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The modelling and simulation method in computer aided cooperation*

by

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Abstract: This paper presents a possibility of applying a modelling and simulation technique in designing a logistic chain in production enterprises. A new approach, based on simulation technique, together with utility function for partnership selection in cooperative production is the main element of the study. The work is oriented at practitioners, who use methods and ways of data exchange in cooperation and create new computer systems aiding in production cooperation. The capacity of simulation technique is illustrated by practical examples.

Keywords: production, co-operation, modeling and simulation, expert systems

1. Introduction: tendencies in management of the logistics chain

Computer technologies are the basic tool of accumulation and exchange of information in contemporary enterprises. Methods of artificial intelligence and expert systems are increasingly commonly used in management processes. People, who manage fulfilment of tasks in the enterprise often ask themselves two questions: *"Why?"* and *"What will happen, when?"*, wanting to perform the tasks possibly well, i.e. quickly, with lower costs and more effectively.

The efficiency of production process depends on many factors. The most important are the organizational structure of the enterprise and the process structure.

The use of current analytical, inferencing and projecting tools is helpful in rationalization of processes. Following instruments are often used:

- benchmarking,
- methods of time resources management,

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– methods of calculation and forecasting of process costs,
– modelling and simulation,
– expert systems.

While some researchers have developed their own rationalization of production processes, others (Chituc and Nof, 2007) have opted to use proprietary cooperation in production. The main objective of this paper is to present a new approach, consisting of *simulation technique* together with *utility function* for partner selection in formation of cooperation in production.

The research reported in this paper focuses on the development of simulation technique approach to partner selection in formation of cooperative production. In the design of the new approach we adopted *utility function*, linking the basic criteria of cost, time and quality, presented in Matuszek, Moczała and Kosturiak (1998). The model, based on the macro run of production processes, includes all processes performed in the company. Besides the processes of transformation of inputs, e.g. materials or information, into the outputs that are products or services, this model also takes into consideration management processes. Those are processes of initiating, organizing, motivating and controlling, as well as the processes of recruitment and development of personnel, finances, information and material means. The production processes can often be realized in different ways, meaning that there is a possibility of designing several variants of production processes. Modelling and simulation give the possibility of verifying these variants (Fig. 1) and make it easier to choose the best one, according to the assumed criteria.

2. Model of the production system

2.1. The conditions and the model of production system

Development of productivity of enterprises requires making the initiation, creation, and extension of cooperative links among enterprises easier. Drawing on the work of Moller, Rajala and Svahn (2005), we suggest that the key issues in managing strategic networks fall within four interrelated levels (Phases I-IV in Fig. 1). Development of methods and ways of data exchange in production enables creation of computer systems aiding in production (Moczała, 2007). Many enterprises create such a value out of cooperation which enables them to gain bigger effects of synergy. The phenomenon of synergy, known well in the past, was used to mean "*a state where the whole is bigger than the total sum of its elements*". The basis for synergy is the creative role of a human, especially in finding the optimal combination of elements of organizational processes.

The main area, where synergy effect appears, is organizational structure and its rules of cooperation, involving work division in the organization. A model of functioning of computer integrated cooperative enterprise, which would be similar to the most modern organizational form, is being created (Fig. 1). This modern form means creating functionally distributed enterprises, called virtual

