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Simulation Model of the Effects of Computerization on the Manufacturing Firm

A manufacturing firm is a complex and dynamic system, which efficiency is measured by system response on market demands **(T)** *and the entire business effectiveness* **(E)**. *Modern information technology (IT) should have a positive effect on these two functions, but it is difficult to determine the value and mode of that influence in advance. Regularities in form* $\mathbf{T=f_1(X_i)}$ *and* $\mathbf{E=f_2(X_i)}$, *describing the effects of implementation new IT in certain business areas on the efficiency of the firm as the whole, are described in this study. These regularities are established on the basis of data resulting from multifactorial experiments in form* $\mathbf{2^{p-k}}$, *carried out on the simulation model of the manufacturing firm. A developed mathematical model is applicable in strategic planning of information system. The results of the research are compared with the results of empirical researches, carried out by several other authors.*

Key words: effectiveness, factorial design of experiments, manufacturing, information technology, modeling, simulation, response function.

1. Definition of the problem

A manufacturing firm can survive in the extremely dinamic modern market only if it offers high quality products and services, together with the constant rise in its entire business efficiency. Manufacturing firms that have a good information system better adjust themselves to the dynamic changes in their environment. Development of a new and improvement of the existing information system is indeed a continuous activity in any firm, whose business goals and strategy change in time, due to the influence of its surroundings. Activities developing the information system are, therefore, executed in a series of linked projects, that introduce new information technology (IT) in various departments of the firm.

A great number of solutions for successful aplication of IT to specific areas of a firm has been described in references. Owing to such solutions, certain measurable effects have been achieved. They are usually expressed in particular indicators, such as: decreasing in stock of manufactured goods or raw-materials, increasing in flow-rate of orders through the workshop, faster delivery and invoicing of delivered goods, etc. A manufacturing firm is, however, a complex and dynamic structure, consisting of a great number of mutually interlinked manufacturing and business subsystems. That's why, although the partial effects of new information technology on one subsystem (of a firm) may be known, it may not always be possible to define directly and precisely its final effect on the rise in efficiency of a firm as a whole. Entire activity of a company proceed in a series of interlinked manufacturing and business activities, so that the effects achieved in one of them, may be lessened or intensified by the processes in other business departments.

Dynamics of complex systems suggest also the possibility of another phenomenon: if new information technology is introduced into several business areas at once, some partial effects may be in interaction so that the value of the final effect is the result of their positive (or negative) synergism.

Due to these reasons, in the stage of designing an information system, it is almost impossible to estimate the expected results of introducing new information technology into a firm as a whole, although its partial effects on one business process can be calculated (or estimated on the basis of experience) with satisfying accuracy.

Contrary to the already mentioned difficulties, the logic of undertaking requires for each investment into new information technology (as well as for any other investment) a precise answer to the question: **what final effect on the efficiency of a firm as a whole can be expected after the implementation of new information technology into one or several departments of the firm**? Complete solution of this problem has not yet been found, so that the achieved positive effect is most often expressed indirectly, following the analysis of business success for a longer period of time, during which new information technology had been introduced.

2. General simulation model of a manufacturing firm

A completely new approach to the previously mentioned problem is given in the following study. It's preliminary idea is that it is possible to build an adequate simulation model for the manufacturing company, that faithfully represents the internal structure and processes occuring in the observed system, as well as stochastic influence of its surrounding (market, competition, accidental interference etc.) that may influence the system..Keeping this in mind, it is possible to perform a sufficient number of simulation experiments on the model, spend an acceptable amount of time and computer resources. Starting from predictable partial effects of implementation of new information technology into every single process, this method enables us to establish its general effect on the entire business system, including the interactions of these partial effects.

An appropriate simulation model was developed in one former study (Brumec, 1990.) , in which the way of development of the simulation model, its detailed internal structure and evaluation procedure were described. For this reason, the main characteristics of that model will only briefly be mentioned in this study.

This model represents the manufacturing system with so-called "intermittent manufacture of standard products"(IMPS); in other words it represents manufacturing, technological and business system, that is still mostly used in different industries. Basic characteristics of this type of production and business system are given in Table I.

Table I: Basic characteristics of IMPS

Parameter	Basic characteristics
Range of manufacturing program	- A group of similar products in standardized variants
Tecnical documentation (drawings, bill of materials, manufacturing routings)	- Made in advance - Prepared for repeated usage - Modular and detailed
Manufacturing subsystem	- Composed of individual machines - Organized according to the similarity of treatment
Leading point of management	- Gathered or estimated demand for a specific planned period
Primary goals of management	- Decrease in delay and increase in certainty of dispatch - Increase in efficiency of a system as a whole

The developed simulation model is structured as it is shown in ***picture1***. It is com- posed of 10 submodels, marked with numbers 1-10, representing the subsystems, among which functional links or flows are established. These flows are not homogenous, but can be classified in 3 different types:

- flow of row-materials **M**,
- flow of orders **O** and
- flow of informations **I**.

The relations and links are marked with indices $_i$ and $_j$ (where $_i$ is the number of input and $_j$ of the output subsystem), and represent a group of data (vectors), whose elements describe the existing relation in as much detail, as it is necessary for the description of the algorithm of interactions among subsystems. For example: order for the manufacturing of parts $\mathbf{O}_{6,2}$ is described with vector consisting of 4 data: quantity of manufacturing parts, production time, requested delivery time and order number. Each subsystem $\mathbf{S}_i$ transforms the input to the output data. It can be simbolically described as:

$$S_i:\left(M_{i,j}, N_{i,j}, I_{i,j}\right) \Rightarrow t_i \Rightarrow \left(M_{k,i}, N_{k,i}, I_{k,i}\right) \qquad (1)$$

