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# MODELLING OF VIRTUAL PRODUCTION NETWORKS

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**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 is not 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 together than each of them separately. Such organization allows for executing high quality product. The maintenance costs of production capacity and used resources are not so high.
In this paper a methodology of rapid prototyping of virtual production networks is proposed. It allows to execute production orders on time considered existing logistic constraints.

**Key words:** virtual organization, production network, production flow planning.

## INTRODUCTION

A high degree of enterprises specialization in limited field of production and much more potential of advanced computer and telecommunication systems like global networking or groupware systems [Tuma 1998, Huang et al. 2008] cause development of cooperation between enterprises carrying out common production orders in virtual production networks. The most popular of them called "virtual enterprises" or "virtual organizations".

The conception of virtual enterprises is characterized by a distinct form of network organization in combination with a high degree of organizational flexibility [Tuma 1998]. 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 [Verwijmeren 2004].

A Virtual Organization (VO) can be seen as a temporary or permanent coalition of geographically dispersed organizations that pool resources in order to achieve common goals [Arenas, Aziz et al. 2008]. It is necessary that the potential partners are ready and prepared to participate in collaboration. The potential for development gives the current exploitation of Internet technology to create virtual enterprises [Arenas, Aziz et al. 2008, Corvello and Migliarese 2007].

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Virtual organizations differ from other traditional enterprises in the following features: dynamics of network reconfiguration with flexibility, agility, operational dimension, competitiveness, resource optimization and innovation. VO can form integration as well as reconfiguration dynamics [Putnik et al. 2005, Camarinha-Matos and Afsarmanesh 2007].

There are different forms of virtual organizations. A well-known form is the temporary cooperation of dedicated enterprises in order to integrate their skills in a certain project and to reduce their individual risk (cooperating form). An example of this solution is a banking syndicate or a consortium of oil companies. A more advanced form is the establishment of a new cooperative enterprise as a network of independent, substitutable companies (cooperative form). This is a kind of a temporary, project-dependent portfolio of core competencies [Tuma 1998, Vidová 2006].

Last time 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. Therefore, it is necessary to work out a method of quick prototyping of virtual production networks in SMEs, which are able to make a new production order on time, according to production capacity and given transportation system of the set of enterprises.

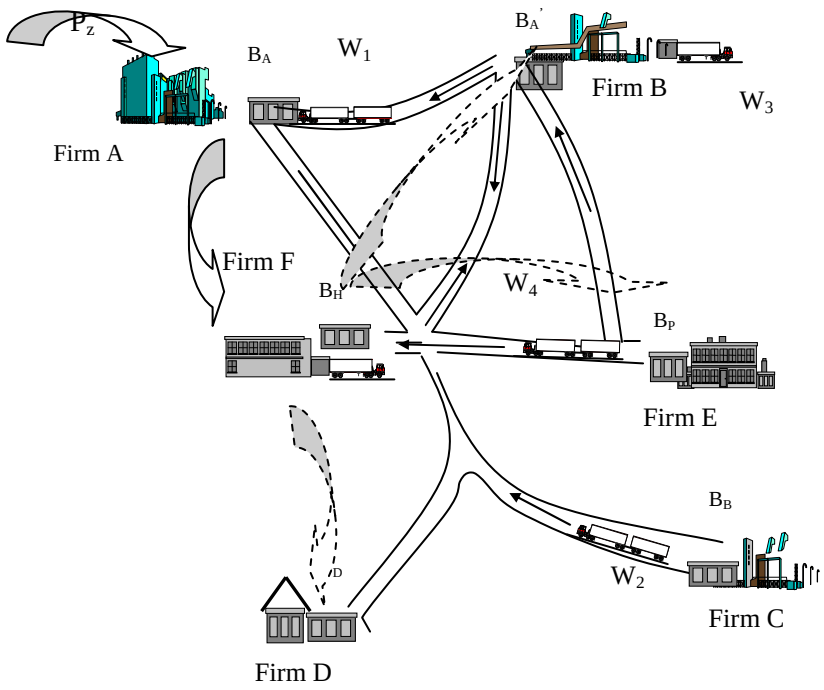
It is not easy to set acceptable variants of virtual production networks because it is a problem of a large complexity. The known and applied methods (like optimization and simulation methods) are very time-consuming, work-consuming and therefore expensive [Zhuge, Chen, Feng, Shi 2002]. It is not possible 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, a new methodology of virtual production networks prototyping is suggested. It allows to execute production order on time, according to logistic constraints. When is given a set of enterprises with known production capacity and there is a production order specified in terms of quality and delivery time, a virtual production network is formed. This paper suggests to use a broker. The broker is an independent enterprise, which 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.