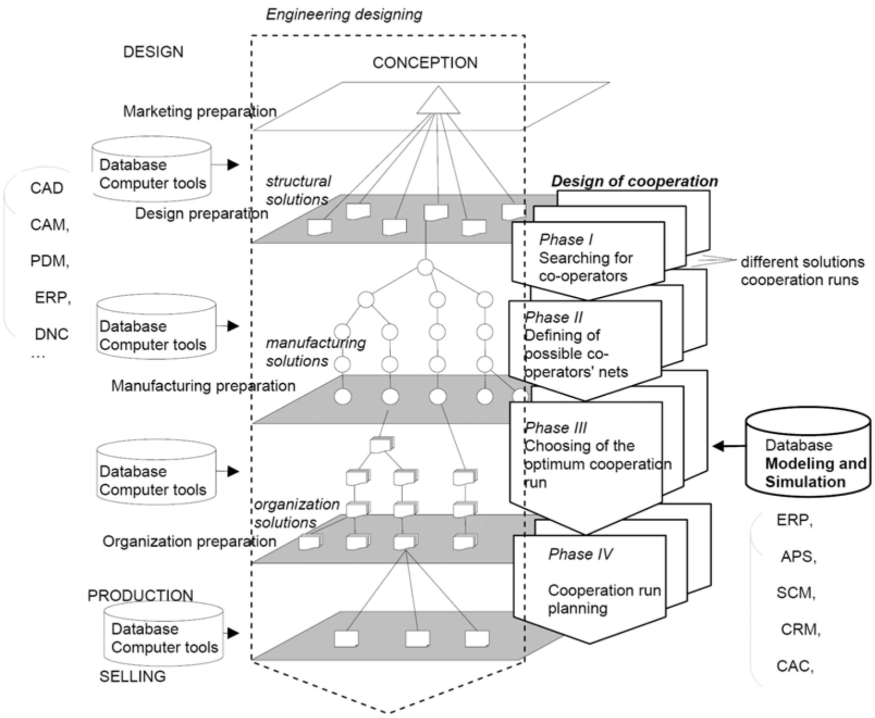

Figure 1. Model of the production system

enterprises. Membership in the organization does not require any civil law agreements. The nature of relationship is established by each member (Zaidat, Boucher and Vincent 2005).

Organization of the logistic chain is strictly connected with computer technology, which is used in the enterprise. The complex enterprise computer systems developed currently are systems of ERP class (Enterprise Resource Planning), defined as sets of integrated software packages, which can offer coherent information flow in the enterprise (Wang, Shen and Xie, 2001). In the area of production, the CAD, PDM, placeCAM and DNC systems work, integrated with the former. Other systems, which are being developed nowadays, are the systems of Supply Chain Management (SCM) and Customer Relationship Management (CRM). These systems integrate the activities among business partners on the strategic, tactical and operational levels and function in integrated chains within the framework of one enterprise on the account of lack of adaptation to changes in chains consisting of independent partners (Moczała, 2007).

2.2. Design of cooperation: defining the co-operators nets

Well realised process of selection is the key to matching co-operators with respective resources, material possibilities, appropriate technologies and well trained staff, compared, in particular, with the order design, guaranteeing achievement of synergic effect and product position on the market. Cooperation design process in the presented aspect can be seen as consisting of four phases, as shown in Fig. 1.

The here discussed problem of cooperation design requires consideration of production design and flow to be broadened with the issue of determination and optimization of organizational structures of labour flow for sets of enterprises. Determining of the optimum production process in cooperation requires multi-criterion evaluation of the variants of cooperation process – production process route in the subset of enterprises. Searching for the solution of the issue is regarded as an NP hard problem.

To make the problem and the respective approach more general, it is reduced to answering the following questions:

- Phase I - do the enterprises which can compete in realization of a certain project exist?
- Phase II - which of these enterprises are able to create the nets, which would have free resources for order realization?
- Phase III - which of these nets of co-operators are able to create optimum production process?
- Phase IV - how to organize and control the cooperative run of production in the net?

Given the lack of earlier information, reaction to coming information, its reception and elaboration of the correct answer take time and as a result the sum of these delays gives information delays in cooperative production process.