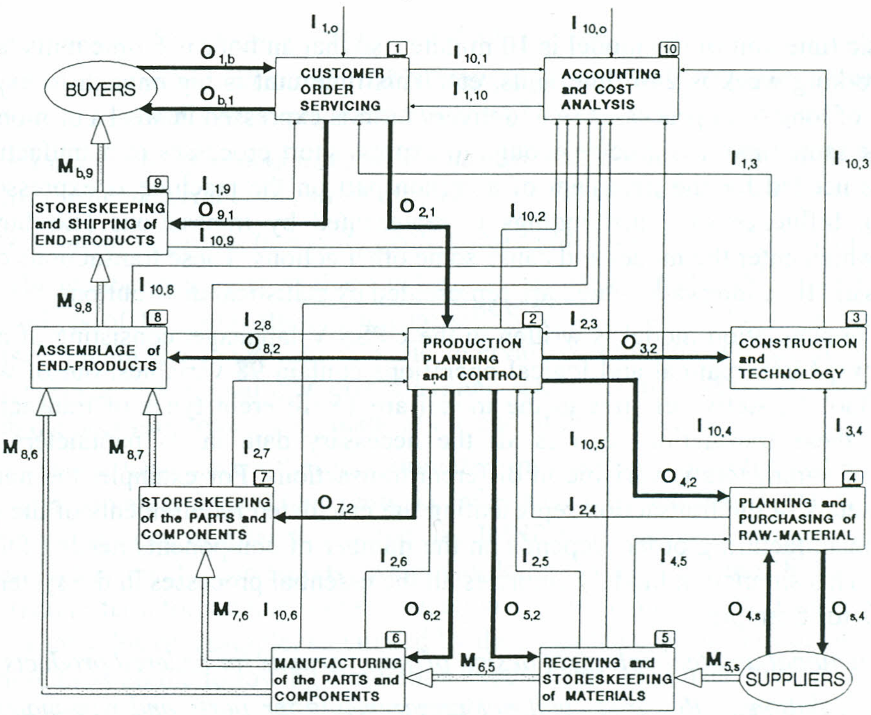
This term has the following meaning: subsystem $\mathbf{S}_i$ transforms the input flows of raw-material $\mathbf{M}_{i,j}$, orders $\mathbf{O}_{i,j}$ and informations $\mathbf{I}_{i,j}$ into output flow of raw-materials, $\mathbf{M}_{k,i}$, orders $\mathbf{O}_{k,i}$ and informations $\mathbf{I}_{k,i}$. For such transformation time $\mathbf{t}_i$ is needed, which can have several components. Number of the input and output vectors is, in generally, different, and they are also differentiated among themselves by the number of data symbolizing their characteristics. This model enables us to establish the algorithm of functioning for every subsystem (i.e. transformation process from input into output), to define the internal state and to describe the relation of the observed subsystem with all the others.

Time flow is one of the most important parameters in any manufacturing system. Therefore, it is adequately represented in this model in 3 ways:

a) Duration of the particular activities, for example time needed for the development of a new product, assembly time for the product, time for requirements planning, etc.

b) Time between two successive iterative actions. For example, the procedure of ordering can be renewed once a week, launching of the components in the workshop can be done every other day etc. During this time no production resources are spent.

c) Time generated within the system itself, e.g. a standstill due to the waiting queues.



FLOW of MATERIALS, PARTS and PRODUCTS	FLOW of INFORMATIONS
$M_{5,s}$ Delivery of raw material	$I_{1,o}$ Forecast of demand
$M_{6,5}$ Issuing of materials in workshop	$I_{1,3}$ Technical characteristics of end-product
$M_{7,6}$ Parts and components for store	$I_{1,9}$ Stock of end-products
$M_{8,6}$ Delivery of manufactured parts	$I_{1,10}$ Price of end-product
$M_{8,7}$ Issuing of stored parts	$I_{2,3}$ Drawings, bill of materials and mnfg. routings
$M_{9,8}$ Delivery of assembled products	$I_{2,4}$ Open orders for purchasing
$M_{b,9}$ Delivery of end-products	$I_{2,5}$ Stock of raw-materials and components
	$I_{2,6}$ Finished manufacturing orders
FLOW of ORDERS	$I_{2,7}$ Stock of manufactured parts
	$I_{2,8}$ Finished assemblage orders
$O_{1,b}$ Customer's order	$I_{3,4}$ Commercial characteristics of raw-materials
$O_{2,1}$ Order for production	$I_{4,5}$ Receiving report
$O_{3,2}$ Order for design a new product	$I_{10,1}$ Accounts receivable
$O_{4,2}$ Order for purchasing a raw-material	$I_{10,2}$ Report about finished production series
$O_{5,2}$ Requisition for material	$I_{10,3}$ Technical specifications for pricing
$O_{6,2}$ Manufacturing order	$I_{10,4}$ Accounts payable
$O_{7,2}$ Requisition for parts and components	$I_{10,5}$ Quantity and value of received materials
$O_{8,2}$ Order for assemblage	$I_{10,6}$ Work spend on each mnfg. order
$O_{9,1}$ Order for delivery requested products	$I_{10,7}$ Transactions for parts and components
$O_{b,1}$ Invoice to customer	$I_{10,8}$ Work spend on each assemblage order
$O_{s,4}$ Order to supplier	$I_{10,9}$ Transactions for end-products
$O_{4,s}$ Supplier's invoice	$I_{10,o}$ Accounting rules

Picture 1: General Model of IMPS

Basic time unit of the model is 10 minutes, so that an hour is 6 time units, a day is 48, working week is 240 time units, etc. This time unit is big enough to express duration of long-term processes (e.g. delivery term is expressed in weeks or months), but at the same time it is precise enough to express short processes in manufacturing (ex. time needed for the treatment of a certain part on the machine is expressed in minutes). Influence of surroundings is represented by transactions (ex. buyer's orders) which enter the model and cause some other actions. These transactions occur at stochastic time intervals, which are represented by statistical distributions.

1. The simulation model is written in the GPSS V language, consisting of about 550 blocks. Mathematical and logical operations contain 98 variables, out of which 12 are Boole's. Active entities in the model are 15 different types of transactions. Each of these transactions carries all the necessary data in its parameters. The number of parameters is variable in different transactions. For example, the number of parameters in the transaction representing the calculated requirements of the parts for one manufacturing order, depends on the number of components needed for that product. This simulation model comprises all the essential processes in the system for IMPS, as for example:

- *functional and technological design of new variants for ordered products;*
- *calculation of the gross and net requirements for parts and raw-materials, with taking into consideration the time surplus for production phases, as well as integration of the requirements according to their lead-time, no matter out of which input orders these requirements come;*
- *launching of the components into production process, with simulation of the entire technological flow for components and their assemblage on available production resources;*
- *statement of production costs, control of stocks, calculation of profits, etc.*

Input data for simulation are data about products, components and raw-materials used in the production system, bill of materials, manufacturing routings and procedures, machines, work places, stockhouse capacity, etc. This data are included in the model through a great number of related matrices. All processes at the entrance into the model and within it are expressed temporarily and evaluated through 35 different indicators, some of which are:

- *number and frequency of coming in orders from buyers,*
- *number of launched orders for manufacturing of components and assemblage of end-products,*

• *utilization level of production resources,*

• *the mean value and standard deviation of processing time for one order inside the system (T_p), and system response function (T),*

• *total costs of production, with analysis made for specific types (ex. work expenses, raw-material costs, stock expenses, purchasing expenses etc.),*

• *economy of production and effectiveness of the company as a whole, etc.*

The number of indicators that can be observed is practically unlimited. Using the possibilities of the simulation language GPSS V, a great number of measurement points is put in the model. At specific intervals of time, the values of interesting phenomena are taken, and memorized as time-series into the matrix of results, out of which the necessary reports are made at the end of the simulation.

