give costs of using this capacity in transaction broker system. This kind of information is updated in on-line mode using computer system. The broker raises production orders which demands using many specialist companies. When enterprises are connected in an effective virtual organization, it assures qualitative correct material flow using outside transportation. At the same time there is not execution disruption of other production orders in cooperating enterprises.

In case of a special kind of difficulty of this problem, it is necessary to create solution in on-line mode. Therefore an algorithm is suggested, based on checking sufficient conditions fulfilment, which guarantees acceptable production order execution [5], [6]. The proposed methodology is shown in Fig. 3.

The presented methodology consists of three stages. In the first stage a set of acceptable variants of network (space of acceptable solutions) PDR_i is formed, which meets the requirements of operation kind. The initial space of potential solutions can be set according to formula 1. Using formula 1 is illustrated in a case study (fourth part of this paper).

$$PDR_I = \prod_{i=1}^m e_{p_i}, \quad (1)$$

where:

e_{p_i} – quantity of enterprises which are able to execute i -operation according to operation kind (for example assembly);

m – quantity of operations in process.

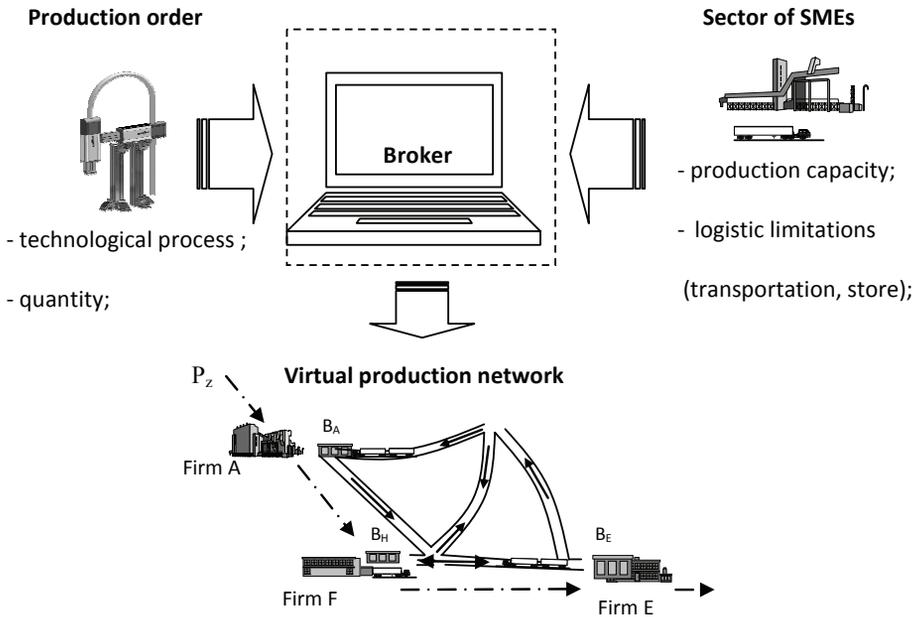


Fig. 2: The production capacity exchange platform.

A set PDR_I is narrowed on the basis of checking next sufficient conditions. In this stage production capacity (machines, workstation, etc.) of each enterprise and sequence of operations are checked. The set is reduced to a set PDR_{II} . It sets time and size of delivery batches.

In the second stage a set of variants is limited to such variants which fulfil conditions connected with transportation and storage systems. Each variant is checked according to available route structure, quantity and capacity of transportation means and storehouse capacity of co-operators. In proposed approach transportation system realizes operations of material transferring between enterprises according to the established schedule. Transportation means with known capacity move along given routes of connected participants of logistic network. The schedule is established on the basis of offers of forwarding enterprises which guarantees availability of transportation means with given capacity in a length of time in given section of route. It allows for quick and credible assessment of possibility of transportation operations execution, without time-consuming and cost-consuming planning of transportation timetable.