Phases of cooperation design – defining the networks of possible co-operators – are described in Moczała (2006). In phase II of cooperative production design, among the potential co-operators there arises a need of finding solutions concerning the free resources, which would guarantee realization of an order in the assumed time, according to the assumed cost and accepted level of quality. Generally, the problem of resource engagement can be solved by:

– a simple communication with an answer about the possibility of order realization, including the need to administer specialized technology and resources, and setting the price conditions; after this, the asked person analyses the order and sends back the answer; then, potential variants of nets are created, which are composed of resources of the chosen sub-composition of enterprises; the basic disadvantage of this traditional procedure is high time consumption of the activities;

– the method based on the computer system of browsing the space of potential solutions, taking into account possibilities of access to production capability, with time limitations considered; the method requires knowing the state of resources engagement of potential collaborators during the whole planning period.

The advantage of using the procedures of browsing with computer aid is the instant output from the analysis. Use of the method of browsing the initial solutions (coming from phase I) consists in balancing the requirements of order realization with possibilities of the analyzed enterprise (Boucher, Bonjour and Grabot, 2007).

Determining of the optimum production process in cooperation (phase III) requires multi-criterion evaluation of the variants of cooperation process - production process route in the subset of collaborative enterprises. The method allows for proposing a solution, which would be the most advantageous when it comes to time or cost of order realization. What is left is the problem of the choice of the best one from the point of view of the commissioning entity and of defining the notion of the best cooperative solution for production.

3. Modelling and simulation in managing of production processes

Production, in general, is not realized with any method, but is carefully planned with special regard to effective use of resources. Modelling and simulation become substantial methods aiding in logistic chain management (Rose, Robin and Girard, 2007).

Efficient analysis of the logistic system functioning requires fulfilment of two conditions:

– collecting and applying information on the realized production process,
– availability of theory and technique assuring the obtainment of an optimum state.

Before analysis, it is necessary to define input parameters of the analysed system, as well as output parameters. Then, an evaluation of the analysed system can be established. Two cases may occur. In the first one, for the assumptions made as to input parameters, simulation is conducted of the system maintenance. In the second one, where different collections of output data exist, there is a problem of finding the optimum to manufacture products with best parameters from the point of view of the assumed criteria. It is difficult to find the optimum solution. Proper planning of particular stages of experimental study, finding of possible variants of solutions and, first of all, proper settlement of evaluation criteria are necessary.

Modelling of cooperation process is mainly based on a static database, i.e. information registered in the data system of the company. This information, e.g. norms of transport and operation time, material norms, information about resources at disposal, costs, etc., are seldom updated. The changes, which occur nowadays and will occur in the nearest future, are not often taken into account.

Using modelling and simulation, we can analyse the effects of changes which are to occur.

Elaboration and implementation of the procedures of ongoing analyses of the production system form the basis for creating dynamic knowledge bases. In such a base there will be currently registered all the present and predicted changes, and information about the effects of production activities, carried out under different production conditions. Owing to this, current analysis of time use, costs and quality, taking the different dynamic changes of working conditions of the company into account, will be possible, see Fig. 2.