First test have shown that the simulation model comes into the stationary state after approximately 30,000 time units, i.e. after a little bit less than 3 year functioning of the real system, or after the system for IMSP fulfils about 150 received buyer's orders. This result correspods with Gordon's study (Gordon,1978), Tocher's empirical criteria for simulation of production systems (Tocher,1963), as well as with significant value of a sample, calculated by the so-called central-limit theorem. Based on these facts all the following simulation experiments were made for 5,5 work-years of the real system for IMPS (i.e. 68,640 time units in the model). During the treatment of the results of simulation (in order to define the regularity of behaviour of the real system on the basis of the behaviour of its model) only the results of the simulation for the last 2.5 years were taken into consideration, while the results of the simulation for the begining period of 3 years were eliminated from the calculations, because they are considered to be the results of insufficiently stabilized process. One simulation experiment takes about 12 minutes of CPU-time on IBM 4381.

3. Verification of accuracy of the model

Accuracy of the model is tested by comparing the results of the simulation, with the data from the past of a real system (Electrical transformers factory of "KONČAR" company, Zagreb), of which starting data are put into the model. The test was done on two statistical variables $\mathbf{T_p}$ and **T**, defined on the following way:

• $\mathbf{T_p}$ is a random variable, representing the time of processing of one order through the firm. It is calculated as the difference between the time of entering of one order into the system and the time of delivery of required goods to the customer.

• **T** is a random variable of difference in time between the requested delivery term and realised delivery term. It can conditionally be explained as "system response" to an order, which is considered as an external impulse.

It was possible to approximate the distribution of measured and simulated values of the variable $\mathbf{T_p}$ to the normal distribution, so that the correspodence between these two values was verified by the standard statistical tests:

t-test for arithmetical mean values,

$\mathbf{H}^2$ (Chi-square)-test for frequencies and

F-test for variances.

Distribution of measured and simulated values for the variable **T** could not be approximated by the normal distribution. Because of that, the validation of the model was done by a nonparametric Mann-Whitney test of means (Shanon,1975).

Correspodence between the measured and simulated values of $\mathbf{T_p}$ and **T**, when the input orders from the customers and internal manufacturing capacity are variable in time, was tested by comparing these values as two time-series. The calculated coefficient of correlation is within $0{,}475 \leq r \leq 0{,}832$, what was estimated as satisfactory.

The tests made have shown that the developed simulation model adequately represents the real production and business system of which data are entered in the model as the parameters of the simulation. *Conclusions about the future behaviour of the real system* (working under the influence of variable external as well as internal factors) *can, therefore, be reached on the basis of an analysis of behaviour of its simulation model.* If the information technology, introduced into various manufacturing and business processes, will be treated as an set of independent variables, it could be possible to define its influence on the behaviour of the manufacturing firm, *on the basis of sufficient number of simulation experiments.*

4. Criteria for estimating an influence of IT on the manufacturing firm

All activities in the system, connected with the execution of received orders (as e.g. acquisition of raw-materials, manufacturing of components and assemblage of end-products) are planned in such a way to meet the requested delivery time. However, because of uncontrollable disturbances (e.g. delay in the acquisition of raw-materials, malfunction of production resources, disagreement between the real and planned time, waiting queues in front of production machines, etc.) as well as the characteristics of the system itself (e.g. production planning or launching of manufacturing orders does not proceed continually but in cycles), the disagreement between the demanded and real delivery time can occur.

Every firm tries to make the above mentioned disagreement as small as possible, because every delay causes reduction in profit, but also the loss of the good reputation on the market. With regard to that demand it would be best to organize the production and business activities in such a way, that there is a sufficient stock of products for urgent orders, or sufficient raw-materials and production capacity reserves (for the manufacturing, if there is not enough products in the stock) to avoid any delay despite unpredictable disturbances. This management strategy would result in better system response, but would also make the production more expensive and reduce the effectiveness of the firm.

It can generally be said, that the request for decrease in response-time and increase in the effectivness are in contradiction. The preliminary idea of this study is that an optimal solution for these contradictory demands is possible, but it depends about a lot of internal and external factors. Therefore, as criteria for the evaluation of the entire quality of management in a manufacturing firm, the following variables are chosen:

- ***system-response time*** **T** (as defined in previous chapter) and

- ***efectiveness of the firm*** **E**, defined as the ratio between total income and total expenses in the firm, during a certain period of time (e.g. one year).

Management strategy for the company can be briefly explained as finding such relations between relevant factors, that in every moment give the minimum value of the statistical variable **T**, with the maximum value of the response-function **E**. It has been supposed that more successful management strategy, in permanently variable business environment, will be achieved in the company, that has a better information system.

Information technology is an important factor for good information system. The goal of this research is therefore, to define the functional relations by which the information technology influences the effectiveness of manufacturing company and system response-time. Entities **T** and **E** will in the further text be considered functions, whose values depend on the level of information technology, implemented in different business areas of manufacturing firm.