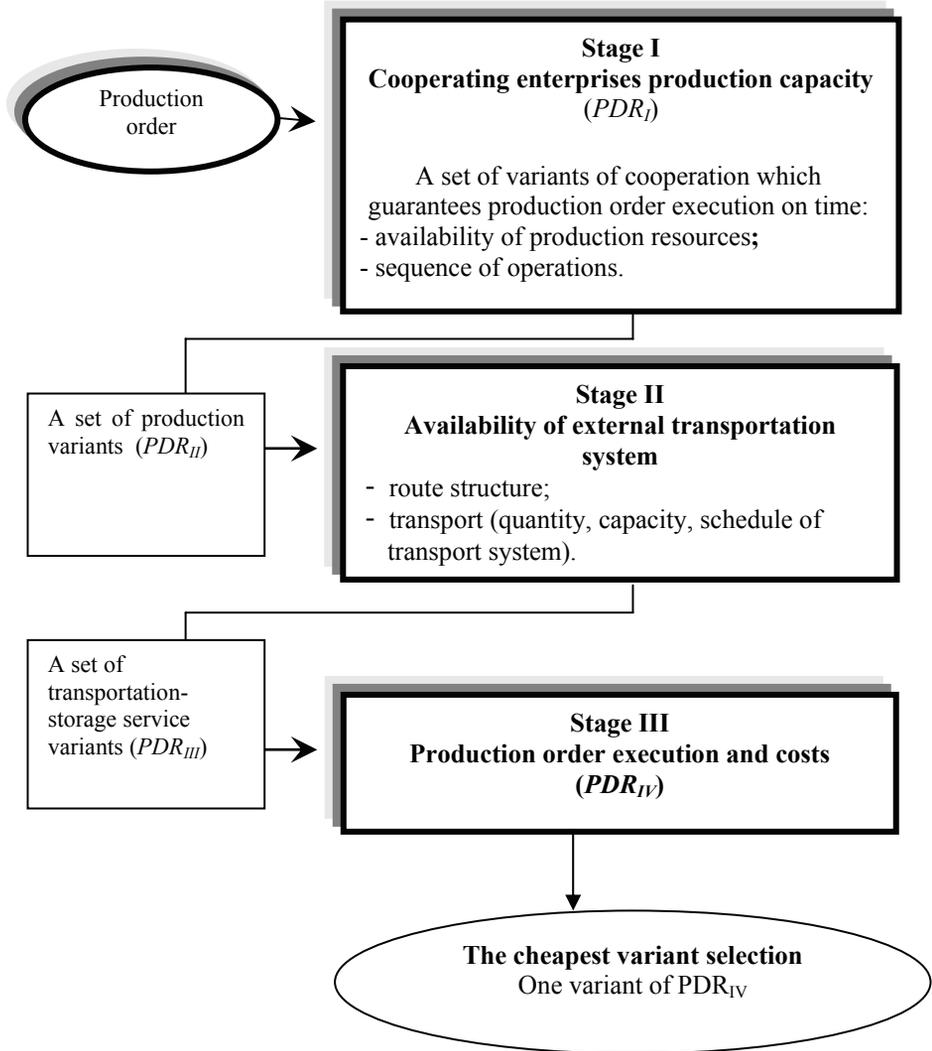


Fig. 3: The methodology of rapid prototyping in virtual production networks

Applying of the suggested solution guarantees possibility of finding quality acceptable solutions, if such are. As a result of this, there are acceptable variants of network (PDR_{III}) with variants of transportation-storage support which guarantee production order execution on time.

In the third stage of suggested methodology, planned cost of production order execution is calculated. It is determined by a set of PDR_{IV} solutions, which guarantees production order execution on time. The cheapest variant is selected. The costs of production order execution are

divided into some groups of costs like: material costs, individual process costs, transportation costs, insurance costs, store costs and costs of broker service.

The individual process costs are determined by cooperating enterprises. Using Activity Based Costing to calculate unit cost of process is proposed. The concept of this method is the basis for assuming that indirect costs arise when enterprise takes activities which serve to produce products or service and deliver them to customers. Activity Based Costing introduces additional stage of calculation in which activities are priced. The level of indirect costs of each product (process) depends on a kind and quantity of activity which is needed for execution [7]. The cost of process calculated in this way is increased by mark-up of co-operators.

