modelling and simulation of production systems, multi-criterion evaluation of variants

Sławomir KUKLA[*]

ANALYSIS OF PRODUCTION SYSTEMS ON THE BASIS OF SIMULATION EXPERIMENT

Abstract

The paper presents results of research obtained on the basis of simulation experiment, whose aim was to analyze the performance of cast iron foundry The computer model of foundry has been planed and conducted in order to compile the schedule of cast production. On the basis of reports from a simulation experiment information was achieved related to activities' duration, load of accessible resources, the problems of storage and transport, bottle necks in the system and appearing queues in from of workplaces. The research used a universal modelling and simulation packet for production systems - ARENA.

1. INTRODUCTION

A growing assortment of foundry production and variant –oriented manufacturing have brought about the necessity of looking for possibilities of larger production flexibility and establishing cooperation with collaborative enterprises in order to lower manufacturing costs. More and more often foundries focus on the processes related to liquid alloy preparation and on making castings on automatic foundry lines, whereas other operations are outsourced (e.g. manufacture of cores, finishing of castings, transport activities, ect.).

The basis of an effective management of an enterprise is getting data and conducting analyses of the borne production costs. In the literature of the subject much space is devoted to technologies and computer systems which aid contemporary enterprises. This subject is also dealt with by software designers who make programs aiding action in this domain with the use of state-of-the-art achievements of information technology. Also, an appropriate management of technical devices' exploitation is of great importance for proper enterprise functioning .

So far, however, no enterprise management system has been designed for the conditions of repeatable, series and large-series production of casts which would enable to evaluate and verify time and costs on the stage of production scheduling and which would take into account the issues of technical devices' exploitation.

By designing and function analysis of cast production systems we meet many variants of possible solutions and their complexity usually makes it impossible to choose the best option. Using optimization techniques for a large scale is impossible because of complexity of foundry processes, lack of stability of production plan, occurring disturbances in the course

[*] Eng. PhD. Sławomir Kukla: Department of Industrial Engineering, University of Bielsko-Biala, ul. Willowa 2, e-mail: skukla@ath.bielsko.pl

of the process and high costs and time of conducting optimization projects. Cost calculation which does not take into consideration the changing conditions of production system functioning and its surrounding is also a far stretched simplification [4, 9, 10].

Hence, a method of modelling and simulation becomes useful (fig. 1)

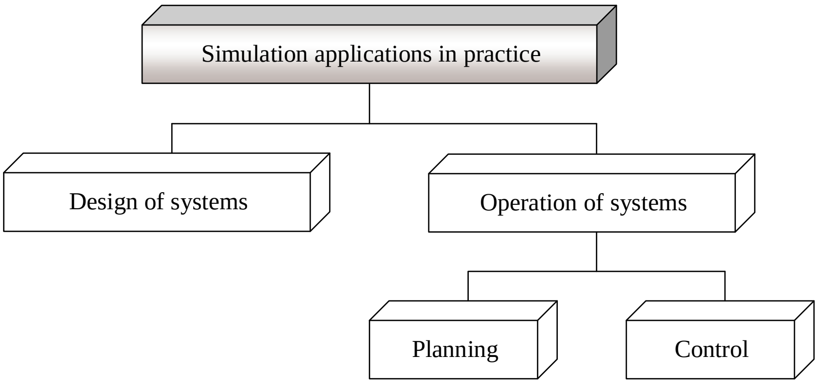

Fig. 1. Simulation applications

2. MODELLING AND SIMULATION OF PRODUCTION SYSTEMS

The model can be used to predict the sequence of physical service events including the products and the whole manufacturing processes. The use of computer technique in enterprise makes integration of production preparation processes and the production itself possible. Costly and sometimes even impossible to conduct industry tests are avoided this way. To manage the production efficiently, one can use a computer model of the real system to conduct many necessary experiments. One can simulate different decision situations to provide the basis for managing in real time (fig. 2).

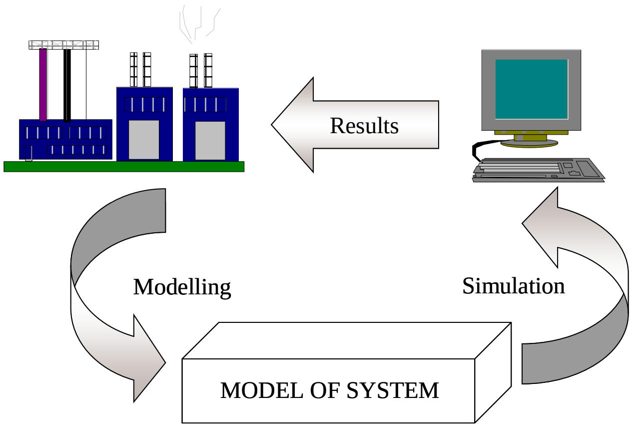

Fig. 2. Modeling and simulation of production systems

Taking into account the reports, which are the results of the conducted modelling experiments, one can compare the model results with actual decisions on the examined system operations and search for the best solution to assembly line service events.

The problem definition is the first step of the simulation project (fig. 3). The following step of simulation project is the data collecting and preparing. Typical simulation data are the process plan, material and information flow, number of machines, workers, production time, etc. When we have prepared necessary simulation data we can construct the simulation model. Simulation model is tested, verificated and validated. When model is all right, we design simulation experiment. We conduct simulation experiment and make evaluation and presentation of the simulation results [1, 2, 3, 7, 8, 11].