5. Selection of independent variables and the strategy of the research

Partial effect of information techology in certain areas of a manufacturing firm was described in numerous references (e.g. Borges,1985 and Kleindorfer,1985), but the algorithm for calculation of their expected contribution to the reduction in response-time of the system **T** and the rise in the entire effectiveness of the firm **E** have never been developed. Therefore the goal of this research is to establish the functional pattern:

$$T = f(X_i) \text{ and } E = f(X_i) \qquad (2)$$

In the above defined expressions $\mathbf{X_i}$ is a set of independent variables, representing the influence of the information technology on certain business areas of the firm. **T** and **E** are the functions describing statistical distribution of system response-time and its effectiveness, which must satisfy next goal conditions:

$$T \Rightarrow T_{min} \text{ and } E \Rightarrow E_{max} \qquad (3)$$

A list of 11 independent variables, describing the level of the information technology implemented in different business areas of the firm, was made during the preliminary research. On the basis of opinion given by 19 experts (with a great knowledge about production processes, business and management) five variables were chosen for further research. These variables, which will be treated as independent factors, are:

$\mathbf{X_1}$ - Introduction of IT into business planning - *factor* **a**,

- $\mathbf{X_2}$ - Introduction of IT into product design and technology area - *factor* **b**,
- $\mathbf{X_3}$ - Introduction of IT into production planning and control activities-*factor* **c**,
- $\mathbf{X_4}$ - Introduction of IT into business administration of the firm - *factor* **d** and

$\mathbf{X_5}$ - Introduction of IT into production scheduling system - *factor* **e**.

As the starting research hypothesis it has been supposed that the influence of choosen factors on previously defined functions can be described with next polynomial approximations:

$$\mathbf{T} = \alpha_0 + \sum_{i=1}^{5} \alpha_i \cdot X_i + \sum_{i=1}^{4} \sum_{j=j+1}^{5} \alpha_{i,j} \cdot X_i \cdot X_j \qquad (4)$$

$$\mathbf{E} = \beta_0 + \sum_{i=1}^{5} \beta_i \cdot X_i + \sum_{i=1}^{4} \sum_{j=j+1}^{5} \beta_{i,j} \cdot X_i \cdot X_j \qquad (5)$$

We will presume that functions **T** and E in expressions *(4)* and *(5)* depend only on the main effects of five examined factors and their mutual interactions, but multiple interactions will be neglected.

To define 16 unknown coefficients in the equations *(4)* and *(5)* at least 16 data are necessary. These data will be gathered in simulation experiments. Such a strategy of simulation was chosen which enables us to gather data on the basis of fractional factorial design with all five factors at two levels. This design of experiments is known in the theory (R5) as design in form $2^{p-k} = 2^{5-1}$. In the course of simulation experiments, carrieds out on the basis of this plan, each of 5 relevant factors is posed on one of two possible levels. In this research those two levels are defined in the following way:

1. **Low level** of a certain factor, later introduced into the calculation as value (-1), is such processing of all activities in a certain business area in which modern information technology is not implemented, and all the processes are done with classical tools.

2. **High level** of the exemined factor is such work organization in which all activities proceed with the maximal support of the modern information technology. In that case we will consider that examined factor is on level **(+1)** .

On the basis of data gathered in references (Borges,1985 and Heinen,1978), expert opinions and experience of the author, duration of certain activities in different business areas was estimated for both levels of the examined factors (*Table II*).

In accordance with the theoretical explanation in (R5) $\mathbf{a}_o$, $\mathbf{a}_i$, $\mathbf{a}_{i,j}$, and $\mathbf{b}_o$, $\mathbf{b}_i$, $\mathbf{b}_{i,j}$ will be considered mathematical coefficients of regression, whose values are estimated statistically on the basis of simulation experiments results. Complete orthogonal plan would require 2^5=32 simulation experiments, carried out on the basis of the following plan:

(1) a b c d e ab ac ad ae bc bd be cd ce de abc abd abe acd ace ade bcd bce bde cde abcd abce abde acde bcde abcde *(6)*

In this expression each "word", consisting of 1 till 5 symbols, represents one simulation experiment, in which those factors that have their "letter" in a particular "word" are on the high level, while the rest of them are on the low level. The experiment in which all factors are on their low level is marked with a "word" (1).

If a "defining relation", according theoretical analysis (Kleijnen,1975) in the form

(1)= abcde *(7)*

is applied on the plan of experiments described with "sentence" (6), then a following fractional 5-factorial design of experiments can be selected:

(1) ab ac bc ad bd cd abcd ae be ce abce de abde acde bcde *(8)*

Table II: Values for two-level design of simulation experiments

Functional area - - research factor	Activities covered with common factor's group	Duration of activity (time units) level (-1)	level (+1)
X_1 =a Business planning period	a1 - Production planning period a2 - Production order release period a3 - Requirements planning period a4 - Material order release period	1040 1040 1040 240	240 240 240 96
X_2 =b Product design and construction	b1 - Customer order identification b2 - Development time per product b3 - Deviation time for technical activities	72-120, UD Dtp ED	4-8, UD Dpp/3, ED
X_3 =c Production planning and control activities	c1 - Preparing products for delivery c2 - Scheduling assembly for end-products c3 - Scheduling manufacturing components c4 - Requirements planning time c5 - Inventory control time c6 - Manufacturing order preparing time c7 - Dispatching of production orders c8 - Manufacturing order control c9 - Delay time for Mfg. orders monitoring	96-192, UD 96-192, UD 96-144, UD 144-240, UD 72, ED 144, ED 144, ND 192, ED 72, ED	4-8, UD 12-24, UD 12-24, UD 12-36, UD 12-36, UD 36, ND 24-48, UD 48, ND 24-48, UD
X_4 =d Business administration	d1 - Delivery and invoicing d2 - Production costs calculation d3 - Information delay time in accounting d4 - Preparing business letters & orders	72-144, UD 192, ND 144, ED 48, ND	6-18, UD 72-120, UD 24, ND 12-24, UD
X_5 =e Quality of production scheduling system	e1 - Assembly components in end-product e2 - Through-put factor for the workshop	Atp, ED Tpf	Atp, ND (0,6-0,8)*Tpf
Abbreviations: Dtp - Development time as defined per each end-product Atp - Assembly time as defined for each end-product Tpf - Through-put factor for workshop as the whole		UD - Uniform probability distribution ND - Normal probability distribution ED - Exponential probability distribution	

