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OPTIMIZATION METHODS IN MODELING AND SIMULATION OF PRODUCTION SYSTEMS

Abstract

The use of the modelling and simulation method in improving production systems is presented. In the analysed example, two stages were distinguished: creation of the simulation model and optimization. The second stage is illustrated by the practical examples of the use of different optimization methods like the orthogonal plan of Taguchi and fuzzy control. By using simulation connected with optimization, it is possible to check almost all admissible variants of the proposed improvements comparatively quickly in order to evaluate them and to choose the best solution.

1. INTRODUCTION

Nowadays production enterprises act in conditions which extort the necessity of ongoing improvement of their activities. Therefore, optimization of the realized production processes becomes a more essential problem [3, 5]. In this aim it is necessary to use different modern methods and tools aiding production. The modelling and simulation method can be an effective basis for improving a production system.

Simulation packets, as for example Arena, are complemented more often in optimization modules, which allow for automatic generating and checking admissible variants and finding the best solution. To fully use this type of computer tools, it is necessary to determine properly right input and output parameters of the analysed production system, that is: almost all parameters describing the given system for which we will change values and the aim which we want to achieve.

Thanks to computer simulation, it is possible to check future solution (improvements of the current production system) and to check if it fulfils the defined requirements. However, optimization methods present a quicker way to find the best variant of improvement of the analysed system. In further part of this paper examples of the use of two experimental research methods are described and also one practical example of the optimization of the realized production process is given.

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2. OPTIMIZATION MODEL OF A PRODUCTION SYSTEM

Efficient analysis of production system functioning requires fulfilment of two conditions:

- collecting and disposing of information about the realized production process,
- having theory and technique assuring the obtainment of the optimum state.

At the beginning of any analyses it is necessary to define the input parameters of the analysed system and output parameters, which will be a result of the conducted analyses and on the basis of which opinion about the analysed system will be accomplished. Two cases can occur here. In the first of them, a simulation of the system maintenance will be conducted for the assumed input parameters. In the second one, different collections of output data may exist, and a problem of finding the optimum may appear to produce articles with the best parameters from the point of view of the criteria of opinion. It is difficult to find the optimum solution. Proper planning of particular stages of experimental research, finding possible variants of solutions and, first of all, proper settlement of opinion criteria are necessary [4, 8]. In further part of this paper a way of conducting research of production systems is presented, which shows the possibility of finding the best solution more effectively.

When many variants of proposed solutions appear while modelling and simulation, research of all the possible combinations and all possible value arrangements of the studied factors is very time-consuming. If it is not possible to examine all arrangements, only these variants should be studied, which are chosen on the basis of subjective opinion of the researcher, his intuition and knowledge about the research object. A lot methods (programs) for conducting research exist which can prove useful here.

One of the examples presented in this paper concerns single-criterion optimization. The simulation model worked out in the ARENA package was checked by the OptQuest tool.

OptQuest is an additional tool being a part of the ARENA simulation package [9, 10]. This software enlarges the possibilities of analysis of production systems which are modelled in ARENA. It allows for finding the optimum solution in the prepared simulation models.

Without this type of tools, finding the optimum solutions for a simulation model would require checking them in a heuristic or random way. This usually involves executing simulation for initially assumed values of input variables. Changing one or more parameters is connected with the necessity of rebuilding the model and carrying out the next simulation. This process should be repeated as long as we get a satisfactory solution. OptQuest automatically changes these values, controls simulation and shows the optimum solution basing on one prepared model in ARENA.

OptQuest is a generic optimizer that makes it possible to separate successfully the optimization solution procedure from the simulation model. This design adaptation of meta-heuristic methods lets you create a model of your system that includes as many elements as necessary to represent the "real thing" accurately.

While the simulation model can change and evolve to incorporate additional elements, the optimization routines remain the same. Hence, there is a complete separation of the model that represents the system and the procedure that solves optimization problems defined within this model.

