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Multi-Criterion Assessment of Different Variants of Casts Manufacturing Processes

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Abstract

The paper presents the issue of production processes improvement in foundries in the area of finishing treatment of iron casts manufactured on automated foundry lines with vertical or horizontal mould division. Due to numerous factors which influence the efficiency of the processes, multi-criterion assessment tools were proposed in order to select the optimal solution for the assumed criteria. After determining the criteria weight using the Saaty method, a simulation experiment was designed and carried out which presents possible scenarios of casts finishing treatment operations. Basing on experiment reports from a computer model, particular solutions were evaluated using the Yager's method. The evaluation of the experiment results was performed by experts who assessed different options according to each of the criteria adopted. After the establishment of the total standardized ratings by averaging the scores given by individual experts, the final decision was generated. Using the presented method, the best solution was chosen from among the analyzed scenarios.

Keywords: Application of information technology to the foundry industry, Automation and robotics in foundry, Multi-criterion assessment of variants, Modelling and simulation of production processes

1. Introduction

Processes of iron casts manufacture belong to the most complex ones in the industry. Their optimization is difficult due to numerous factors influencing their course and because of many criteria that must be taken into account in their assessment.

Criteria are the basis for assessment in the pursuit of optimal choice, they clarify the description of the problem and form a factor that orientates activities towards rationalization of production systems.

In the classical methods of evaluation we can distinguish quantitative criteria (e.g. number of castings produced, cost of a workplace, turnaround time), and the criteria of a qualitative nature (e.g. less important, important, very important) [1-3].

Considering the nature of information data, w can distinguish the following criteria:

- deterministic (specified values, such as the number of pieces, efficiency, cost, cycle time),
- probabilistic (random variables represented by probability distributions such as reliability of the machines, breakdown times, etc.,
- fuzzy (subjective variables such as ergonomics, ease of use).

In situations when we do not have objective values of the characteristics related to the analyzed solution variants, we can apply a simulation experiment and multi-criterion evaluation tools. A computer model allows to analyse various decision situations which influence the course of casts manufacturing processes without the need of experimenting in production conditions. One of major problems in production management is also skilful manufacturing costs estimation and control [4-7].

2. Research object, aim and methodology

The presented research object is a system of manufacturing iron casts. The aim of the research is to improve production systems in foundries in the area of clearing and finishing treatment of casts produced in automated foundry lines.

For analyzing possible solutions of manufacturing processes improvement the technique of modelling and simulation of production systems was applied (Fig. 1). From among the planned and conducted simulation experiments the options were eliminated which do not fall within the set of feasible solutions due to the accepted limits (untimely execution of the order, too high costs, etc.) [8-10].

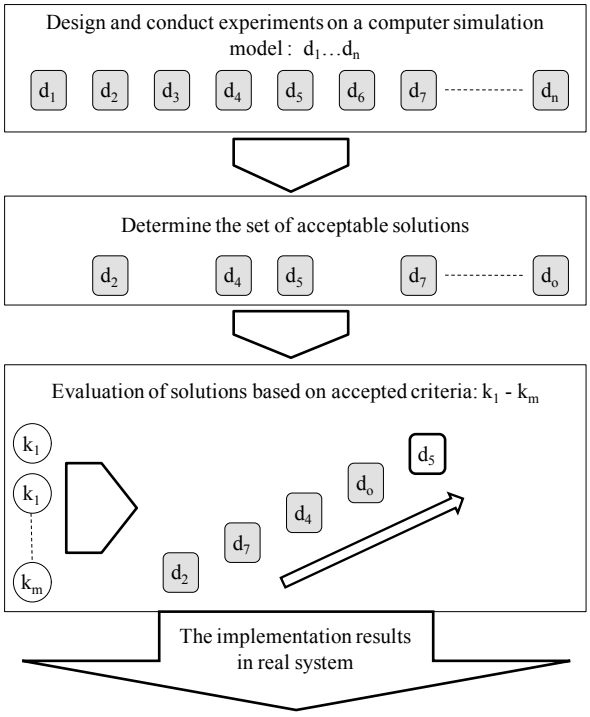


Fig. 1. Multi-criterion evaluation of variants basing on a simulation experiment

Due to the need to consider a higher number of criteria when valuating particular variants of the course of the production process, the Yager's point ranking method was applied (Fig. 2).