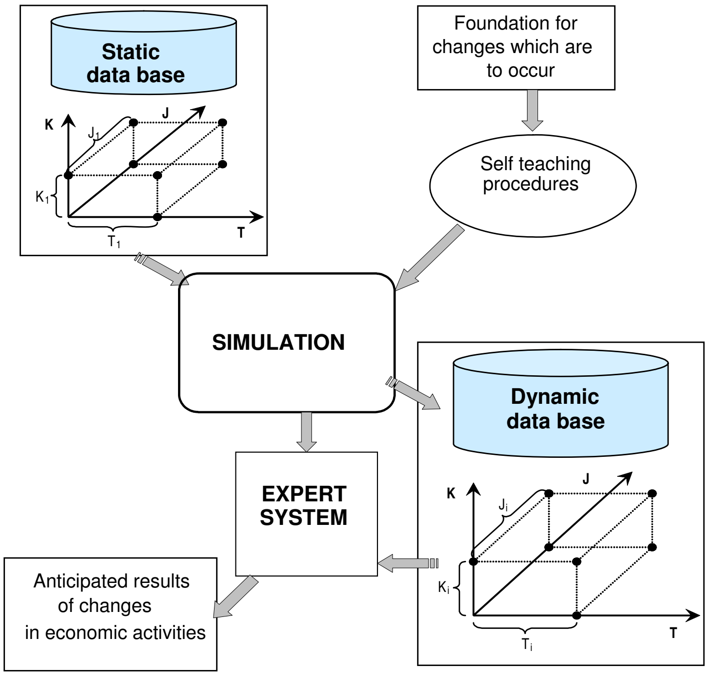

Figure 2. Process of anticipation of changes in economic activities of a self-teaching system

Modelling and simulation are universal techniques, finding increasingly wide usage in the enterprises. They are more and more important in aiding to design new cooperation processes, and also aiding in their management. They make possible tracing of production functioning and detection of bottlenecks. Tracing of effects of proposed changes is made possible, too. Selection of the best variant is made easier. Not only manufacturing process, but also supply and sale processes can be taken into account.

Simulation experiments derived from the model were created on the basis of a single, dynamic, optimal, and sequential plan, Fig. 3 (Matuszek, Kukla and Plinta, 2006; Plinta, 2007). The hierarchy of the examined factors should be described according to their influence on the output value. The sequence of examined factors can be set as follows:

X_1 – choice of the schedule variant of production,
X_2 – choice of the way of supplying production line with raw materials,
X_3 – choice of the way of selling products.

If at least one product out of a certain number ends after the set time limit or self-costs exceed the set cost level, the proposed production variant is not accepted.

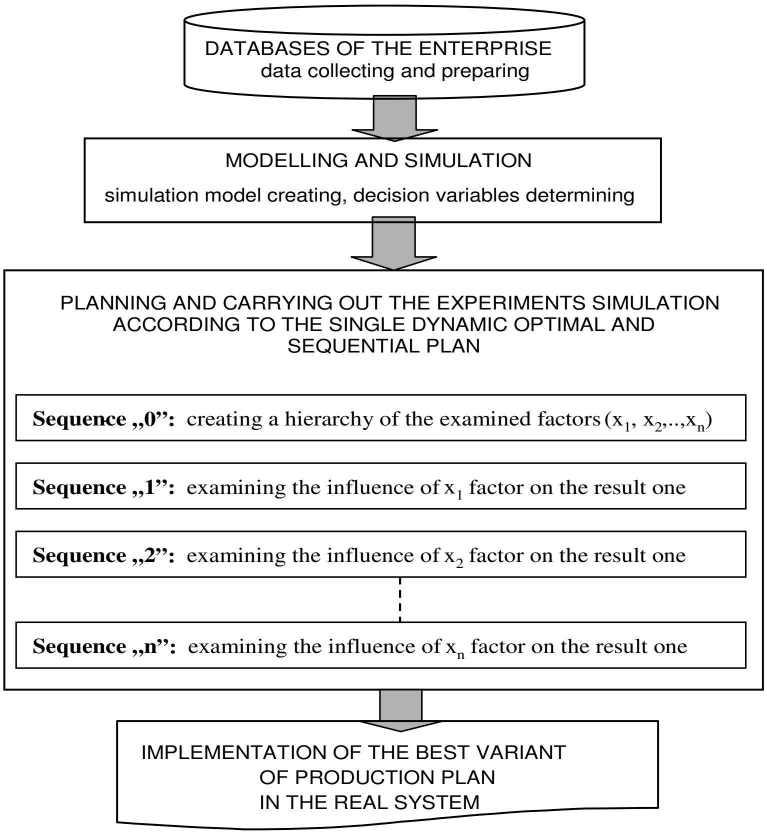

Figure 3. Modelling and simulation, an efficient tool aiding in management of production

4. Choice of the optimal cooperation run

The choice of the optimal cooperative production scheme requires browsing through the set of potential cooperating agents from the point of view of criteria of time, cost and production quality. Solutions form the point of view of time and cost criteria, optimal in the Pareto sense, are presented in Fig. 4. Optimal solutions to the production process with cooperation design (I) with *i*-enterprise are replaced with a new optimum – solutions N1-N4 of cooperation by (N) design with participation of collaborating enterprises (or solutions O5-O6 with lower risk - probability of non-delivery). New solutions, optimal in Pareto sense, are more innovative.