The optimization procedure uses the outputs from the simulation model to evaluate the inputs to the model. Analyzing this evaluation and previous evaluations, the optimization procedure selects a new set of input values. The optimization procedure performs a special "non-monotonic search," where the successively generated inputs produce varying evaluations, not all of them improving, but which over time provide a highly efficient path to the best solutions.

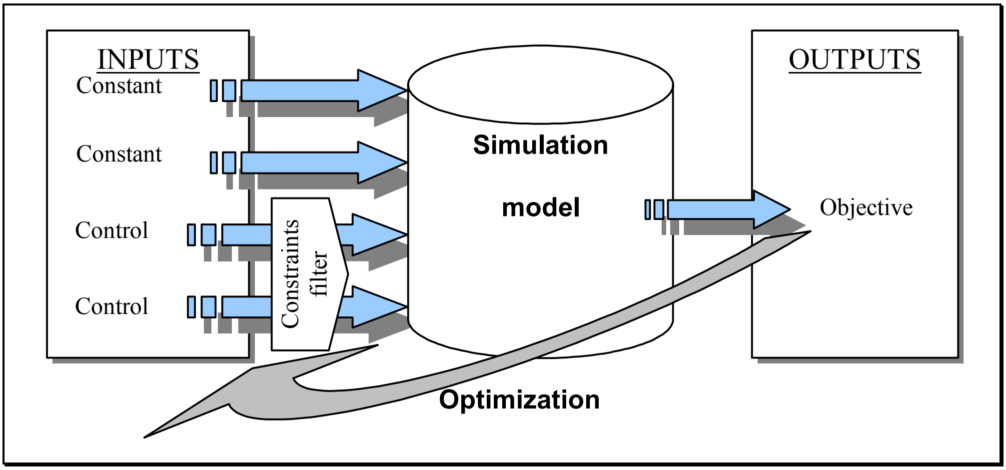

Fig.1. Optimization model in OptQuest

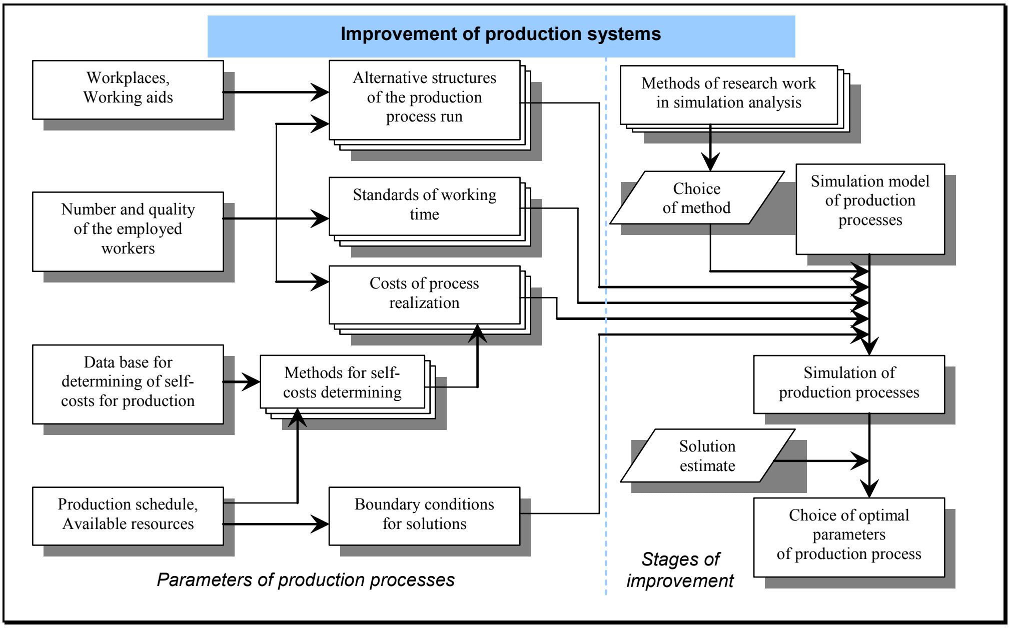

Fig.2. Input data bases for calculations and determination of optimal parameters in simulation analysis

The problem of proper determination of optimal parameters of production process run reduces to solving the following problems (fig.2):

- determination of proper input data,
- choice of the method for determining optimal parameters of a process run.