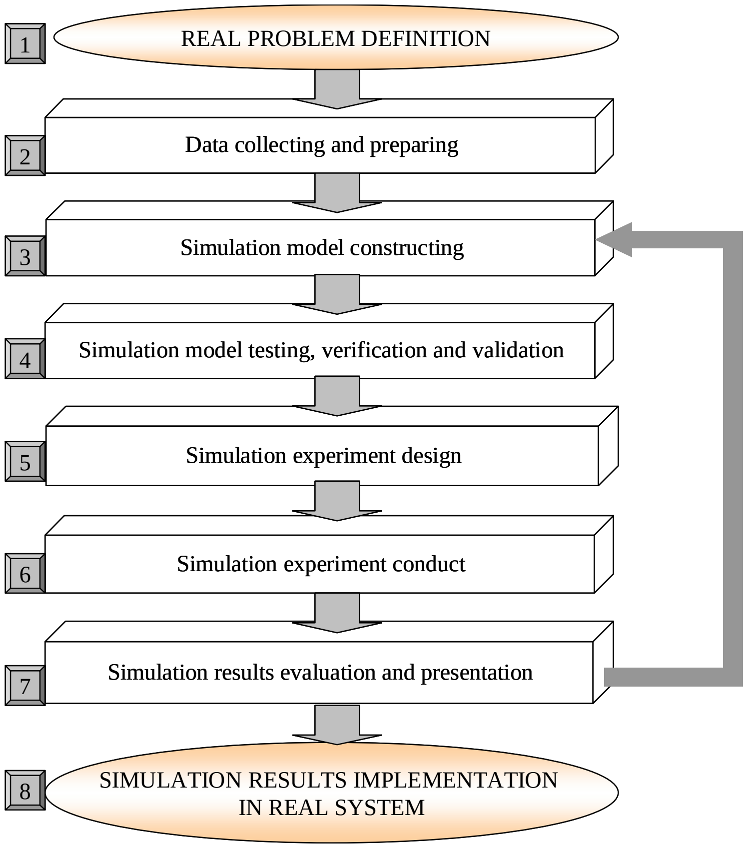

Fig. 3. Main steps in simulation Project

Modelling of devices' operation, such as systems of furnaces or foundry lines as well as modelling of functioning of the whole foundry departments are not commonly used due to lack of the prepared computer software ready to deliver practical application for foundry industry. In this case the gist of modelling does not consist in mathematical description of physical phenomena occurring in the given object, but in describing functional connections between elements of the analyzed object (e.g. foundry department), and the external conditions [5, 6].

3. DESCRIPTION OF THE RESEARCH OBJECT

The object of the research in the paper is a system of iron castings manufacturing on automated foundry lines (fig. 4).

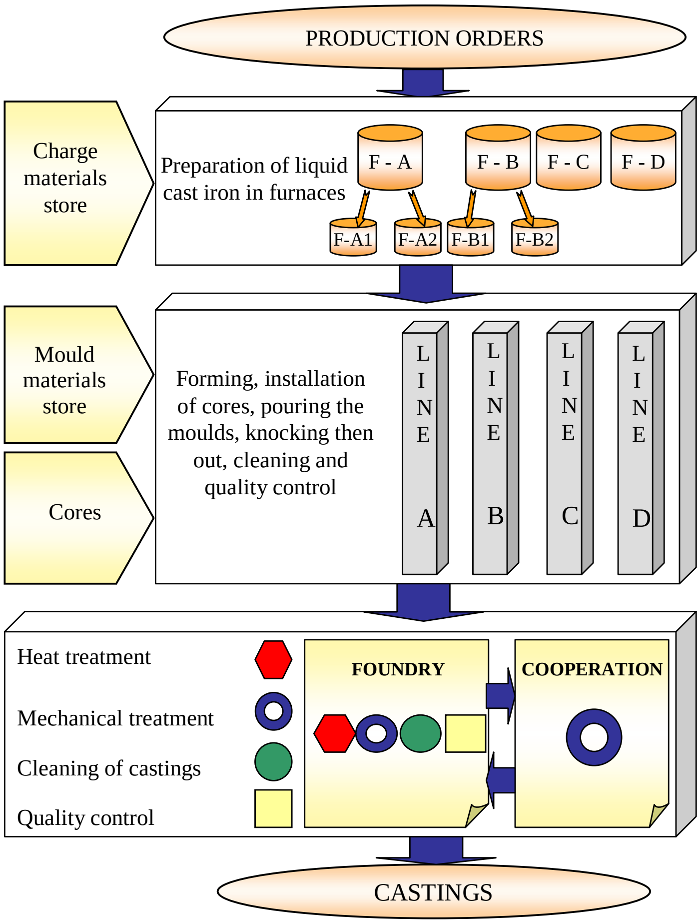

Fig. 4. Manufacturing system of iron castings on automated foundry lines

The analysis of the actual production service events helped create a scheme of the research objective. Figure 5 illustrates the process where output values are impacted by a combination of input values and assembly line failures.

Simulation tools are proposed for use in analyzing the functioning of the production system The analysis in Pareto allows one to choose the best solution (fig.6), where the criterion of optimization will be the cost of the produced castings determined on ZAR (enterprise account sheet) basis. In addition the criteria of quality and time will be regarded as an additional restrictions.