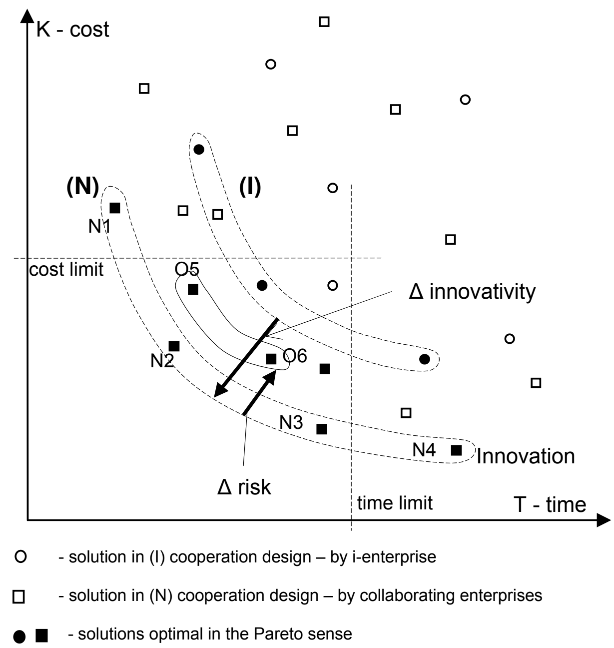

Figure 4. Optimization of the logistic chain on the basis of Pareto analysis (variants from analysed production system bellow)

The choice of unequivocally optimal cooperative production run is more difficult, as we are looking for a solution, which is optimal from the point of view of many criteria. We need a method that would allow for carrying out a multi-criteria optimization with respect to time, cost and quality of order realization, as well as taking into account the estimated risk of failure in fulfilling the requirements by a given variant of the network of cooperating enterprises (Moczala, 2007).

4.1. Utility evaluation

The problem of finding the optimal decision is a mathematical optimization problem. The method, which provides single evaluation with different criteria, is utility analysis of projects of the course of production cooperation process. Utility evaluation should take place continuously in the course of design after phase II, which was finalized by setting the network variants of the course of cooperation process (production process of VE).

A utility function rationalizes a preference relation. In order to simplify calculations, various assumptions have been made of utility functions. In respect to the basic criteria in production of time, cost and quality, the model of the course of cooperative production process, subject to the proposed optimization approach, has a structure described by the graph (Fig. 5):

$$G_N = V_N, L_N \tag{1}$$

where:

$V_N = \{v_i; i = 0, 1, ..., N\}$ – set of nodes,

$L_N = \{l_{ij}; i = 0, 1, ..., N-1; j = 1, 2, ..., N\}$ – set of edges.

Each node of the graph may be associated with an event, which begins or ends a task of cooperative production process, and an edge represents the task itself. Each task (activity) may be attributed with:

- t_{ij} – time of realization of task i, j
- $k_{ij}(t_{ij})$ – function interpreted as the cost of activity realization l_{ij} with time of realization t_{ij}.

It is assumed that $\{0 \leq a_{ij} \leq t_{ij} \leq b_{ij}\}$, where b_{ij} may be called normal time, and a_{ij} — emergency time, which means that realization with shorter time may cause wrong designing of the process. Moreover, t_{ij} may take only integer values.

Each activity (production task) is connected with the value q_{ij}, explicitly presenting the gained quality, usually gained accuracy class, the number of faults (faulty products) and even more parameters – a vector of quality.

