Rationalization of foundry processes on the basis of simulation experiment

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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. A simulation model of automobile industry foundry was made. The course of the following processes was analyzed in a computer model: preparation of liquid cast iron, forming and filling the moulds, cooling and stamping the castings, cleaning and finishing treatment. The sheets of multi-criterion evaluation were prepared, where criteria and variants were assessed by means of subjective point evaluation and fuzzy character evaluation. The paper presents an analysis example of finishing activities of castings realized in foundry on traditional machines and efficient presses and in cooperation. 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.

Keywords: Application of information technology to the foundry industry; Automation and robotics in foundry; Modelling and simulation of production systems; Multi-criterion evaluation of variants; Finishing treatment of iron castings

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 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, etc.).

On the basis of observing production enterprises from the foundry industry we can draw the conclusion that when it comes to construction and technology, the possibilities of cost reduction decrease. More imperfections, which influence the costs, can be found in the field of production organization, planning and management. If cost reduction is oriented on eliminating wastage, we get a positive effect in structuring plant culture. The results include: simplifying the course of the realized processes, increase in workers' involvement in the realized changes, decentralization and increased flexibility of an enterprise [1, 2].

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.

We can distinguish seven types of wastage in a production process (Fig. 1). It is necessary to improve processes by increasing the share of value-making operation in a production cycle, elimination of losses and reduction of operations that support value-making.
2. The aim and research methodology

The paper presents the application of computer simulation to show the behaviour of production system (Fig. 2), as well as the use of multi-criterion tools for variant evaluation in rationalization of manufacturing processes of castings on the example of finishing treatment.

Simulation will make it possible to verify the duration of activities, detect the hidden costs related to frequent production stops due to production processes limitation and lack of material. Simulation will also make it possible to analyze production capacity of devices which influence unit costs of castings thanks to reasonable use of production workplaces without complicated formulas or equations that are difficult to solve by analytical methods [3, 4, 5, 6, 7, 8, 9].

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, number of produced castings), there is also probabilistic evaluation (e.g. reliability functions) and evaluation according to fuzzy criteria (e.g. level of customer satisfaction, quality of produced goods) [10, 11, 12, 13, 14].

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 an 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. Particular \( b_{ij} \) values of the built matrix are 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.

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:

\[
B \cdot Y = \lambda_{\text{max}} Y \tag{1}
\]

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

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

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. 3).
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.

\[
d_{i} = \frac{c_{i1}}{w_1} + \frac{c_{i2}}{w_2} + \cdots + \frac{c_{in}}{w_n}
\]

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.

\[
D_{\text{max}} = \max_{i} D_{i}
\]

### 3. Description of the obtained results

The main interest of this paper is the system of manufacturing iron castings on foundry lines [15, 16, 17]. 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 4 and table 1 present possible variants of the course of finishing, thermal treatment and casting cleaning.

![Fig. 4. Variants of the casting finishing treatment](image)

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

<table>
<thead>
<tr>
<th>Number</th>
<th>Description of operation</th>
<th>Station</th>
</tr>
</thead>
<tbody>
<tr>
<td>80</td>
<td>Machining operation in foundry</td>
<td>Station of machining operation in foundry</td>
</tr>
<tr>
<td>90</td>
<td>Machining operation in cooperation</td>
<td>Station of machining operation in cooperation enterprise</td>
</tr>
<tr>
<td>100</td>
<td>Thermal treatment</td>
<td>Furnace</td>
</tr>
<tr>
<td>110</td>
<td>Cleaning</td>
<td>Casting cleaning plant</td>
</tr>
</tbody>
</table>

After building and testing a simulation model, which presents the processes of liquid cast iron preparation, moulding and pouring on automatic foundry lines, the model was extended by processes related to cast finishing (Fig. 5).

![Fig. 5. Simulation model of production system made in ARENA](image)

Consider the method and the place of realization of finishing activities, the following variants of solutions were suggested:

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

The following criteria were suggested for evaluation of subsequent variants of solutions for finishing processes:

- cost of finishing activities in the analyzed period,
- length of the production cycle,
- quality of activities (services).

Unit matrices of criteria importance were built using the Saaty’s method and a summary matrix of criteria importance was prepared. The weights of particular criteria were estimated and the evaluation of all variants was made according to the assumed criteria. Point evaluation was normalized. Next, total normalized evaluation was made and decision function was estimated.

Table 2. Results of multi-criterion evaluation of variants of the casting finishing treatment

<table>
<thead>
<tr>
<th>Coordinates of the proper vector</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Y = \begin{bmatrix} 1.6993 \ 0.7523 \ 0.5484 \end{bmatrix} )</td>
</tr>
</tbody>
</table>

| Decision function: \( D = \frac{0.0454}{W_1} + \frac{0.0877}{W_2} + \frac{0.1556}{W_3} + \frac{0.1043}{W_4} \) |
| Prefer solution: Variant 3 with maximum value in decision function: \( 0.1556 \) |
Results of this research, which were presented in table 2, show that the preferred variant of the process of the finishing process for castings is variant 3.

4. Conclusions

The advantage of taking up cooperation with external companies in case of cast finishing is the possibility of negotiating a good price for services and no need to manager this part of the process. Disadvantages include prolonging of the production cycle, the need of additional weighting and transporting castings and problems with service quality. Realization of finishing activities in a plant may be connected with the need to employ new workers and purchase new workplaces. There exists a possibility of efficiency increase of finishing treatment in case of some castings by using presses for such activities. Presses are more expensive and more complex in operation, but using them in finishing increases the efficiency of activities several times in comparison to traditional methods. A disadvantage here is the need to clean the castings again.

Thanks to modelling and simulation it will possible to check different scenarios of solutions related to the course of finishing of castings without the need to experiment on the real system. Simulation results can undergo multi-criterion evaluation and the best solution can be chosen, according to the assumed criteria.

References