## MODEL OF 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:
Firms A, B, C, D, E, F – enterprises which are able to execute production order $P_z$;
$W_1, \ldots, W_4$ – means of transport;
- process material flow $P_1$;
- alternative process material flow $P_1$.

Source: own work

Fig. 1. The model of virtual production network
Rys. 1. Model wirtualnej sieci produkcyjnej

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 = ($O_1$, $O_2$, …, $O_i$), marked as a vector. The elements of this vector are characterized by partial operations which are executed in individual enterprises.

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?

In considered case there is assumed the following hypothesis: There is an effective computational methodology of virtual networks variants prototyping for enterprises from SMEs which have production capability in conditions of deterministic resources and logistic constraints of the system.

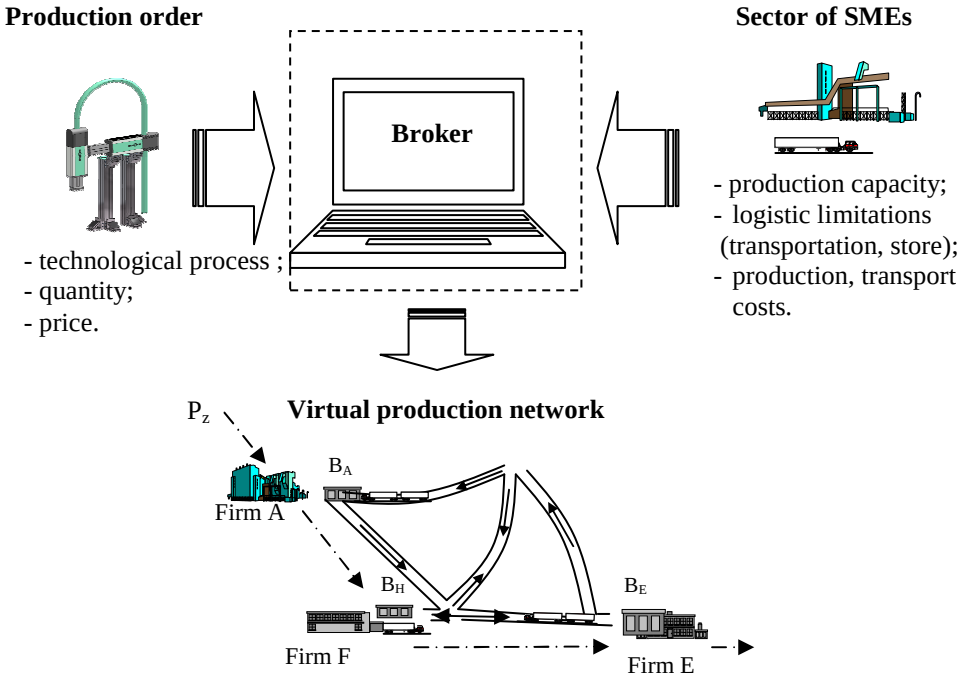
The main goal of research is to propose a methodology of rapid prototyping of a virtual production network. The following partial goals have to realize to fulfill the main goal:

- to work out a model of virtual production network of SMEs;
- to work out a set of sufficient conditions, fulfillment of which guarantee production order execution in a network on account of resources and logistic constraints;
- to work out a proposal of an algorithm based on checking of sufficient conditions sequence.

## RAPID PROTOTYPING OF VIRTUAL PRODUCTION NETWORKS

The prototyping of virtual production organizations (networks) based on selection such enterprises which have production capacity and allow for production orders execution. 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 [Saniuk S. and Saniuk A. 2009]. 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.