The input data of this method include [11-13]:

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

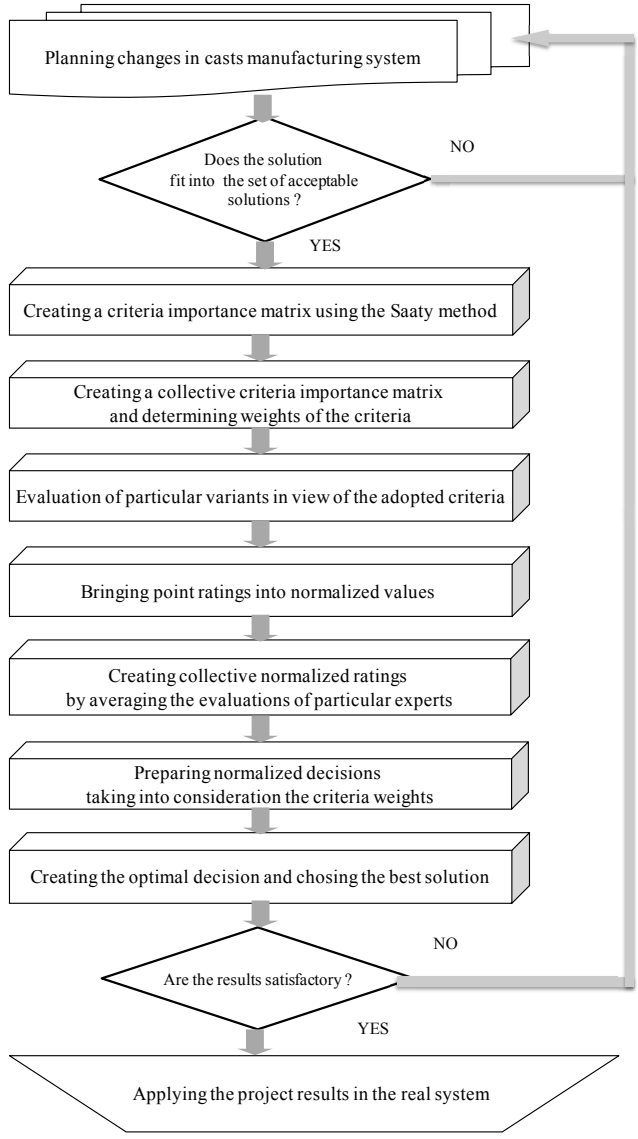


Fig. 2. Multi-criterion valuation of variants according to Yager's method

To assess the validity of the criteria and evaluate the different options, some decision-makers were established. Each of the decision-makers is responsible for the construction of a matrix of criteria validity ratings using the Saaty method, in order to compare criteria in pairs. Particular values b_{ij} of the composed matrix have been assumed as follows [14]:

- $b_{ij} = 1$, 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 definitely more important than k_j,
- $b_{ij} = 2, 4, 6, 8$ – intermediate values between the above situations,
- $b_{ji} = 1/b_{ij}$.

Subsequently, one collective matrix of criteria importance was created. For this common matrix an eigenvector Y is looked for, which satisfies the following matrix equation:

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

where: B– the collective criteria importance matrix, Y – eigenvector of the matrix, λ_{max} – maximum eigenvalue of the matrix B.

The eigenvector Y has as many coordinates as adopted criteria, and these coordinates must satisfy the following condition:

$$\sum_{j=1}^{m} y_j = m \tag{2}$$

where: y_j is the j-th coordinate of the eigenvector Y.

The coordinates of the eigenvector, called weights, express the importance of the corresponding criteria. Using the Power method the eigenvalue and the corresponding eigenvector are determined. Thereafter, point ratings are brought $S_{ij}(e)$ to normed values $c_{ij}(e)$.

It is assumed that $S_{ij}(e)$ $(i=1,...,n,\ j=1,...,m)$ are point ratings assigned to particular variants of the production process course in view of the assumed criteria given by e-th expert.

The next stage of the Yager's method consists in creating overall ratings normalized by averaging the scores given by individual experts (p – number of experts).

$$c_{ij} = \frac{1}{p}\sum_{e=1}^{p} c_{ij}(e) \tag{3}$$

Further proceeding is to create standardized decisions by raising components of following normalized ratings to the power of proper weight.

$$d_j = \sum_{j=1}^{m} c_{ij}^{\,y_j} / w_i \tag{4}$$

After transcribing, formula 4 takes on the following form:

$$\begin{aligned} d_1 &= c_{11}^{y_1} / w_1 + c_{21}^{y_1} / w_2 + ... + c_{n1}^{y_1} / w_n \\ d_2 &= c_{12}^{y_2} / w_1 + c_{22}^{y_2} / w_2 + ... + c_{n2}^{y_2} / w_n \\ &\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ d_m &= c_{1m}^{y_m} / w_1 + c_{2m}^{y_m} / w_2 + ... + c_{nm}^{y_m} / w_n \end{aligned} \tag{5}$$