3. OPTIMIZATION METHODS

3.1. Orthogonal plan of Taguchi

The use of the Taguchi's orthogonal plan aims at limiting the quantity of the created simulation models. In the situation when we define *n*-improvements, it is possible to create 2^n variants of possible solutions and it is possible to connect them with each other. Thanks to the method mentioned above it is enough to check *n+1* variant to estimate importance of the proposed improvements. The production system which was analysed with this method is presented below on the figure 3.

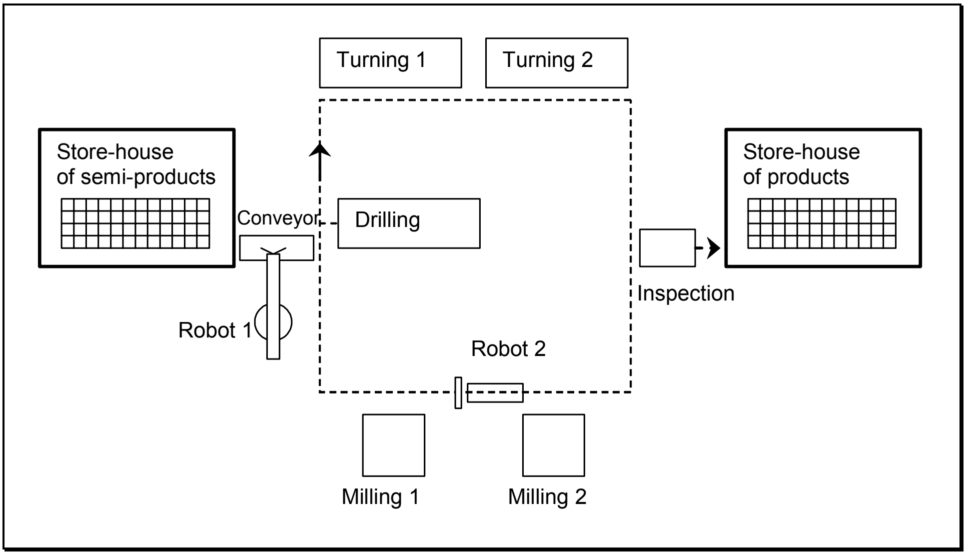

Fig. 31. Production system layout

On the basis of analysis of its functioning, seven most important improvements were distinguished. For each of them two levels were determined. Implementation was market by "+", and omission by "–".

Determined improving action and its influence on the analysed production system:

A – adding buffers in front of and behind workplaces

A^- - without buffers, A^+ - with buffers

B – increasing the number of robots in internal transport (2nd robot)

B^- - 1 robot, B^+ - 2 robots

C – increased robot speed

C^- - current speed, C^+ - increased speed

D – increased conveyor speed

D^- - current speed, D^+ - increased speed

E – modernization of the turning machine No 1 (increasing efficiency)

E^- - current efficiency, E^+ - increased efficiency

F – modernization of the turning machine No 2 (increasing efficiency)

F^- - current efficiency, F^+ - increased efficiency

G – modernization of the drilling machine

G^- - current state, G^+ - future state

The complete experiment remains 2^7, which means 128 simulations. By the use of the orthogonal Taguchi's program we should create only 8 models (7 improvements +1). The first variant presents the current state of the analysed system. Every next variant has different combination of four improvements. Application of improvements in all variants is presented in the table 1. For each variant four simulations were conducted (simulation for four days of work). The results (volume of production) from all runs of simulation are presented below in the table.