Source: own work

Fig. 2. The production capacity exchange platform
Rys. 2. Platforma wymiany zdolności produkcyjnych

The network organizing requires to solve a large-scaled computational complexity problem. Known and used methods especially optimization and simulation methods are very time-consuming, work-consuming and cost-consuming. Using of these methods makes difficult a possibility of acceptable solution finding in on-line mode. Therefore, an algorithm is suggested, based on checking sufficient conditions fulfillment, which guarantees acceptable production order execution [Saniuk S., Saniuk A. 2008]. Checking of sufficient conditions sequence (a set of algebraic-logical conditions) reduces an initial set of solutions (formula 1) on account of resources and logistic constraints. The final solution is a set of variants which fulfillment of discussed constraints. The proposed methodology is shown in Fig. 3.

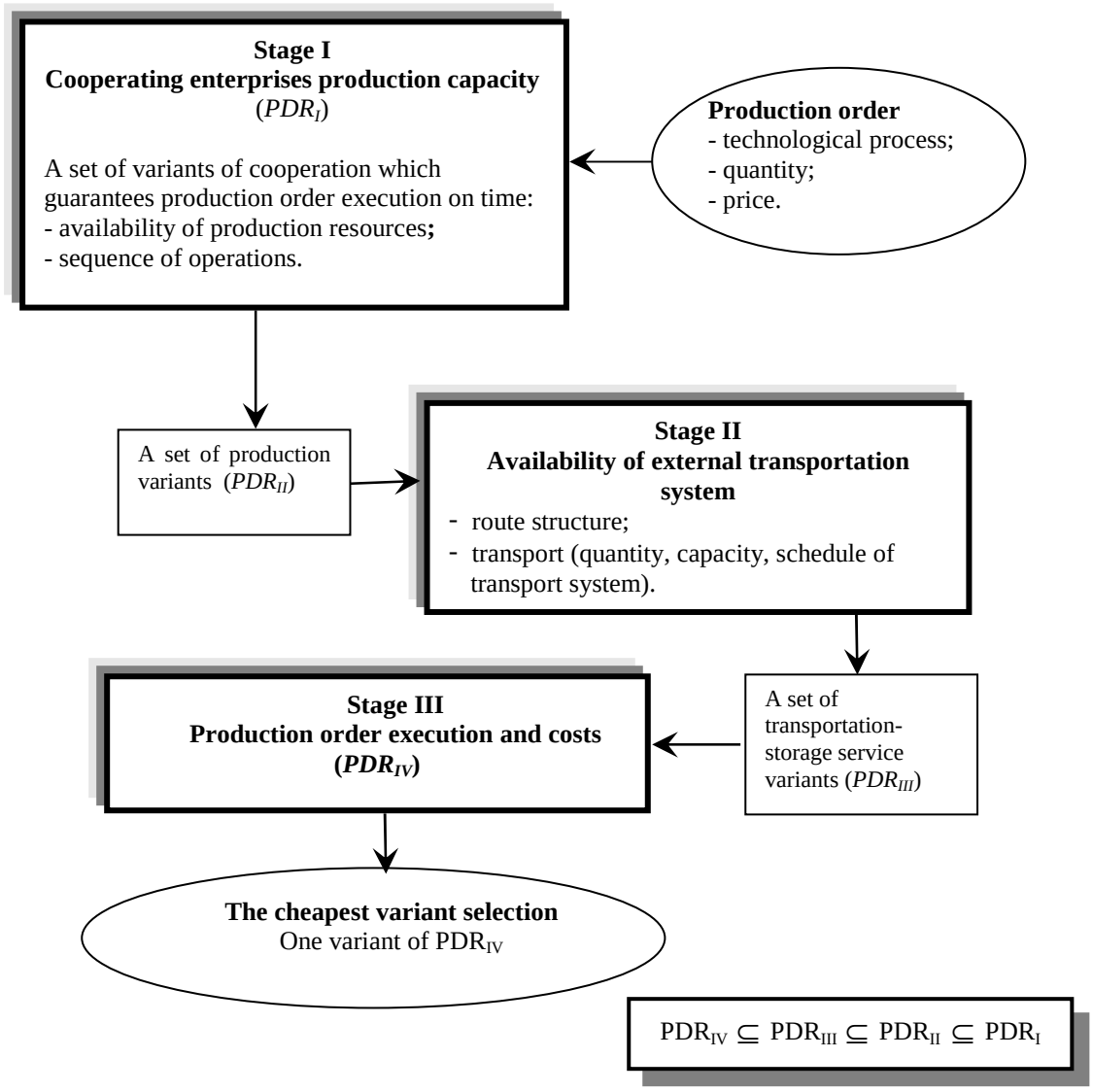



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Fig. 3. The methodology of rapid prototyping in virtual production networks
Rys. 3. Metodyka szybkiego prototypowania wirtualnych sieci produkcyjnych

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:

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

m - quantity of operations in process.

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.

Appling 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 [Stadtler 2005]. 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 does not exist a set of enterprises, which guarantees a production order execution on time.