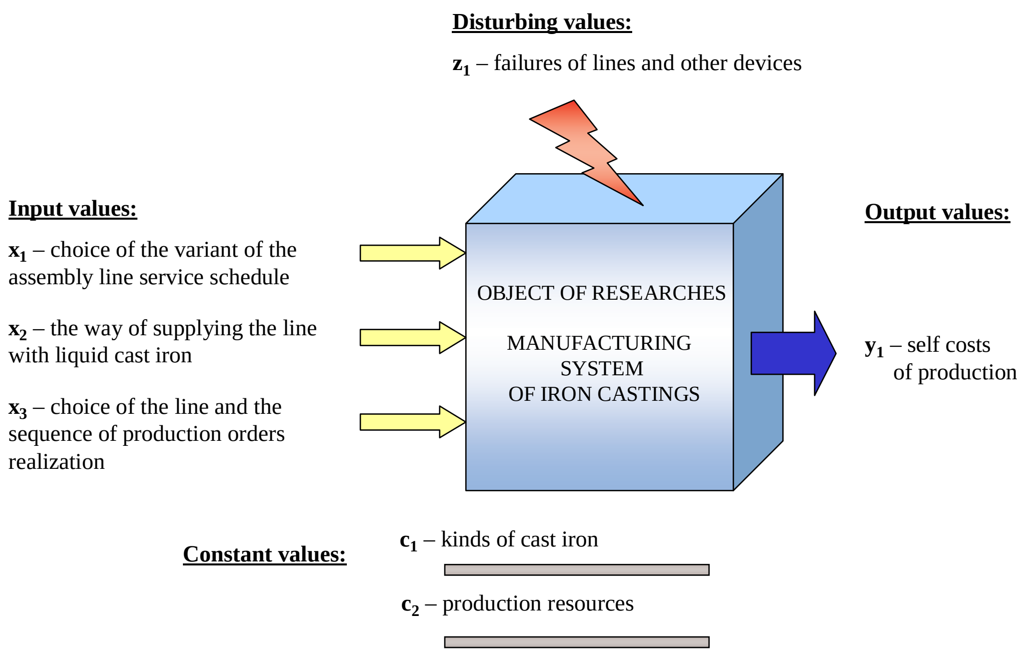

Fig. 5. Model of research object

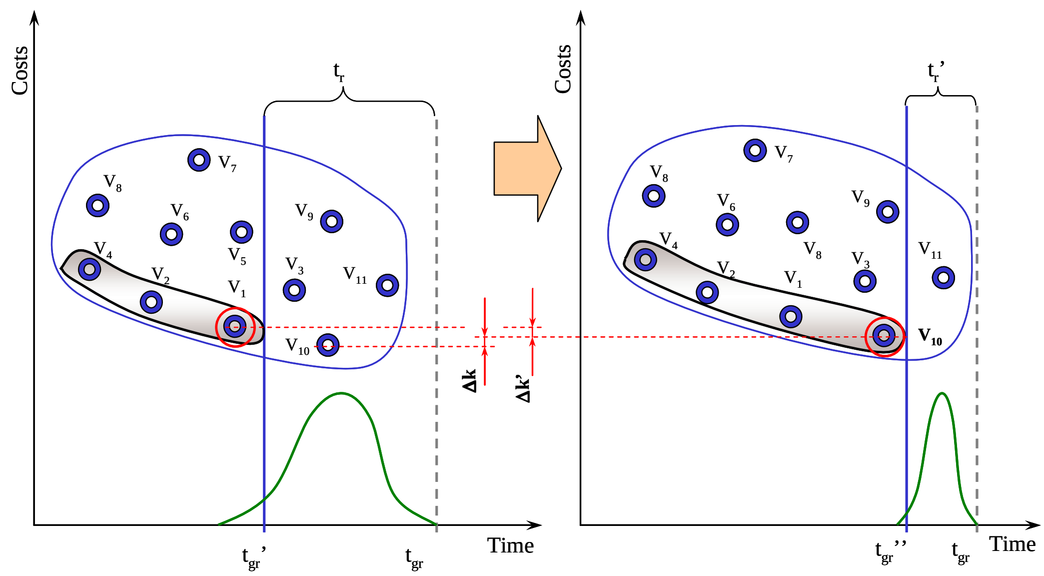

Fig. 6. Optimization of the iron casting production processes on the basis of Pareto analysis

4. DESCRIPTION OF THE OBTAINED RESULTS

On the basis of factor analysis of the research object different variants of schedules of the course of melting and work of foundry lines were generated (fig. 7).