Table 11. Results from simulation

Simulation No.	Actions							Results				
	A	B	C	D	E	F	G	1st day	2nd day	3rd day	4th day	Total
1	-	-	-	-	-	-	-	8	7	7	7	29
2	-	-	-	+	+	+	+	9	13	10	10	42
3	-	+	+	-	-	+	+	8	7	10	9	34
4	-	+	+	+	+	-	-	6	5	7	4	22
5	+	-	+	-	+	-	+	8	9	8	9	34
6	+	-	+	+	-	+	-	9	9	11	9	38
7	+	+	-	-	+	+	-	10	10	9	9	38
8	+	+	-	+	-	-	+	9	8	7	6	30
Σ								67	68	69	63	267

The realized simulation makes estimation of the proposed improvements possible. We can sort them according to their influence on the analysed production system.

We make punctual evaluation of particular variants by adding of values of results from simulations. We should separately add values from variants where the given improvement was implemented (for example on A we have 34 + 38 + 38 + 30 = 140) and where it was omitted (for A we have 29 + 42 + 34 + 22 = 127). The difference between these values is a final result (for A we have 140-127 = 13). The results for particular improvements are presented in the table 2.

Table 22. Effects for particular actions

Action	Effect	Action	Effect
A-	127	E-	131
A+	140	E+	136
A	**13**	E	**5**
B-	143	F-	115
B+	124	F+	152
B	**-19**	F	**37**
C-	139	G-	127
C+	128	G+	140
C	**-11**	G	**13**
D-	135		
D+	132		
D	**-3**		

The best evaluated improvement is connected with the highest value. Improvement F got the biggest number of points. For the analysed example, order of improvements implementation according to their importance (influence on results) is the following:

F, A, G, E, D, C and B

The proposed improvements should be implemented in this sequence. Also, we can choose a few first improvements from this list for implementation.

3.2. Fuzzy control

In production practice, besides evaluation of variants according to criteria with the specified character, we can use probabilistic evaluation or evaluation basing on fuzzy criteria [1, 2, 7]. Informative data, which should have deterministic or probabilistic character, are often defined also in a fuzzy way, because necessary time for determining them precisely or the cost of their gathering does not permit for their use in the optimization project.

The theory of fuzzy sets permits on representation of imprecise notions in the form of fuzzy sets, which are generalization of the well-known notion of the set. Fuzzy sets let us take into account the degree of partial belonging elements to the set and are described by the function with values from the interval $\langle 0,1 \rangle$.

Rationalization of the production system can be realized by evaluation of particular proposed variants of changes in the production system with the use of the simulation technique. With implementation of new projects we have not sufficient quantity of information with deterministic character. Therefore, the simulation technique can be used to show the foreseen behaviour of the analysed system and the estimation of particular variants of solutions will be realized by experts appointed by company's management.

Many different tools and methods for solving problems are described in literature [4, 6, 11]. One of them is the method using decision-makers' subjective punctual evaluation, which is used for evaluation of the choice of production process structure.

Input data of this method are [6]:

- number of criteria *m=3*,
- number of variants of manufacturing process run *n=6*,
- elements of matrix of individual criteria importance $B = \left[b_{ij} \right]$,
- elements of matrix $C = \left[c_{ij}(e) \right]$, which are the point estimate if the *i*-variant according to *j*-criterion, passed by *e*-expert.

Each expert is liable for the construction of the importance matrix of estimation criteria with the Saaty's method in comparing pairs according to the determined criteria.

In the next step there is one summary matrix of validity criteria. For the summary matrix there was a search eigenvector *Y* (table 4), fulfilling the following matrix equation:

$$B\,Y = \lambda_{\max}\,Y \tag{1}$$

where:

B - the summary matrix of criteria importance,
Y - eigenvector,
$\lambda_{\max}$ - the maximum eigenvalue of matrix *B*.

Coordinates of the eigenvector, called weights, express the importance of corresponding criteria. Applying the involution method we can determine the eigenvalue and its eigenvector. For this task the numeric procedure written in Pascal language was used.