Events, which start or end the tasks of production process, and are nodes of a graph, v_i, may be analyzed similarly as in Matuszek, Moczała and Kosturiak (1998), and we can attribute to them the following collections of functions, corresponding to time, quality and cost:

$$T^n_{s_n} = \max\left(T^{n-1}_{s_{n-1}} + t_{n-1,n}, ..., T^1_{s_1} + t_{1n}, t_{0n}\right) \tag{2}$$

$$Q^n_{s_n} = \max\left(Q^{n-1}_{s_{n-1}} + q_{n-1,n}, ..., Q^1_{s_1} + q_{1n}, q_{0n}\right) \tag{3}$$

$$K^n_{s_n} = \left(K^{n-1}_{s_{n-1}} + k_{n-1,n} + k_{n-2,n} + ... + k_{1n} + k_{0n}\right) \tag{4}$$

The values $T^n_{s_n}$, $Q^n_{s_n}$, $K^n_{s_n}$ are the basic parameters, determining the optimality of the cooperative production process, with the required quality ensured by the

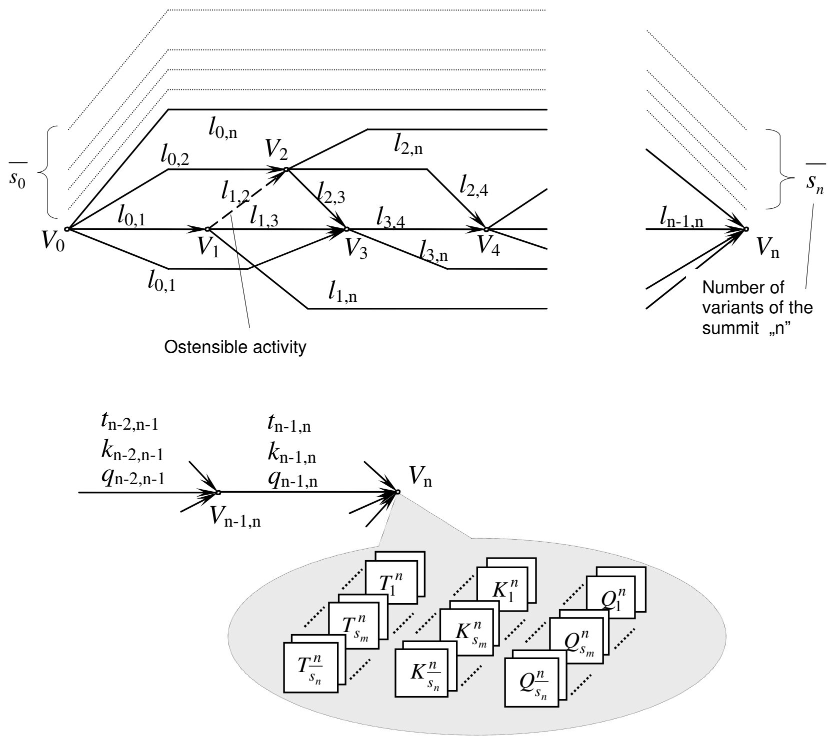

Figure 5. A graph of the cooperative production process

admissibility condition. The choice of the variant of the course of production cooperation process may be done by estimating the *utility function*, which links the basic criteria of cost, time and quality. In case one of the factors (K, T, Q) appears to be a stronger limiting one, we can introduce explicit weights α, β, γ for factors into the utility function.

Taking into account risk, i.e. probability w_n of non-delivery, the utility function can be formulated as follows:

$$U_N\left(\lambda\,{}^{N}_{s_N}\max\right) = \underset{\lambda^n_{s_n}}{\mathrm{MAX}} \sum_{n=1}^{N} w_n \left(T^n_{\bar{s}_n} - T^n_s\right)^{\alpha} \left(K^n_0 - K^n_{s_n}\right)^{\beta} \left(Q^n_{s_q} - Q^n_{s_n}\right)^{\gamma} \quad (5)$$

where $\alpha + \beta + \gamma = \Omega, \Omega$ being a constant; for $n = 0$, function $U_0 = 0$.