Using the properties of the “defining relation” *(7)*, it is possible to express all regression coeficients in expression *(4)* and *(5)*, estimated on the basis of the experiment plan described in the sentence *(8)*. These coefficients are:

a) coefficients of linear members of the regression polynom, describing the main effects of all 5 exemined factors, confounded with coefficients of 4-factorial inteactions i.e.:

$$a_1 \to \alpha_1 + \alpha_{2345} \qquad b_1 \to \beta_1 + \beta_{2345}$$
$$a_2 \to \alpha_2 + \alpha_{1345} \qquad b_2 \to \beta_2 + \beta_{1345}$$
$$a_3 \to \alpha_3 + \alpha_{1245} \quad \text{and} \quad b_3 \to \beta_3 + \beta_{1245} \qquad (9),\ (10)$$
$$a_4 \to \alpha_4 + \alpha_{1235} \qquad b_4 \to \beta_4 + \beta_{1235}$$
$$a_5 \to \alpha_5 + \alpha_{1234} \qquad b_5 \to \beta_5 + \beta_{1234}$$

b) coefficients of all 10 2-factorial interactions, confounded with 3-factorial interactions:

$$a_{12} \to \alpha_{12} + \alpha_{345} \qquad a_{24} \to \alpha_{24} + \alpha_{135}$$
$$a_{13} \to \alpha_{13} + \alpha_{245} \qquad a_{25} \to \alpha_{25} + \alpha_{134}$$
$$a_{14} \to \alpha_{14} + \alpha_{235} \qquad a_{34} \to \alpha_{34} + \alpha_{125} \qquad (11)$$
$$a_{15} \to \alpha_{15} + \alpha_{234} \qquad a_{35} \to \alpha_{35} + \alpha_{124}$$
$$a_{23} \to \alpha_{23} + \alpha_{145} \qquad a_{45} \to \alpha_{45} + \alpha_{123}$$

Coefficients $\mathbf{b}_{ij}$ for regression polinom *(5)* have the same form as coefficients $\mathbf{a}_{ij}$ and therefore they are not listed.

Supposing that 3-factorial and 4-factorial interactions can be neglected, it is possible on the basis of expressions *(9)*, *(10)* and *(11)*, to estimate coefficients of all the main effects and of all their 2-factorial interactions in the regression polynoms on the basis of 16 simulation experiments, made according to the plan described by the sentence *(8)*. In this case, regression polynoms *(4)* and *(5)* represent mathematical model of phenomenon which has been researched. If the values of mathematical model, calculated in this way, do not agree with the results of simulation in specific points of experimental space, then the starting hypothesis that the researched process can be described with linear polynom, should be abandoned. On the other hand, if the mathematical model agree (in statistical acceptable confidence interval) with the simulation results, it can be considered that simulation model (which produces such results) represents real IMPS.

6. Results of the simulation and the mathematical model of the examined phenomenon

In accordance with the theoretical explanation in the previous item, partial multifactorial experiment plan in the form 2^{5-1} was carried out for both goal functions **T** i **E**. Results are shown in the *Table III.*

Levels of specific factors in each simulation experiment are shown in the second column of *Table III.* Column 3 i 4 show the simulation result values of **T** and **E** and columns 5 i 6 show the values of these variables calculated on the basis of the expressions *(4)* i *(5).* In order to estimate possible mistakes of the experiment, three repetitions were

Table III: Results of the simulation experiments 2^{5-1} and values evaluated by the mathematical models (4) and (5)

Ord. No. of Experiment	Type of Experiment	Results of Simulation T	E	Values calculated by Model T	E
1.	**(1)**	1919,3	1,433	**1931,2**	**1,435**
2.	**ab**	1470,3	1,459	**1505,1**	**1,461**
3.	**ac**	858,6	1,498	**881,0**	**1,497**
4.	**bc**	1229,0	1,492	**1179,6**	**1,491**
5.	**ad**	1368,8	1,444	**1348,6**	**1,449**
6.	**bd**	1657,5	1.478	**1647,2**	**1,472**
7.	**cd**	1014,2	1,486	**1023,1**	**1,479**
8.	**abcd**	555,7	1,529	**597,0**	**1,535**
9.	**ae**	1320,1	1,473	**1269,4**	**1,468**
10.	**be**	1493,6	1,487	**1528,0**	**1,491**
11.	**ce**	907,6	1,492	**943,9**	**1,498**
12.	**abce**	558,2	1,559	**517,8**	**1,554**
13.	**de**	1599,5	1,478	**1588,5**	**1,479**
14.	**abde**	1151,8	1,507	**1162,3**	**1,505**
15.	**acde**	496,7	1,541	**538,3**	**1,542**
16.	**bcde**	858,3	1,533	**836,9**	**1,535**
17.		1183,5	1,488		
18.	**a,b,c,d, e=0**	1155,9	1,491	**1158,6**	**1,493**
19.		1215,1	1,497		

made at the central point of the plan (i.e. for **a=b=c=d=0**). It was done in such a way that three independent simulations of 5.5 year work term were made with different initial seeds (Bobilier,1976) for a random number generator.

Estimate of the regressive polynoms coefficients *(4)* and *(5)* in accordance with the expressions *(9)*, *(10)* and *(11)* are shown in the matrix equation *(12)*:

$$\mathbf{B} = \left(\mathbf{X}' \cdot \mathbf{X}\right)^{-1} \cdot \mathbf{X}' \cdot \mathbf{Y} \qquad (12)$$

In this expression **X** is a matrix of the experiment plan, **B** is the gradual vector of the regressive coefficients and Y is the gradual vector of the simulation experiments' results. Matrix **X** has the following form:

$$\mathbf{X} = \begin{array}{cccccccccccccccc}
1 & -1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 & 1 \\
1 & 1 & 1 & -1 & -1 & -1 & 1 & -1 & -1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 \\
1 & 1 & -1 & 1 & -1 & -1 & -1 & 1 & -1 & -1 & -1 & 1 & 1 & -1 & -1 & 1 \\
1 & -1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 \\
1 & 1 & -1 & -1 & 1 & -1 & -1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 \\
1 & -1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 \\
1 & -1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 & -1 & 1 & 1 & -1 & -1 \\
1 & 1 & 1 & 1 & 1 & -1 & 1 & 1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 \\
1 & 1 & -1 & -1 & -1 & 1 & -1 & -1 & -1 & 1 & 1 & 1 & -1 & 1 & -1 & -1 \\
1 & -1 & 1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & -1 & -1 & 1 & 1 & -1 & -1 \\
1 & -1 & -1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 & -1 & 1 & -1 & -1 & 1 & -1 \\
1 & 1 & 1 & 1 & -1 & 1 & 1 & 1 & -1 & 1 & 1 & -1 & 1 & -1 & 1 & -1 \\
1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & 1 & -1 & -1 & -1 & -1 & 1 \\
1 & 1 & 1 & -1 & 1 & 1 & 1 & -1 & 1 & 1 & -1 & 1 & 1 & -1 & -1 & 1 \\
1 & 1 & -1 & 1 & 1 & 1 & -1 & 1 & 1 & 1 & -1 & -1 & -1 & 1 & 1 & 1 \\
1 & -1 & 1 & 1 & 1 & 1 & -1 & -1 & -1 & -1 & 1 & 1 & 1 & 1 & 1 & 1 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\
1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{array}$$

Regressive coefficients for polynoms *(4)* and *(5)* are calculated on the basis of the simulation experiment results for the values of **T** and **E** in *Table III* and according to the matrix equation *(12)*. Results of the calculation are given in *Table IV*.