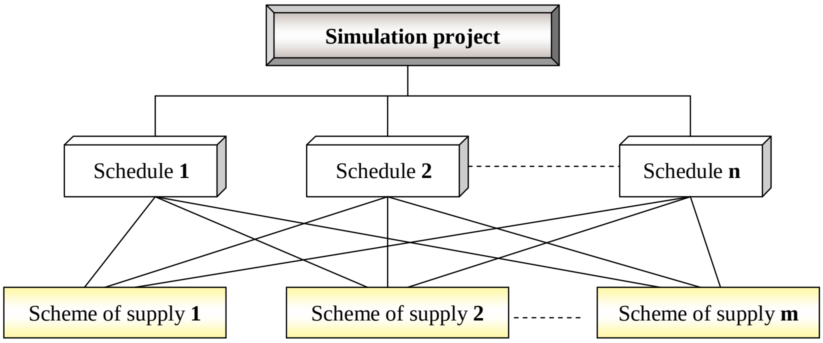

Fig. 7. Variants of schedules of the course of melting and work of foundry lines

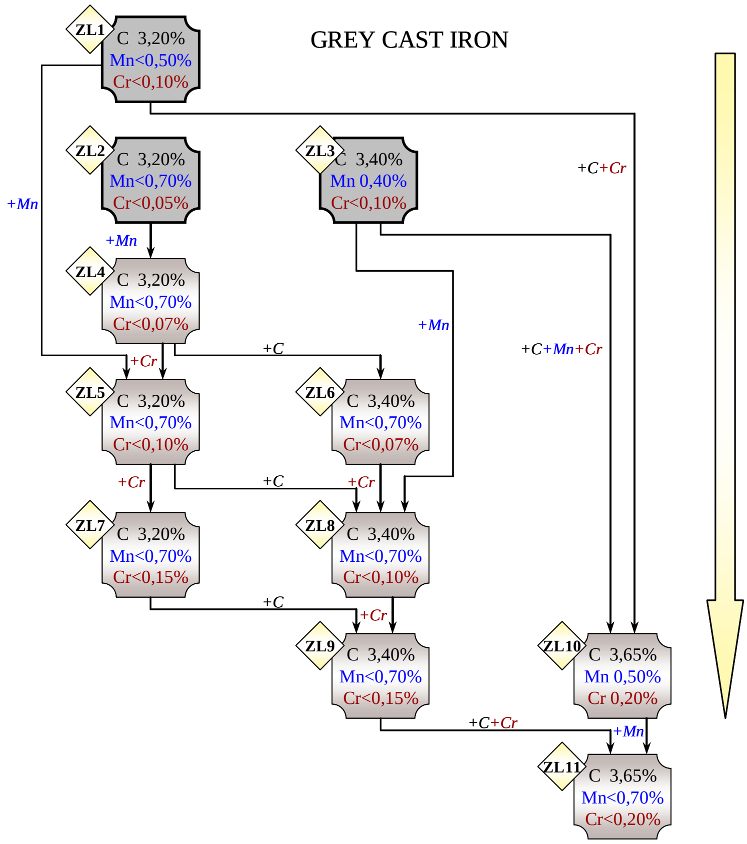

Fig. 8. Chemical constitution of grey cast iron – change of constitution

The way of supplying the line with liquid cast iron was depended on chemical constitution of cast iron (fig. 8 and 9).

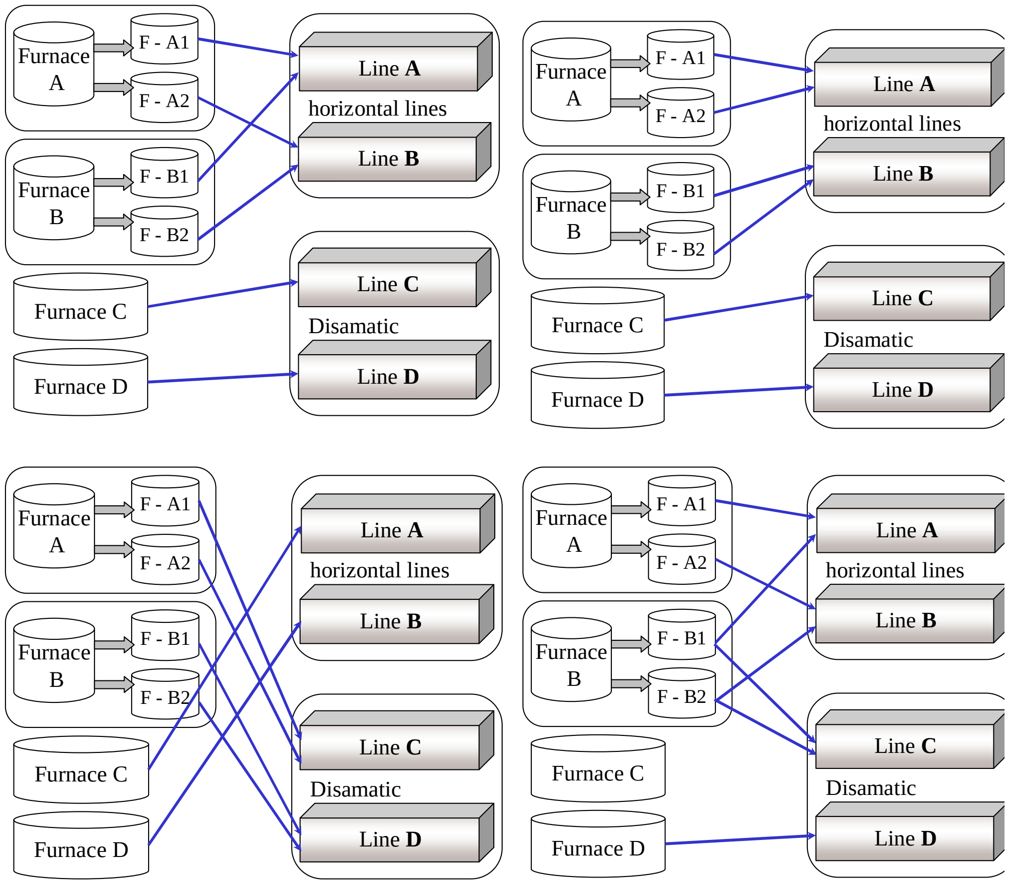

Fig. 9. The way of supplying the lines with liquid cast iron

On the basis of the conducted simulation experiments, a rational choice was made of the variant of melting process course in the sense of sequence of order realization, the size of production parts, the choice of the line and input and order of castings. The variants of manufacture scheduling were prepared on the basis of deformed data. The criteria for variants' evaluation were: time of order realization and self costs of cast production.

$$f(K_{mb}, K_{st}^{st}, K_{st}^{z}) \rightarrow \min \qquad (1)$$

where:

- K_{mb} - direct material costs,
- K_{st}^{st} - fixed stand costs,
- K_{st}^{z} - variable stand costs.