For the criterion of quality optimized by the *admissibility condition* (see Moczała, 2007) the thus defined utility function may be reduced to the form:

$$U_N\left(\lambda_{s_N}^N \ \max\right) = \underset{\lambda_{s_n}^n}{MAX} \sum_{n=1}^{N} w_n \left(T_{\bar{s}_n}^n - T_s^n\right)^{\alpha} \left(K_0^n - K_{s_n}^n\right)^{\beta}. \tag{6}$$

In the reduced form, without consideration of the probability of non-delivery, *wn*, the form of the function is described by Matuszek, Moczała and Kosturiak (1998), where the course of the project is optimized only with respect to two factors: cost and time of realization.

The admissible process realization (N, s_N), fulfilling the assumption expressed by (6), may be called optimal. This brings together two approaches to optimization of production process design according to the quality criterion (or admissibility condition):

1) minimization of realization time with the assumed limit of production means,
2) minimization of total cost of project realization within the assumed termination date.

When there is certainty of carrying out the design according to the assumed structure up to the final node, it is possible to simplify the utility function, omitting the sign of a sum and probability w_n in formula (5), i.e. taking into account only the parameters of the final node. In the case when the values of variables attributed to particular tasks are known, it is possible to analyse and evaluate solutions for the cooperation process by means of utility function. This method gives a deterministic evaluation of particular criteria. Implementation of the above described method of search for the optimal solution for production design requires access to databases of collaborating enterprises.

5. Example of modelling and simulation of the logistic system

In the analysed system office furniture is produced: a two-part office wardrobe with shift door and a desk with a cabinet on wheels.

The aim of the realized analyses was to test the present system functioning and the different possibilities of development.

The following assumptions were made:

- time of realization of production (1 month),
- planned volume of production (600 pieces),
- demand for particular materials was defined,
- distances between suppliers and the firm were specified as well as the distance between firm and recipients (wholesalers and shops),
- the mode of transport, times of transport and the unit cost (per km),

– potential firms were situated in the places, with which cooperation could be realized (preparation of materials and assembly),
– parameters of simulation were defined (time of cycle e.g. week or month, and the number of cycles).

Table 1 contains the description of variants of simulation models. The production process was analysed and different programmes of production were compared. For different variants (see Fig. 4) the resource availability and costs of production were compared. In the analysed case, factors (K, T) were standardised to the interval 0-1 and we arbitrarily introduced weights α, β into the utility function. The values of weights were assessed by the experts and in the same way the probability of non-delivery, w_n, was established. In consecutive simulation models selected operations (cutting of panels, assembly) were realized in cooperation. A shorter time of production process realization was achieved for variant N1, lower cost of production for variant N4 and lower risk - probability of non-delivery - for variant O6 (see Fig. 4 and Table 1).

Table 1. Variants of simulation models (Matuszek, Kukla and Plinta, 2006)

Variant	Description
1	The whole process is realized within the company - all materials are compiled and processed in the company. Assembled wardrobes and desks are sent to wholesalers and shops.
2	Furniture panels and fibreboards will be purchased after they are cut to suitable dimensions, directly from the supplier.
3	Cooperation was established with the company veneering the edges of furniture panels.
4	Assembly workplaces were liquidated and prepared elements are assembled directly at the customers.
5	Cooperation was established with the company which assemblies desks and wardrobes.
6	Production process was improved by partly cooperation (increase of production efficiency was accepted at the level of about 10% level for checking the capacity of distribution network of finished articles).

Results from the simulation made comparing different variants of proposed changes in the analysed production system possible. They were compared from the point of view of time and cost of order realization. The best results were achieved in variant 6 (see Fig. 6 and Table 2).