Table IV: **Calculated values of coefficients and their significance**

T			E		
Coefficient	Value	Significance	Coefficient	Value	Significance
a_0	1158,6	yes	b_0	1,4931	yes
a_1	-181,2	yes	b_1	0.0082	yes
a_2	-31,9	yes	b_2	0.0124	yes
a_3	-343,9	yes	b_3	0.0232	yes
a_4	-65,9	yes	b_4	0.0064	yes
a_5	-105,5	yes	b_5	0.0157	yes
a_{12}	-6,6	no	b_{12}	0.0002	no
a_{13}	-11,3	no	b_{13}	0.0073	yes
a_{14}	-13,4	no	b_{14}	0.0024	no
a_{15}	14,7	no	b_{15}	0.0031	no
a_{23}	22,4	no	b_{23}	-0.0004	no
a_{24}	-0,1	no	b_{24}	-0.0002	no
a_{25}	-0,9	no	b_{25}	-0.0003	no
a_{34}	-12,7	no	b_{34}	-0.0004	no
a_{35}	0,9	no	b_{35}	-0.0007	no
a_{45}	44,2	yes	b_{45}	-0.0004	no

Significance of calculated coefficients is verified by the Fisher's test and registered in the third and sixth column of *Table IV* for each coefficient. Taking into consideration only the significant coefficients, the mathematical model of the influence of information technology, implemented in five basic business areas, is:

$$T = 1158{,}6 - 181{,}2 \cdot a - 31{,}9 \cdot b - 343{,}9 \cdot c - 65{,}9 \cdot d - 105{,}4 \cdot e + 44{,}2 \cdot d \cdot e \ \ [\mathrm{TU}] \tag{13}$$

$$\mathbf{E} = 1{,}493 + 0{,}008 \cdot \mathbf{a} + 0{,}012 \cdot \mathbf{b} + 0{,}023 \cdot \mathbf{c} + 0{,}006 \cdot \mathbf{d} + 0{,}016 \cdot \mathbf{e} + 0{,}007 \cdot \mathbf{a} \cdot \mathbf{c} \tag{14}$$

Values of the functions **E** and **T**, calculated on the basis of the mathematical models *(13)* and *(14),* are registered in the last two columns of *Table* III. Correspondence between calculated values and values resulting from the simulation is obvious. Nevertheless, the adequacy of the mathematical models is additonally verified by the statistical test, based on the studies by R. Fisher and G. Snedecor (Shanon,1975). In this case, variants of the response and effectiveness function values resulting from thę simulation were compared with the values **T** and **E** calculated by the mathematical model. The statistical tests showed that both models are adequate, with reliability over 95%.

7. Influence of the selected factors on the manufacturing firm

In accordance with criteria defined in item 4, the entire effects of introducing modern information technology into five different business areas will be considered. The analysis will be made on the basis of the mathematical models *(13)* i *(14)*.

7.1 Influence of IT on the response system function

Mathematical model defined by the expression *(13)* shows that by shifting any examined factor from the low **(-1)** to the high **(+1)** level, that is to say, by introducing information technology into any of the examined areas, positive effect is achieved, expressed by a certain reduction of function **T** (measured in Time Units - TU, used in simulation model). Interactions between individual factors are not significant, except the interaction between factors **d** and **e**, in which negative synergistic effect can be observed. That means that reduction of delay **T**, in case when both **d** and **e** factors are on the high level, is smaller than the sum of the individual contribution of both these factors.

The system shows the maximum response time ($\mathbf{T}_{max}$=1931,2 TU) when all the factors are on the low level, i.e. when modern information technology is not introduced in any of the five examined business areas. The system would have the minimum response time ($\mathbf{T}_{min}$=474,4 TU) for input orders in the case when modern information technology (with presupossed partial effects on specific business activities) would be introduced in all business areas.

Further analysis of the expression *(13)* shows that the contribution of introducing new information technology in business activities (factor d) is relatively small, altough not negligible. Effect of factor **c** (introducing information technology into production planning and control) has the biggest positive effect on function **T.** Such result could be expected if we keep in mind the number and importance of these activities and their influence on the manufacturing firm (as shown on ***picture 1***).

The second most important factor is factor **a** (frequency of business planning). However, it has to be mentioned that reduction of delay (181.2 TU), in the case when factor **a** shifts from the low to the high level, is considerably smaller than the difference in duration of planning cycles for both extreme cases (1040-240=800 TU); it is, indeed, smaller than half of that difference. This subdued influence can be explained if we presuppose that the frequency of launching production orders does not depend exclusively on the size of the planning cycle of a firm, but also on some other factors, as for example, the volume of production series (that is to say that production orders are launched when the required quantity is approximately equal to the optimal series). This hypothesis should be verified in further research into the simulation model.

7.2. Influence of the examined factors on the effectiveness of a manufacturing firm

Matematical model of influence of introducing information technology into selected business areas on efectiveness of a firm as a whole is described with function *(14)*. Mathematical expression shows that all five factors have considerable positive effect on the effectiveness of a manufacturing firm, i.e. that the shift of each factor from the low (-1) to the high (+1) level increases effectiveness. For all that, factor **a** (business planning period) and factor **c** (introducing of computers into production planning and control activities) positively affect each other (positive synergetic effect). This can be seen from the last member of the polynom, representing their interaction. Other interactions are not statistically significant.

The most important positive effect on function **E** has the factor **c** (introduction of new information technology into production planning and control), factor **e** (improvement of the schedulling system) and factor **b** (introduction of new information technology into the technical office). Such importance of factors **c** and **e** is expected and well known among the experts (e.g. Borges,1985 and

Heinen,1978), while the importance of factor **b** presents a certain surprise, because it is usually thought that the introduction of new information technology into the technical office (e.g. CAD, bill of materials organization and maintenance using computer) has positive effect on the quality and duration of manufacturing process, but not on the effectiveness of the whole system. The important influence of factor **b** on the increase the entire effectiveness of a manufacturing firm has, however, been mathematically expressed and experimentaly verified in this study. Such positive effect can be explained as a consequence of reduced duration of activity in the technical office, which consequently provides for the timely planning of needs and temporally coordinated launching of various production orders.