In considered approach all variants which guarantee production order execution on time are distinguished. The information about costs allow for selection of the cheapest variant of cooperating network.

When a set of solutions runs out, the proposed methodology is assumed to reject planned production order. Information about reasons of rejecting is known. It means, that there can not be executed production order on time.

4. CASE STUDY

There are six independent production enterprises: A, B, C, D, E and F which entered to the production capacity exchange platform and two means of transport W1, W2. Each production company can make only some technological operations, what is shown in Table 1.

Tab. 1: Time and costs of operations realization

Company/operation	operation 1 (time/cost) per unit	operation 2 (time/cost) per unit	operation 3 (time/cost) per unit
Firm A	10 ut*/2 \$	X	X
Firm B	X	X	10 ut / 7 \$
Firm C	15 ut / 3 \$	X	X
Firm D	X	22 ut / 22 \$	12 ut / 8 \$
Firm E	22 ut / 6 \$	X	13 ut / 12 \$
Firm F	X	5 ut / 10 \$	x

* units of time

The broker gets a new planned production order Z_1 to execute in virtual organization. This production order is characterized by volume of pieces output $Q=3\ 000$ and the time limit $T_E=5500$ units. A customer (employer) determined maximum price of production order execution 95 000 \$. The production process of this order consists of three technological operations: o1, o2, o3.

The presented approach permits to select resources (partners of a virtual organization) that guarantee the completion of production order within a fixed time limit and with relatively low

costs considering logistic limitations. Using of proposed methodology allows for six enterprises for selection, which can form a virtual production network. The first operations will be made by enterprise A, C and E. The second one will be made by D and F enterprise and the third can be made by enterprise B or D or E. In Table 1, there is presented time (in units of time) and cost (in \$ per piece of product) of each operation execution in every enterprise.

On the basis of the methodology, which is illustrated in Fig. 3, variants of network are formed. Depending on a kind of technological operations, there can be formed 18 variants of network ($3 \times 2 \times 3 = 18$) (see formula 1). There is a set PDR_I .

Next, availability of resources in each enterprise in a given time is checked. The first operation cannot be realized in company C. So a set is reduced to 12 variants. Six variants are rejected (C-F-B, C-F-D, C-F-E, C-D-B, C-D-D and C-D-E).

In the second stage existed variants according to availability of transportation are examined, what is shown in Tab. 2. The cooperating enterprises are operated by forwarding enterprises. Two means of transportation carry components between cooperating firms.

Vehicle capacity and transportation schedule in considered time is known. There are no means of transport in stretches between enterprise A and D (A-D) and A and F (A-F) in a needed time. So a determined set of variants is reduced to 8 variants. Six variants are rejected (E-D-B, E-D-D, E-D-E, E-F-B, E-F-D, E-F-E). It has created a set PDR_{II} .

Tab. 2: Transportation routs and delivery times

Track	Transportation routs (transportation time/ cost)
W₁	Firm A – Firm F (100ut/500\$) Firm F – Firm D (100ut/450\$) Firm A – Firm D (200/750\$)
W₂	Firm F – Firm B (100ut/480\$) Firm F – Firm E (120ut/400\$) Firm D – Firm B (130ut/800\$) Firm D – Firm E (100 ut/790\$)

In the next stage costs of production order of each variant are calculated. The variants with costs of execution above 95 000 \$ are rejected. There are three variants (A-D-B, A-D-D, A-D-E). In these variants the costs of execution amount to 97 550 \$, 96 750 \$ and 109 540 \$ respectively. It has formed a set PDR_{III} .

Finally, three variants of production order Z_1 execution are established. These variants are shown in Tab. 3. The second variant has been accepted to execution, because costs of this variant are the lowest. The three acceptable variants are presented in Fig. 4, too.