After excluding the schedule variants which did not fulfill time limitations (V1, V2, V3, V6), estimation of costs of the remaining variants was started basing on the factory spreadsheet.

Figure 10 presents a graph of stand costs and direct material costs.

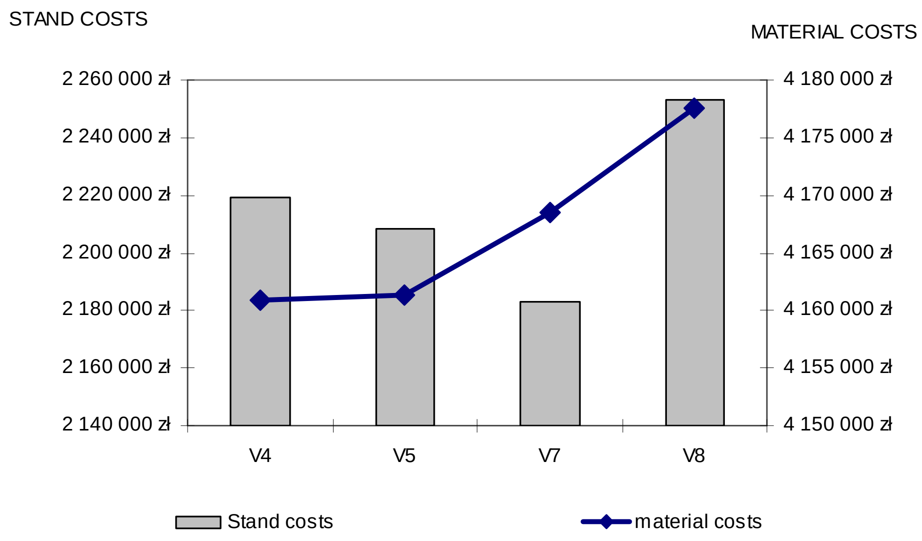

Fig. 10. Stand costs and material costs on the basis ZAR

Figure 11 presents a graph of collective self cost borne in the report period, which show that the preferred (the best) variant of production scheduling is the one signed as V7.

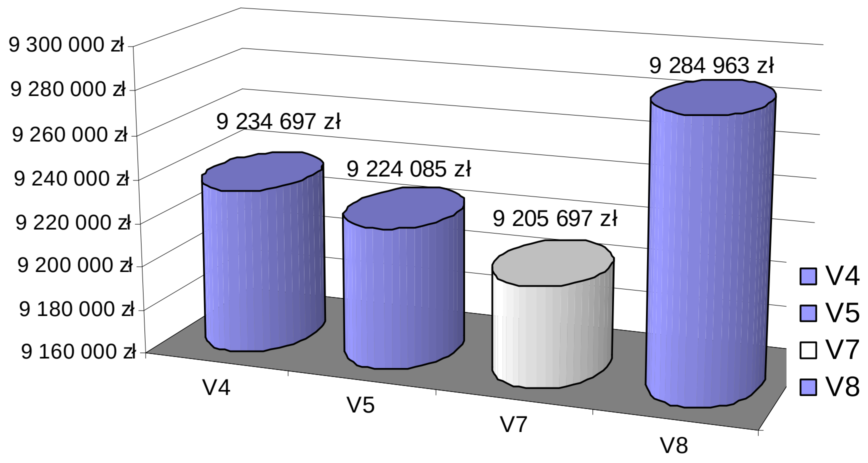

Fig. 11. Self cost on the basis ZAR

5. MULTI-CRITERION EVALUATION OF VARIANTS

When analyzing production systems performance, we need to take into consideration numerous criteria and evaluate their importance. In production practice, next to variant evaluation according to precise criteria (e.g. cost, time), there is also probabilistic evaluation (e.g. reliability functions) and evaluation according to fuzzy criteria (fig. 12) [12, 13].

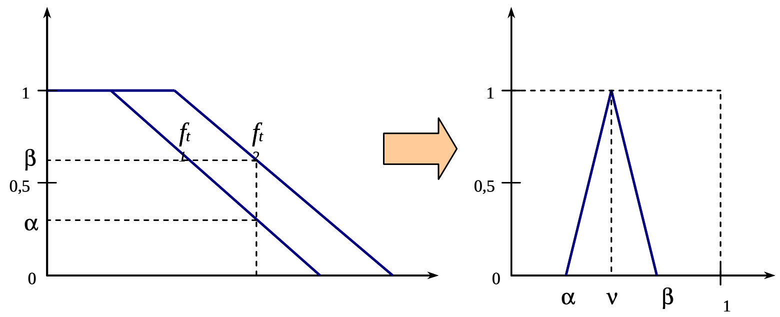

Fig. 12. Evaluation of variants on the basis fuzzy set

The input data in the method of multi-criterion evaluation described above is:

- number of criteria *m*,
- number of variants of production process *n*,
- elements of value matrix of particular criteria $B = [b_{ij}]$,
- elements of table $C = [c_{ij}(e)]$, which are normalized point evaluation of i-th variant according to the j-th criterion given by e-expert.