After determination of the eigenvector and the eigenvalue, the next stage was realized, which was connected with normalization of the punctual evaluations $S_{ij}(e)$ to the normalized values $c_{ij}(e)$ from the interval $\langle 0,1 \rangle$ presented in table 3. The subsequent stage of evaluation is connected with creation of the total normalised evaluations by averaging evaluations given by particular experts.

$$c_{ij} = \frac{1}{p}\sum_{e=1}^{p} c_{ij}(e) \tag{2}$$

where:

p – number of experts (*p*=3).

The next step is connected with creation of the normalised decisions by involution of each component of the next normalised estimations to the even power suitable weight.

$$d_j = \sum_{j=1}^{m} c_{ij}^{\,y_j} / w_i \tag{3}$$

Table 33. Creating of the normalized decisions

Criterion	Variants of solutions					
	A	**B**	**C**	**D**	**E**	**F**
k_1	0,0919	0,1527	0,2974	0,2283	0,2720	0,1987
k_2	0,0609	0,0081	0,1041	0,0159	0,1232	0,0391
k_3	0,5341	0,5217	0,4439	0,2549	0,3719	0,3898

The result is the optimum decision, of which there is the rational run of manufacturing process which fulfils all received estimation criterions (table 4).

$$D = D_1 + D_2 + \ldots + D_n \tag{4}$$

The best variant of the analysed production process run, under the assumed criteria, is the variant with the largest component in optimum decision.

$$D_{rac} = \max_i D_i \tag{5}$$

For the estimation of variants according to all criteria, taking into account their importance, the software tool was prepared and used. On the basis of results from simulation research, all variants were estimated from the point of view of all defined criteria. As a result of the conducted analysis, the best variant is E (table 4).

Table 4. The multi-criterion estimation of variants in case of internal transport

Weights of criteria:	$Y = \begin{bmatrix} 0,87471 \\ 1,65601 \\ 0,46928 \end{bmatrix}$
Decision function:	$D = 0,0609/A + 0,0081/B + 0,1041/C + 0,0159/D + \underline{0,1232/E} + 0,0391/F$
Preferred solution:	Variant E with the largest value in optimum decision: **0,1232**

The use of the multi-criteria method permits in a simple and effective way to choose a rational run of the production process. Thanks to evaluation of importance of particular criteria and taking into account their weights, it is possible to estimate particular variants to sort them in the order from the best to the worst.

The described example and advantages from the use of the modelling and simulation method and the fuzzy control mentioned above prove their usefulness in solving problems connected with designing and analysing of the production processes.

4. THE PROJECT OF PRODUCTION PROCESS OPTIMIZATION

The presented below simulation model was worked out in the ARENA packet and was checked by the OptQuest tool [9, 10].

The project for improvement of the treating seat for machine elements (pivots) was realized in two stages:

- creation of the simulation model in Arena;
- execution of optimization with the usage of the OptQuest tool.

The first stage in this project was connected with modelling, that is with determination of all indispensable workplaces, processes, time of their realization and time for transfer of material between workplaces. This boils to placing the proper objects representing workplaces in space of the simulation model and defining their parameters describing their functioning. It is possible to get this information from technological documentation and by observation of the real system's functioning. Table 5 represents the example of the technological data card including the main input data for simulation.

Table 5. Manufacturing process for pivots

No. of operation	Name of operation	Workplace	Operation time	
			Tpz[hour]	Tj [min]
10	Cutting	Cutter	1,50	3,00
20	Warm up	Furnace 1	0,25	0,25
30	Forging	Forging hammer	2,00	2,00
40	Grinding	Grinder	0,50	0,50
50	Sand blasting	Sanding vehicle	1,00	40,00
60	Heat treatment	Furnace 2	1,00	25,00
70	Inspection	Inspection station	0,50	0,50
80	Packing	Packing station	0.50	1,00

After creating the model (fig.4), the first simulation was conducted in order to check its correctness, determine present production abilities, find a bottle-neck and determine the duty for workplaces. On the basis of the conducted analysis of reports from the first simulation, critical resources were indicated, which decisively influence the whole system functioning. Parameters describing these resources should be controls in the optimization model. They are input variables in the simulation model, which will be changed in the settled range of value by the optimization software. In the analysed example, the following parameters were chosen as controls:

- batch size,
- number of workers working in the seat,
- number of inspection stations.