Tab. 3: Characterization of variants

Variant	Company	Total costs	Execution time
1	A – F – D	60 950 \$	81200 ut
2	A – F – B	57980 \$	75200 ut
3	A – F – E	72900 \$	84220 ut

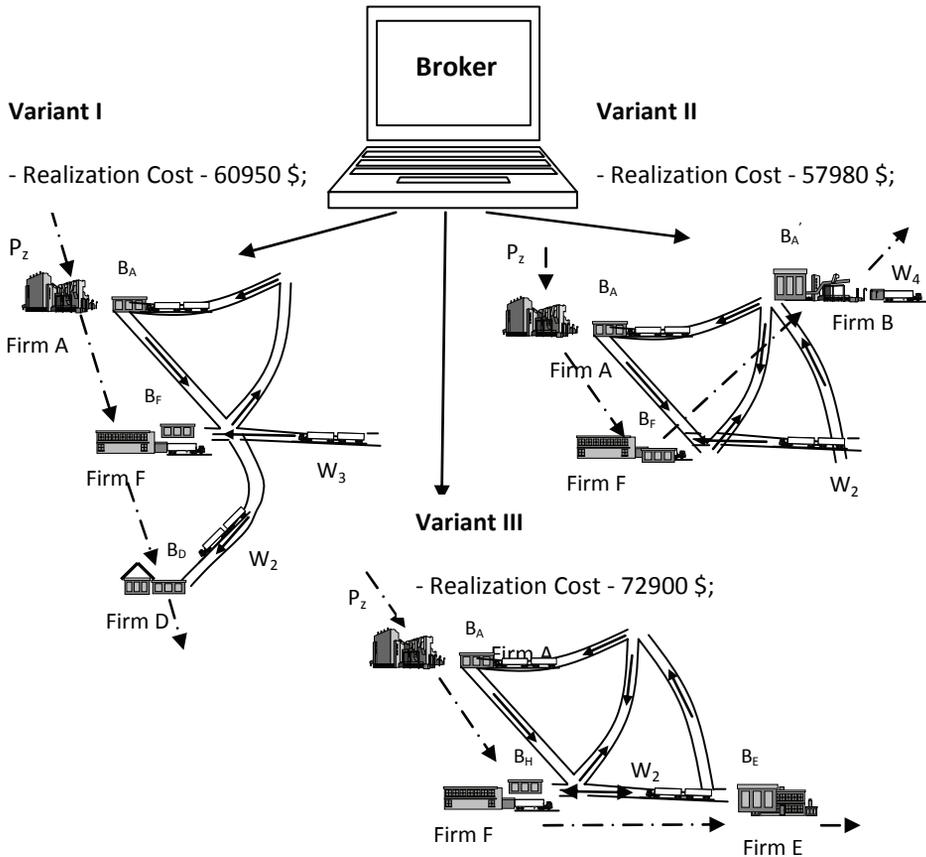


Fig. 4: Variants of production order realization

5. CONCLUSIONS

The possibility of using production potential of cooperating enterprises allows for development of small and medium-sized enterprises (SMEs). It means that SMEs organized as virtual production network can compete with much bigger enterprises of much higher capital. These solutions allow for better usage of production potential, increase of SMEs production system productivity outcome and reduces costs.

The most important problem of forming virtual production network is lack of methods and computer systems which would allow for quick and credible specifying of new possibility of production undertaking realization. Therefore there is a need to form an exchange production capacity platform using a methodology of quick prototyping of acceptable production network organization and production workflow which guarantees accurate execution of production orders.

In this paper a methodology based on propagation of constraints of cooperating enterprises is suggested. The main goal of this methodology is to select co-operators that are able to

execute production processes in a network and, assuming possibility of planned production order, to realize them in conditions of transportation systems and storage constraints.

The further research concentrates on describing technological operations and logistic operations (transport, storage) of potential co-operators and also on working out of computer exchange production capacity platform. This platform will allow for quick prototyping of virtual production network which will be flexible and economically effective.

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