For importance evaluation of criteria and for evaluation of variants experts are employed. Each expert is responsible for building matrices of importance evaluation for criteria according to Saaty's method, which consists in comparing subsequent pairs of the assumed criteria (fig. 13).

Expert 1

	k1	k2	k3
k1	1	2	2
k2	0,5	1	1
k3	0,5	1	1

Expert 1

	k1	k2	k3
k1	1	1	2
k2	1	1	2
k3	0,5	0,5	1

Expert 1

	k1	k2	k3
k1	1	4	5
k2	0,25	1	1,25
k3	0,2	0,8	1

Fig. 13. Building matrices of importance evaluation for criteria according to Saaty's method

Particular b_{ij} values of the built matrix are assumed as follows:

- b_{ij} = 1, if k_i and k_j are equally important,
- b_{ij} = 3, if k_i is slightly more important than k_j,
- b_{ij} = 5, if k_i is much more important than k_j,
- b_{ij} = 7, if k_i is significantly more important than k_j,
- b_{ij} = 9, if k_i is absolutely more important than k_j
- b_{ij} = 2, 4, 6, 8 - indirect values.

Saaty’s method:

$$O(e)=\begin{bmatrix} o_{1,1} & \cdots & o_{1,j} & o_{1,j+1} & o_{1,j+2} & o_{1,j+3} & \cdots & o_{1,n-1} & o_{1,n} \\ & & \vdots & & & & & & \\ & & o_{i,j} & o_{i,j+1} & o_{i,j+2} & o_{i,j+3} & \cdots & o_{i,n-1} & o_{i,n} \\ & & & o_{i+1,j+1} & o_{i+1,j+2} & o_{i+1,j+3} & \cdots & o_{i+1,n-1} & o_{i+1,n} \\ & & & & o_{i+2,j+2} & o_{i+2,j+3} & \cdots & o_{i+2,n-1} & o_{i+2,n} \\ & & & & & o_{i+3,j+3} & \cdots & o_{i+3,n-1} & o_{i+3,n} \\ & & & & & & & \vdots & \\ & & & & & & & o_{n-1,n-1} & o_{n-1,n} \\ & & & & & & & & o_{n,n} \end{bmatrix} \tag{2}$$

$$o_{i,j}=1 \ \ (for \ \ i=j; \quad i,j=1,2,...,n) \tag{3}$$

$$o_{i+1,j+2}=\frac{o_{i,j+2}}{o_{i,j+1}} \ \ (for \ \ i=j; \quad i,j=1,2,...,n-2) \tag{4}$$

$$o_{i+1,j+1}=o_{i,j+1}\cdot\frac{o_{i+1,j}}{o_{i,j}} \qquad (i=1,2,...,n-3 \ ; \ \ j=i+2,i+3,...,n-1) \tag{5}$$

$$o_{i,j}=\frac{1}{o_{j,i}} \ \ (i,j=1,2,...,n) \tag{6}$$

Further, one summary matrix of criteria importance is created. For this matrix, a proper vector Y is looked for, which fulfills the following matrix equation:

$$B\,Y=\lambda_{max}\,Y \tag{7}$$

Proper vector Y has so many coordinates as many criteria were assumed, and these coordinates have to fulfill the following condition:

$$\sum_{j=1}^{m} y_j = m \tag{8}$$

Coordinates of the proper vector, called the weights, express the importance of particular criteria and they have been estimated by means of special software (Fig. 14).

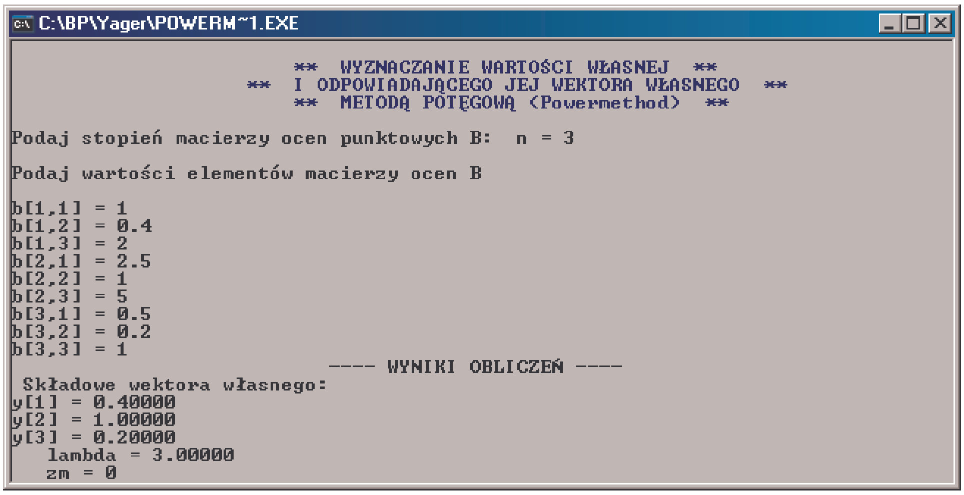

Fig. 14. Coordinates and value of the proper vector – special software

The next step is to evaluate the variants according to the assumed criteria, the evaluation is normalized, and summary normalized evaluation is created by averaging the evaluation given by experts. Further activities consist in making normalized decisions by raising each component of subsequent normalized evaluation to the power which equals the adequate weight.