For the above-mentioned variables, lower and upper bounds were determined, which results from the real production conditioning, for example from the way of transport of parts, the maximum level of employment, accessible production surface etc. In the analysed example, the following constraints were accepted:

– possible batch sizes from 10 to 80 at 5 parts,
– number of workers not larger than 14,
– maximum 3 inspection stations (it is the bottleneck).

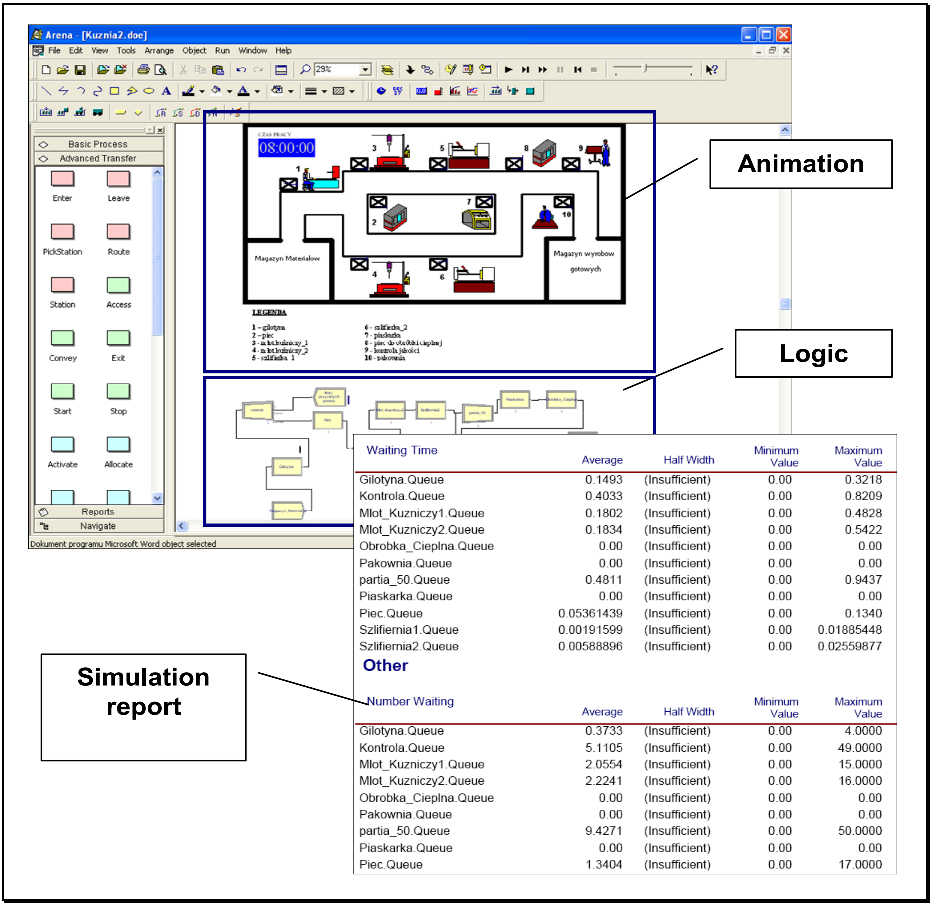

Fig. 4. Simulation model for the pivots‘ treating seat

Several simulations of the run of process altering the objective function were conducted. At the beginning, the aim of research was to find the solution with the maximum size of production of final products (150 parts) – fig. 5.

It turned out that many variants fulfil this condition. These variants were sorted according to the number of workers and number of parts waiting for the inspection station, which is introduced in table 6.

The optimization results above-presented show that with six production workers and two quality inspection stations, the number of produced units is 150. In the queue for inspection wait mostly two units (average 2.2 parts). Very similar result was achieved for the batch size of 25 parts, employing seven workers and using also two inspection stations. The number of parts was the same, but the size of average queue was smaller – 1.836 parts.