## EXAMPLE OF RAPID PROTOTYPING OF NETWORKS

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. Forming of network variants in Fig.4.

Table 1. Time and costs of operations realization
Tabela 1. Czasy i koszty realizacji operacji produkcyjnych

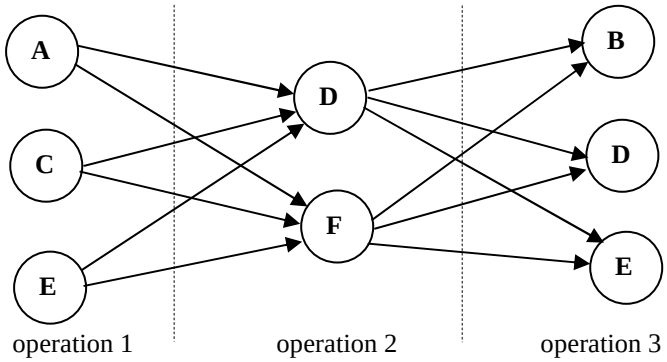
| Company/operation | operation 1 (time/cost) per unit | operation 2 (time/cost) per unit | operation 3 (time/cost) per unit |
|---|---|---|---|
| **Firm A** | 10 ut*/2 $ | - | - |
| **Firm B** | - | - | 10 ut/ 7 $ |
| **Firm C** | 15 ut/ 3 $ | - | - |
| **Firm D** | - | 22 ut / 22 $ | 12 ut / 8 $ |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

* units of time

Source: own study

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: operation 1, operation 2 and operation 3.

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.

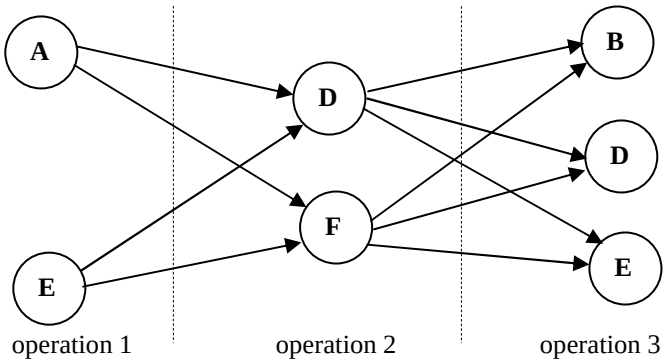



Source: own study

Fig. 4. Forming of network variants
Rys. 4. Wariantowanie sieci

On the basis of the methodology, which is illustrated in Fig. 2, variants of network are formed. Depending on a kind of technological operations, there can be formed 18 variants of network (3x2x3=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), what is shown in Fig. 5.

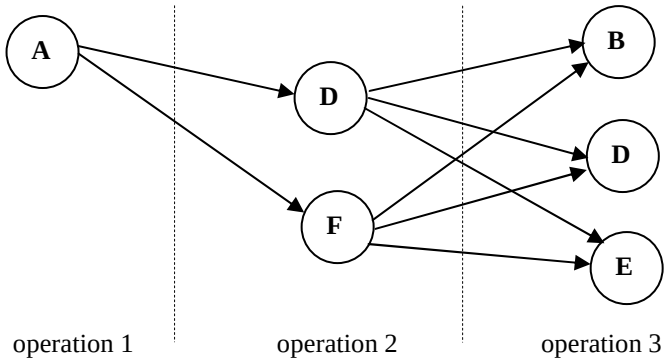



Source: own study

Fig. 5. Forming of network variants
Rys. 5. Wariantowanie sieci

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 E and D (E-D) and E and F (E-F) in a needed time. So a determined set of variants is reduced to 6 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 $PDR_{II}$ (see Fig. 6).