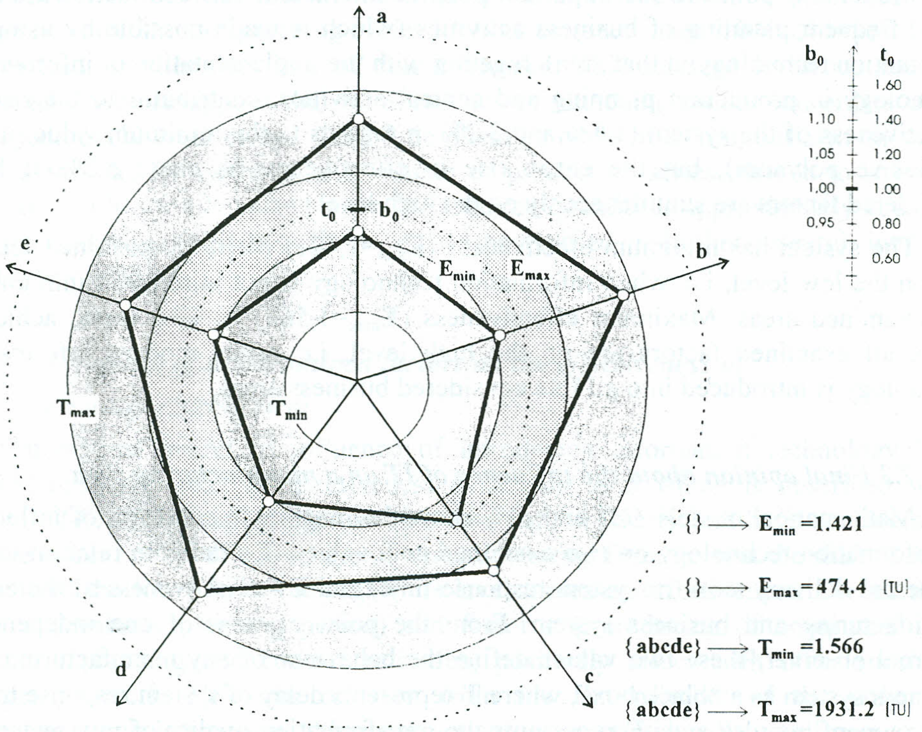
Model *(14)* points to the important positive interaction between factors **a** and **c**. More frequent planning of business activities (which is made possible by using of information technology in that area), together with the implementation of information technology in production planning and control activities, contributes to the rise in effectiveness of the system (1.1% and 3.2% in regards to the minimum value of the regressive polynom), but the entire rise in effectiveness is about 5.3% if both considered factors are simultaneously on the high level.

The system has minimum efectiveness ($\mathbf{E}_{min}$=1,421) when all examined factors are on the low level, i.e. when information technology is not introduced into any of the examined areas. Maximum effectiveness ($\mathbf{E}_{max}$=1,566) is, vice versa, achieved when all examined factors are on the high level, i.e. when modern information technology is introduced into all five considered business areas.

7.3 Final opinion about the influence of IT on a manufacturing firm

Mathematical models *(13)* and *(14)* show the magnitude and form of influence of information technology on two examined goal values: **T** - delay in relation to the requested delivery term (or system response-time) and **E** - effectiveness of the entire manufacturing and business system. From the point of view of one independent external observer, these two values define the behaviour of any manufacturing and business system as a "black box", where **T** represents delay of system response to the environment impulse and **E** represents the transformation quality of raw materials, energy, work and information within the system. General picture about the nature of influence of examined factors can be seen in so-called Kiviat's graph (***picture** 2*).

The diagram in ***picture 2*** shows how the values of **T** and **E,** depend on individual changes of factors **a** to **e,** from their high to the low level. Functional values for **T** and **E** are shown in the relative relation to the values of general members $\mathbf{a}_0$ and $\mathbf{b}_0$ of regressive polynoms *(13)* and *(14)*, i.e. in the relative relation to the value of the regressive function in the case when all factors are on the middle level (**a,b,c,d,e=0**). Circles in the diagram show also the maximum ($\mathbf{T}_{max}$ and $\mathbf{E}_{max}$) and minimum ($\mathbf{T}_{min}$ and $\mathbf{E}_{min}$) values of regressive functions, achieved in a certain combination of relevant factors.



Picture 2: Influence of observed factors on effectiveness and response function

The range of possible values is defined on the graph for each regressive function:

$$T_{min} \leq T \leq T_{max} \; ; \; E_{min} \leq E \leq E_{max} \qquad (15)$$

The range of possible values (in the real system, of which data are taken as parameters of the simulation) is relatively wide for **T** and relatively narrow for **E**. Analysis of the graph leads to the following conclusions:

1. The range of maximum improvement of the manufacturing system effectiveness, achieved by introduction of information technology into five examined areas is 10.2%. That is approximately equal to the relation between profit and entire income of an ordinarily successful firm.
2. Influence of information technology on the entire reduction of delay time **T** is relatively big (T_{max}-T_{min}=1368.4 time units, i.e. 5.7 weeks). The greatest particular influence on the response time reduction has factor **c** (introduction of information technology into production planning and control activities).
3. The maximum effect on the system effectiveness is achieved when all the examined factors are present. There is no dominant factor, because none of them makes more than the third of the entire possible effect, but the most important is factor **c**.
4. There is no contradiction between the effects of individual factors, although there are two aims of **optimisation**: to achieve the maximum of effectiveness (E_{max}) and, in the same time, the shortest possible system response time on orders from the market (T_{min}). Combination of factors giving the maximum effectiveness also gives the minimum response time.
5. The best double effect (i.e. simultaneous decrease of **T** and increase of **E**) of all factors is the effect of factor **c**. This is clearly seen in the graph ***(picture 2)***, because the angles of the polygon for **T** and **E** are closest exactly at the axis **c**. This eliminates any dilemma about the order of projects in the strategic plan for introduction of IT in manufacturing firm: from the stand-point of the entire effects, introduction of computers should begin in production planning and control department (if there is no possibility to introduce a new information system into all departments of the firm at once).
6. Value of coefficients in functions *(13)* and *(14)* suggests the order in the strategic plan of introducing information technology into various departments of the

manufacturing firm: bigger coefficient suggests the greater priority because it also provides for greater effects.