As a result, one so called optimal decision is taken, on the basis of which a rational production process course is chosen that best meets all of the criteria adopted for evaluation.

$$D = D_1 + D_2 + ... + D_n \tag{6}$$

In the adopted method, the optimal decision is the minimum type decision. The i-th component of the optimum decision, corresponding to the i-th variant is assumed to be the smallest i-th component from particular decisions $d_1, d_2,...,d_m$.

$$D_i = \min_j c_{ij}^{\,y_j} \tag{7}$$

The best variant of the production process is a variant, which corresponds to the largest component in the optimum decision, which is the highest value of the degree of belonging.

$$D_{rac} = \max_i D_i \tag{8}$$

3. Description of the obtained results

The method of multi-criterion variants evaluation presented in point 2 above was adopted for assessing variants of casts finishing treatment processes. Assessment criteria included estimated costs of treatment operations, delivery time and ergonomics of a work position.

First, the importance of particular criteria was evaluated using the Saaty method and the eigenvector of the matrix was determined (Fig. 3). Figure 4 presents point ratings of the assessed variants according to each criterion.

Expert 1

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

Expert 2

	k1	k2	k3
k1	1	3	5
k2	0,33	1	1
k3	0,2	1	1

Expert 3

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

Cumulative matrix validity of the criteria B

	k1	k2	k3
k1	1	3,000	5
k2	0,333	1	1,667
k3	0,214	0,600	1

$$Y = \begin{bmatrix} 1{,}9354 \\ 0{,}6601 \\ 0{,}4045 \end{bmatrix}$$

Fig. 3. Criteria importance evaluation - the Saaty method

Criterion	Expert	Variants					Sj(e)
		V_1	V_2	V_3	V_4	V_5	
k_1	E_1	4	3	3	4	3	17
	E_2	1	2	4	5	2	14
	E_3	2	4	4	4	4	18
k_2	E_1	3	2	4	7	5	21
	E_2	1	3	5	8	6	23
	E_3	3	4	6	3	5	21
k_3	E_1	5	3	5	8	4	25
	E_2	2	4	4	6	3	19
	E_3	2	3	4	2	2	13

Fig. 4. Point rating of variants according to the assumed criteria

The criteria included costs of production treatments estimated basing on a company accounting sheet, lead times of production orders and work ergonomics.

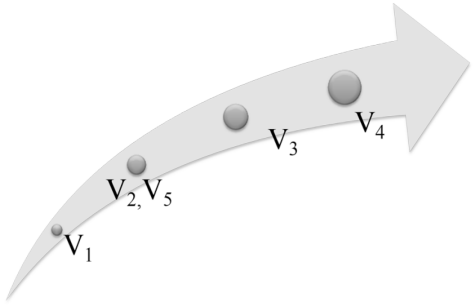
Subsequently, results of creating normed decisions obtained by raising components of following normalized ratings

to the power of proper weight were summarized in the table in Figure 5.

Criterion	Variants				
	V_1	V_2	V_3	V_4	V_5
k_1	0,0220	0,0364	0,0573	0,0802	0,0364
k_2	0,2326	0,2715	0,3804	0,4262	0,3960
k_3	0,4680	0,5076	0,5609	0,5828	0,4732

Fig. 5. Creating normalized decisions

As a result of the presented proceedings, the most favorable variant was chosen from among the analyzed options, which turned out to be the solution numbered with 4. (Fig. 6).



Variants	V_1	V_2	V_3	V_4	V_5
min	0,0220	0,0364	0,0573	0,0802	0,0364

Fig. 6. Creating the optimal decision and ranking of variants

4. Conclusions

Thanks to applying modelling and simulation of production systems it is possible to check different scenarios of solutions related to finishing treatment of iron casts. The experiment results do not, however, present an unequivocal answer which of the simulated variants is optimal. The results allow for estimating execution times of production orders and their cost on the basis of company accounting sheet. Assuming a suitable workflow diagram on a position we can determine its ergonomics in a point scale.

Applying a multi-criterion assessment according to Yager makes it possible to select a rational course of the production process easily and efficiently. Thanks to importance assessment of particular criteria and considering their weights in further proceedings it will be possible to evaluate particular variants of the process and rank them from the best to the worst one.

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