The production resources at disposal make possible production increase by about 10% without any necessity of additional financial expenditure.

In Fig. 6 the variants of simulation model with two cooperating firms is introduced: the firm which cuts and veneers panels and the firm which assemblies parts compiled in exemplary firm. This simulation model was implemented in ARENA software.

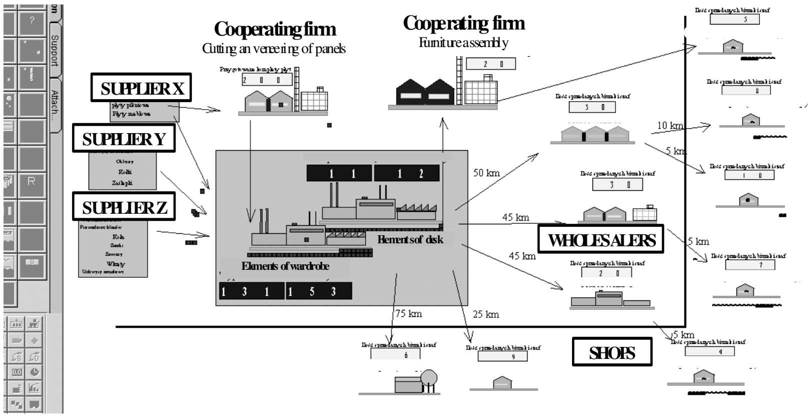

Figure 6. Simulation model

Table 2. Part of simulation report for variant 6

SIMULATION REPORT – Variant 6	
Desk	256 (quantity of produced desks)
Wardrobe	300 (quantity of produced wardrobes)
Shop 1	19 (quantity of sold furniture)
Shop 2	14 (quantity of sold furniture)
Shop 3	21 (quantity of sold furniture)
Shop 4	27 (quantity of sold furniture)
Shop 5	16 (quantity of sold furniture)
Shop 6	12 (quantity of sold furniture)
Shop 7	15 (quantity of sold furniture)
Wholesaler1	14 (quantity of sold furniture)
Wholesaler2	14 (quantity of sold furniture)
Wholesaler3	11 (quantity of sold furniture)
Panel preparation	80 (quantity of panels prepared in cooperation)
Assembly cooperation	10 (quantity of furniture assembled in cooperation)
UTILITY OF PRODUCTION 0.675	

Owing to the work with the simulation model:

– production capabilities of the present system were checked and the influence of proposed changes on production capability of the company, costs of materials, manufacturing, transportation and cooperation was assessed,
– different directions of company development in the domains of supply and sales were compared,
– a simulation model was developed, which can be used to manage production process (for testing possibility of realizing different production orders).

6. Conclusions

The research reported in this paper focuses on the development of simulation technique to partnership design in formation of production cooperation. In this new approach we have adopted *utility function*, linking the basic criteria of cost, time and quality. In the case when the values of variables attributed to particular tasks are known, it is possible to carry out analysis and evaluation of solutions of cooperation process works by means of utility function. This method gives a deterministic evaluation of the given values of particular criteria. Modelling and simulation are a universal technique, finding increasingly wide use in enterprises. Their importance, as a technique aiding in design of new production systems and production management, increases. Thereby, tracing the production functioning and detection of weak points becomes possible, similarly as tracing of effects of the proposed changes. The choice of the best variant of solution is made easier. Simulation can be also used for management of production processes, as a tool for checking the possibility of realizing different production orders for different available resources, taking into account not only manufacturing itself, but also supply and sale processes. Building of such a complex model can be approached in two ways: by creating a generalized model of the whole system or by extending particular subsystems. On the other hand, it is possible to create models of definite subsystems, to be later joined into one. The disadvantage of modelling of such complex production systems is that it requires a lot of work. Then, however, it becomes easy to make different changes in the model - to create different variants of the analysed production system. Verification of different variants and selection of the proper one can bring significant advantages for the company.

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