7. Partial computerization of one business area brings about certain effects (different in different business areas), but doesn't lead to any revolutionary result. Only the introduction of new information technology into all business areas could bring approximately that effects, what are objectively possible for the organization and business strategy of the considered manufacturing firm.

8. Comparison of the research results with other empirical researches

Possible effects of the implementation of information technology in the firm management, especially into production, has been the subject of a great number of researches in the world. We will mention only some relevant researches. For example, Borges and Hilderbrandt, on the basis of the research carried out in "Forschungsinstitut fuer Rationalisierung" in Aachen, write in their study (Borges, 1985) about the repeatedly demonstrated positive effect of partly computerized production management on the efficiency of a firm. R. Schnabel and H. Nadzeyka in their dissertations (according to Borges, 1985) prove statistically significant relevance of production organization for the aberation on the requested delivery terms (function **T** in this research) and its relevance for the **working capital**, required for manufacturing (comparable to function **E** in this study). With the rise in the level of organization, connected (according to these authors) with the computer supported planning and production, flow time of production orders, as well as the need for working capital, is considerably lessened. Considering the effects of computer implementation into production management, these authors mention some effects realised in the practice, such as:

- a) reduction of the average components stock 10%,
- b) reduction of the average end-products stock 15%,
- c) reduction of the average delay of production work orders 40-50%.

The mentioned data can be compared with the results of this research which is an additional indirect confirmation of the adequacy of the simulation model. Savings a) and b) usually result in the rise in profit 4-5% and the rise in effectiveness of the system calculated here is 10.2%. Reduction in the average work order delay is 40-50% and that corresponds to reduction in response delay 74.3%. Results achieved by the simulation in this study, are almost two times more favourable than the ones reported by the above mentioned authors. However, this can be easily explained: data in mentioned reference refer only to the production part of the production and business system, while the research described here relates to production and business system as a whole. Therefore, it can be expected that the effects achieved only in the production are multiplied on the level of the production and business system as a whole.

Conclusions in reference (Borges,1985) are however reached on the basis of the statistical analysis, carried out in real production systems. Therefore, Borges and Hilderbrandt regretfully conclude that the procedure by which these regularities could be exactly quantified has not yet been developed. But, research procedure carried out on the simulation model and applied in this study, make possible not only the required quantification, but also the exactly estimating of the expected effects of introduction a new information technology into production and business systems. It is the author's belief that procedure presented in this study is an adequate solution to the problem as defined at the beggining, and also an useful support by the strategic planning of a new information system for the manufacturing firm.

9. Conclusion

Simulation modeling is an useful research tool, that can be applied in the research of regularities of processes in complex system, even when other procedures can not. It is mostly used in systems in which problems of waiting queues are considered. This research procedure can also be applied in the analysis of complex systems, such as manufacturing firms. The study shows that it is possible to make an adequate simulation model of a manufacturing firm and to describe mathematically, after processing of simulation results, the regularities of firm behaviour in stohastically variable environmental influences. In strategic planning of information systems and evaluation of the expected results of introducing new information technology, experience and intuition can be replaced by precise calculations. In this research a theoretical approach was defined, verified on the real manufacturing system, and the polynomial approximations in forms $\mathbf{E}=f(\mathbf{X}_i)$ and $\mathbf{T}=f(\mathbf{X}_i)$, describing the effects of introducing new IT in certain areas of a manufacturing firm on effectiveness and response function of such firm as a whole, were calculated. Contribution of IT to business efectiveness of manufacturing firm was quatified. The amount and nature of these influences were defined, and objective determining of order of introducing IT into certain areas was possible, in the case whe the project of establishing IT is carried out in several successive phases. Results of the research were compared with the empirical researches of other authors, which also confirmed the fitness of such an approach

Results of the study suggest further possible researches. During simulation experiments on the model it was presupposed, that business processes and the internal structure of a manufacturing system are constant, i.e. such as are shown in *picture 1*. However, it would be interesting to carry out a research about a possible increasing of the effects of introducing new IT with simultaneous changes of the internal structure of IMPS, changes in certain algorithms of business processes (e.g. elimination of stockhouses, what corresponds to the japanese manufacturing concept "just-in-time"), introducing of a new algorithms for demand forecasting, other kind of cooperation between production planning, sales and product design activities, etc. In production, as the only activity, in which new values for meeting people's needs are established, every posibility for the entire increase in the effectiveness of the production system should be intentionally used. Experiments made on simulation model, instead on the real system, enable us to establish the effects of intended changes objectively and in advance, without losses in the real system, during a short period of time and with acceptable costs

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Brumec J. Simulacijski model efekata kompjutorizacije proizvodnog poduzeća

Sažetak

Ponašanje proizvodno-poslovnog sustava (PPS), izloženog utjecaju velikog broja promjenljivih čimbenika iz okoline, ima prividno stohastički karakter. Predskazivanje budućih stanja sustava ili procjena efekata poduzetih upravljačkih mjera teško je i nesigurno. Optimalno upravljanje takvim sustavom nemoguće je organizirati bez poznavanja zakonitosti njegovog ponašanja.

Istraživanje na modelu simulacijom pomoću računala jedan je od načina da se tijekom prihvatljivog vremena utvrde zakonitosti ponašanja PPS-a, izloženog vanjskim ili unutarnjim promjenama. U radu je opisan razvoj modela PPS-a za diskontinuiranu proizvodnju standardnih proizvoda, te istraživanje ponašanja realnog sustava kompjutorskom simulacijom na njegovu modelu.

Postupak polazi od dekompozicije sustava na elemente, uz definiranje tipova i vrsta njihovih međudjelovanja, a završava izradom modela u simulacijskom jeziku GPSS i pripremom podataka za izvođenje simulacije. Diskutiran je problem validacije modela i postizanja stacionarnog stanja. Opisana je strategija simulacije, primjerena istraživanju utjecaja odabranih čimbenika na ponašanje sustava. Na

temelju rezultata simulacije, dobivenih faktorskim planom pokusa 2** (n-k), izračunata je funkcija koja povezuje virjeme odziva i efektivnost PPS-a s promjenama određenih čimbenika. Opisani postupci ilustrirani su konkretnim istraživanjima.