Source: own study

Fig. 6. Forming of network variants
Rys. 6. Wariantowanie sieci

Table 2. Transportation routes and delivery times
Tabela 2. Trasy i czasy operacji transportowych

| **Track** | **Transportation routs (transportation time/ cost)** |
|---|---|
| **$W_1$** | Firm A – Firm F (100ut/500$ )<br>Firm F – Firm D (100ut/450$)<br>Firm A – Firm D (200/750$) |
| **$W_2$** | Firm F – Firm B (100ut/480$)<br>Firm F – Firm E (120ut/400$)<br>Firm D – Firm B (130ut/800$)<br>Firm D – Firm E (100 ut/790$) |

Source: own study

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.

Table 3. Characterization of variants
Tabela 3. Charakterystyka dopuszczalnych wariantów

| Variants | Companies | 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 |

Source: own study

## 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 reduce 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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# MODELOWANIE WIRTUALNYCH SIECI PRODUKCYJNYCH

**STRESZCZENIE**. Obecnie wiele przedsiębiorstw, szczególnie z sektora MŚP, specjalizuje się w bardzo wąskim zakresie produkcji. Żeby produkować lepiej, szybciej i taniej, wymagane jest tworzenie wirtualnych sieci produkcyjnych kooperujących przedsiębiorstw. Ponadto, niektóre zlecenia produkcyjne nie mogą być zrealizowane, ponieważ nie istnieje przedsiębiorstwo o dostatecznym potencjale produkcyjnym. W tym przypadku zlecenia tego typu mogą zostać zrealizowane w produkcyjnych sieciach kooperujących przedsiębiorstw. Większe zdolności produkcyjne i różnorodność zasobów kooperujących sieci przedsiębiorstw pozwala zatem wspólnie zrealizować dużo więcej zleceń niż każde z nich z osobna. Taka organizacja umożliwia wykonywanie wysokiej jakości produktów przy niskich kosztach utrzymania i wykorzystania zdolności produkcyjnych.
W artykule zaproponowano metodologię szybkiego prototypowania wirtualnych sieci produkcyjnych, które pozwalają na terminową realizację zleceń produkcyjnych uwzględniając istniejące ograniczenia logistyczne.

**Słowa kluczowe:** wirtualna organizacja, sieci produkcyjne, planowanie przepływu produkcji.

# MODELLIERUNG DER VIRTUELLEN PRODUKTIONSNETZWERKE

**ZUSAMMENFASSUNG.** In der heutigen Zeit spezialisieren sich viele Unternehmen (besonders kleine und mittlergroße Unternehmen) in einem begrenzten Bereich der Produktion. Es fordert die Bildung der virtuellen Produktionsnetze von kooperierenden Unternehmen um besser, schneller und billiger zu produzieren. Abgesehen davon, können einige Fertigungsaufträge nicht realisiert werden, weil es keinen Unternehmen mit der genügenden Produktionskapazität gibt. In diesem Fall können die virtuellen Produktionsnetze von kooperierenden Unternehmen diese Fertigungsaufträge realisieren. Diese Netze haben größeren Produktionskapazitäten und viele verschiedenen Ressourcen. Deshalb können sie mehr Fertigungsaufträge realisieren als nur einer von ihnen. Solche Organisation ermöglicht hochwertigen Produkten zu herstellen. Die Unterhaltungskosten der Produktionskapazität und verwendeten Ressourcen sind nicht so hoch.
Eine Methode des "Rapid Prototyping" von virtuellen Produktionsnetzen wird in diesem Artikeln vorgeschlagen. Sie erlaubt die Produktionsaufträge termingerecht in angegebenen logistischen Begrenzungen.

**Codewörter:** virtuelle Organisation, Produktionsnetz, Flussplanung der Produktion.

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