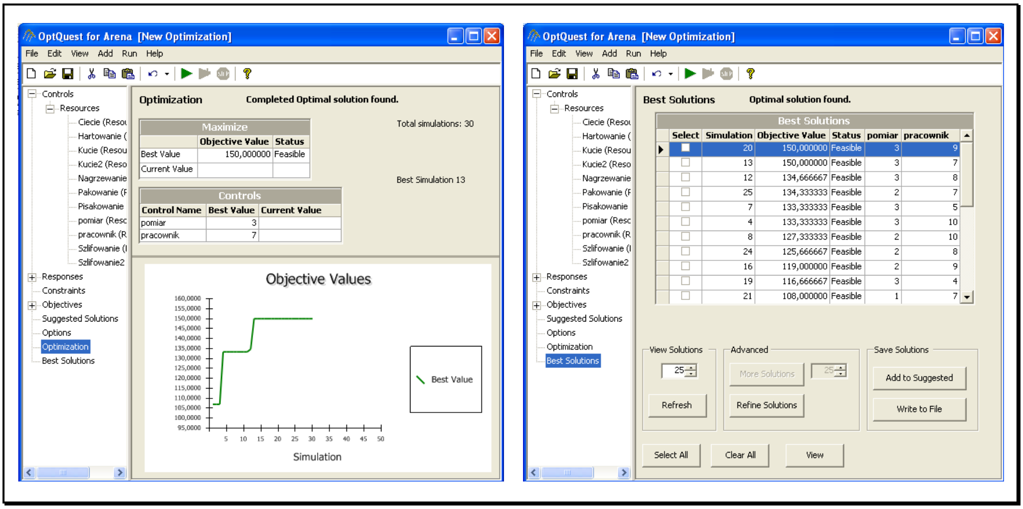

Fig. 5. Optimization model for the pivots‘ treating seat

Table 6. List of the best variants

No.	Controls			Results from simulation
	Batch size	Number of workers	Number of inspection stations	Quantity of final products
1	30	6	2	150
4	25	7	2	150
2	30	7	1	150
3	30	7	2	150
5	25	8	2	150
6	30	8	2	150
7	30	9	2	150
8	30	10	2	150
9	30	11	2	150
10	30	12	2	150

In the next optimizations constraints were altered. For example, the best variant with the batch size limited to 50 parts was with 8 production workers and two inspection stations only. With this constraint we can produce maximally only 106 parts of final products.

The use of the modelling and simulation method helps design the system approximated to the optimum in respect to the number of machines, level of costs and time of task realization. On the basis of the presented example, we can notice that by altering the batch size, the number of workers or workplaces, it is possible to examine several variants of the production system and choose the variant fulfilling the expected requirements. However, with such approach to generating new variants, we are not sure that we will not skip some solution which would give better result. Checking all variants is very time-consuming, and often even impossible to realize. Software like OptQuest automates the process of checking variants of improvements. Thanks to this, we can find the best solution quickly and easily.

5. CONCLUSIONS

At the beginning of every analysis it is necessary to define input parameters of the analysed system, and also output parameters which will be the result of the conducted analyses, and on the basis of which the opinion about the analysed system will be accomplished. We can define here two cases. In the first one, simulation for checking behaviour of the system is realized for the defined input parameters. In the second case, we have the set of different input data, where exists the problem of finding the optimum. It is connected with finding such input data which gives the best result according to the assumed criteria. In this approach the problem is to find the optimum solution. It is necessary to plan particular stages of experimental research properly to find possible variants of solutions, and first of all to set criteria for evaluation of the proposed variants in a proper way.

If during modelling and simulation many variants of the proposed solutions appear, the research including all possible combinations, all possible arrangements of values of factors will be too time-consuming. If it is not possible to check all possible variants, we should apply one of the experimental research methods described in this paper methods. They make it possible to find the optimum solution without the necessity of checking all the possible variants. On the other hand, we can check and choose only these variants, which are the best from the point of view of experts, their intuition and knowledge about the research object.

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