$$d_j = \sum_{j=1}^{m} c_{ij}^{\,y_j} / w_i \tag{9}$$

$$\begin{aligned} d_1 &= c_{11}^{y_1} / w_1 + c_{21}^{y_1} / w_2 + \ldots + c_{n1}^{y_1} / w_n \\ d_2 &= c_{12}^{y_2} / w_1 + c_{22}^{y_2} / w_2 + \ldots + c_{n2}^{y_2} / w_n \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ d_m &= c_{1m}^{y_m} / w_1 + c_{2m}^{y_m} / w_2 + \ldots + c_{nm}^{y_m} / w_n \end{aligned} \tag{10}$$

Consequently, one decision function is created, on the basis of which a reasonable course of production process is chosen (minimum type decision). The best solution is the variant, in which component in decision function is the biggest, that is the largest value of the level of membership.

$$D_i = \min_j c_{ij}^{y_j} \tag{11}$$

$$D_{rac} = \max_i D_i \tag{12}$$

After being received from the line, castings undergo mechanic finishing. This finishing can be realized in a plant or in cooperation using traditional grinding tools or other techniques. Figure 15 and table 1 present possible variants of the course of finishing, thermal treatment and casting cleaning.

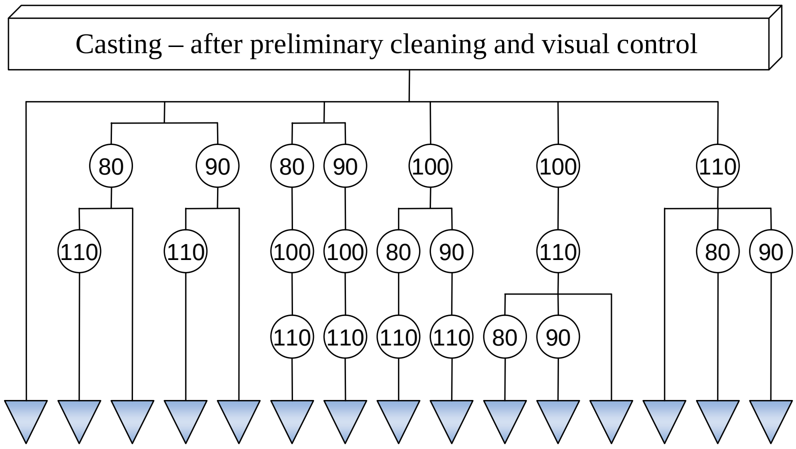

Fig. 15. Variants of the casting finishing treatment

Tab. 1. Graph description of variants of the casting finishing treatment

Number	Description of operation	Station
80	Machining operation in foundry	Station of machining operation in foundry
90	Machining operation in cooperation	Station of machining operation in cooperation enterprise
100	Thermal treatment	Furnace
110	Cleaning	Casting cleaning plant

Considering the method and the place of realization of finishing activities, the following variants of solutions were suggested (fig. 16):

- model 1: all castings are treated in cooperative plants,
- model 2: castings are ground in a foundry according to accessible resources, the rest in cooperation,
- model 3: all castings are treated on foundry premises equipped additionally with presses used for cast finishing,
- model 4: all castings are treated on the premises of a plant with traditional methods after installing additional grinding workplaces.

Unit matrices of criteria importance were built using the Saaty’s method and a summary matrix of criteria importance was prepared.

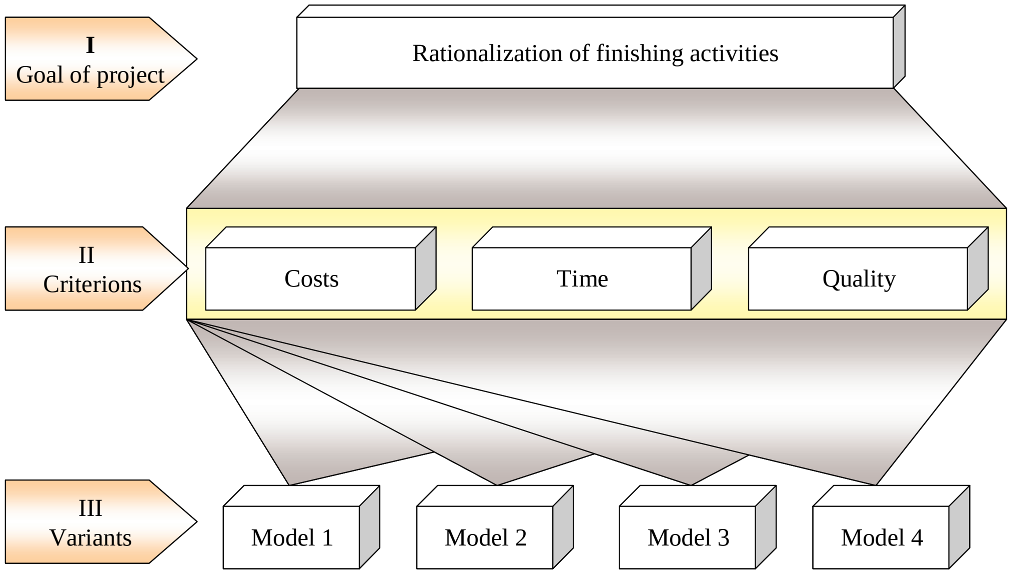

Fig. 16. Rationalization of finishing activities

The weights of particular criteria were estimated and the evaluation of all variants was made according to the assumed criteria (table 2). Point evaluation was normalized.

Tab. 2. Evaluation of variants

Criterion	Expert	Variants				Sj(e)
		M_1	M_2	M_3	M_4	
k_1	E_1	4	3	5	3	15
	E_2	1	3	5	4	13
	E_3	2	4	4	4	14
k_2	E_1	3	2	7	5	17
	E_2	1	3	8	5	17
	E_3	3	4	3	6	16
k_3	E_1	5	4	8	5	22
	E_2	2	4	6	4	16
	E_3	2	3	2	4	11

Next, total normalized evaluation was made and decision function was estimated (table 3).

Tab. 3. Estimated of decision function

Criterion	Variants			
	M_1	M_2	M_3	M_4
k_1	0,0454	0,0877	0,1556	0,1043
k_2	0,2290	0,2768	0,4604	0,4254
k_3	0,3881	0,4518	0,5231	0,4978

Results of this research, which were presented in table 4, show that the preferred variant of the process of the finishing process for castings is variant 3

Tab. 4. Results of multi-criterion evaluation of variants of the casting finishing treatment

Coordinates of the proper vector	$Y = \begin{bmatrix} 1{,}6993 \\ 0{,}7523 \\ 0{,}5484 \end{bmatrix}$
Decision function:	$D = \frac{0{,}0454}{M_1} + \frac{0{,}0877}{M_2} + \frac{0{,}1556}{M_3} + \frac{0{,}1043}{M_4}$
Prefer solution:	Variant **3** with maximum value in decision function: **0,1556**

6. CONCLUSIONS

Production processes are usually very complex. It happens that improving one link of a process results in worse functioning of the other. Choosing the size of production lot can exemplify this situation. Large lots are disadvantageous due to prolonged production cycle, increase of reserves, and longer time of reaction on customer needs. Small lots, on the other hand, cause frequent set-up change on workplaces.

Thanks to simulation, it will be possible to analyze problems related to changing assortment of production and to changing size of orders in the automotive market. Manufacture of larger casts with larger cross-sections and bigger demand for liquid metal on one form is connected with the need of diminishing line speed or with investments related to line rebuilding in order to prolong the way of cast cooling. Speed decrease of lines will reduce the system efficiency, without any influence on fixed costs in the report period. Consequently, fixed stand costs in calculation on the product will increase due to smaller quantity of the produced casts in relation to the available fund of work line time.

After implementing the investment which consists in line modernization, fixed stand costs will increase in the report period. Consequently, higher costs will be calculated on a larger number of produced casts in the available fund of work time. By means of computer model it will be possible to evaluate the efficiency of furnaces preparing liquid cast iron and lines in their present state and after modernization, without the need to experiment on the real system, and by means of ZAR it will be possible to estimate unitary stand costs depending on the load of foundry lines.

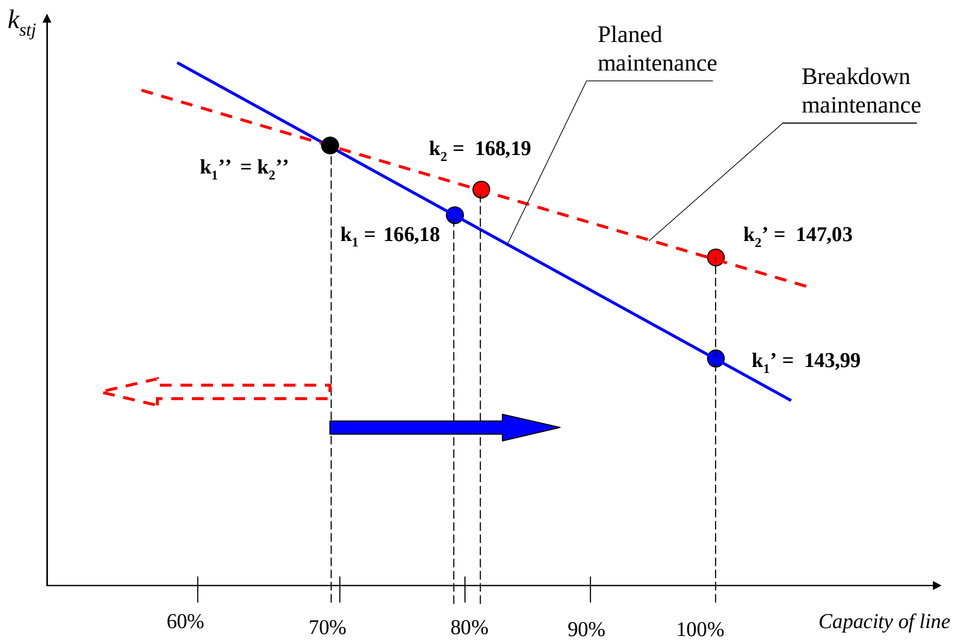

Fig. 17. Model of lines service

To solve the problem of optimal usage of foundry lines a model of line service should be created (fig. 17). It should consider the organizational possibilities of the enterprise on the basis of the prepared exploration database. Creating proper service schedules should improve efficiency from the organizational and technical aspects of managing the automated line and decrease the loses because of disruptions. With the help of the simulation technique the influence of the proposed schedules of automatic foundry lines service on the functioning of the system of iron castings manufacturing can be estimated.

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