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# USING THE QUALITY FUNCTION DEPLOYMENT METHOD IN THE DESIGN OF DIE CASTING CELLS

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**Abstract**

The present work proposes, by using the Quality Function Deployment (QFD) method, to account for customer requirements in the design of specialized cells for die casting. The proposed method allows for the evaluation of the client's requirements related to the degree of automation, working parameters, and the cost of the designed cell. Considering the specifics of machine casting, two QFD matrices have been developed and the expert evaluations necessary for their use have been determined. Application of the method allows precise definition of the design assignment and reduction of the risk of significant changes in the cell construction at later stages of the design and related costs.

**Keywords:** Design; Die Casting Cells; Quality Function Deployment Method; Industrial Automation

## 1. Introduction

In the industry, in the large-scale and mass production of parts of metals and alloys with a low melting temperature, the methods of machine casting under pressure, in metal moulds (Die) are mainly used [2]. For this purpose, special machines are used, which are designed to hold open and close the two halves of the mould, to keep the mould closed while the liquid metal is fed into the cavity and to provide the necessary pressure to fill the mould cavity of the mould with molten metal [1].

Industrial robots allow the operation of these machines to be fully automated by creating specialized cells for machine casting under pressure. The use of such cells improves the quality of manufactured products, safety, working conditions and reduces the cost of manufactured parts.

Currently, a number of companies offer machines for pressure casting [10], industrial robots for automating various stages of the operation of these machines, and specialized cells for the machine casting of high pressure [8], [9], [11]. This great variety poses the question of finding an optimal solution for the conditions of a specific company wishing to automate the production of details from metals and alloys with a low melting temperature.

The present work proposes, by using the Quality Function Deployment (QFD) method, at the design stage of specialized cells for machine Die casting, to determine the requirements of the user and to select the main components of the cell, which will significantly reduce the time for design, manufacture, and commissioning of the cell.

## 2. Design of die casting cells

The main component in the structure of an automated Die casting cell is the Die casting machine, which performs the main process operation. The automation of the operation of this machine can include the following different levels:

- Partial automation of the operation of the machine - only some of the auxiliary operations related to the operation of the machine are automated: supply of molten metal to the machine, lubricating of the form, removal of the casting from the machine;
- Full automation of the machine's operation - all auxiliary operations related to the machine's operation are automated;
- Full automation of the operation of the machine with additional processing of the obtained casting - all auxiliary operations related to the operation of the machine are automated and inclusion in the cell of additional automated operations for processing the obtained casting such as: cooling, trimming (removal of the back scrap), control, etc.

Depending on the goals pursued with automating the operation of the Die casting machine, a cell for the Die casting may include a different combination of the components shown in Fig. 1.

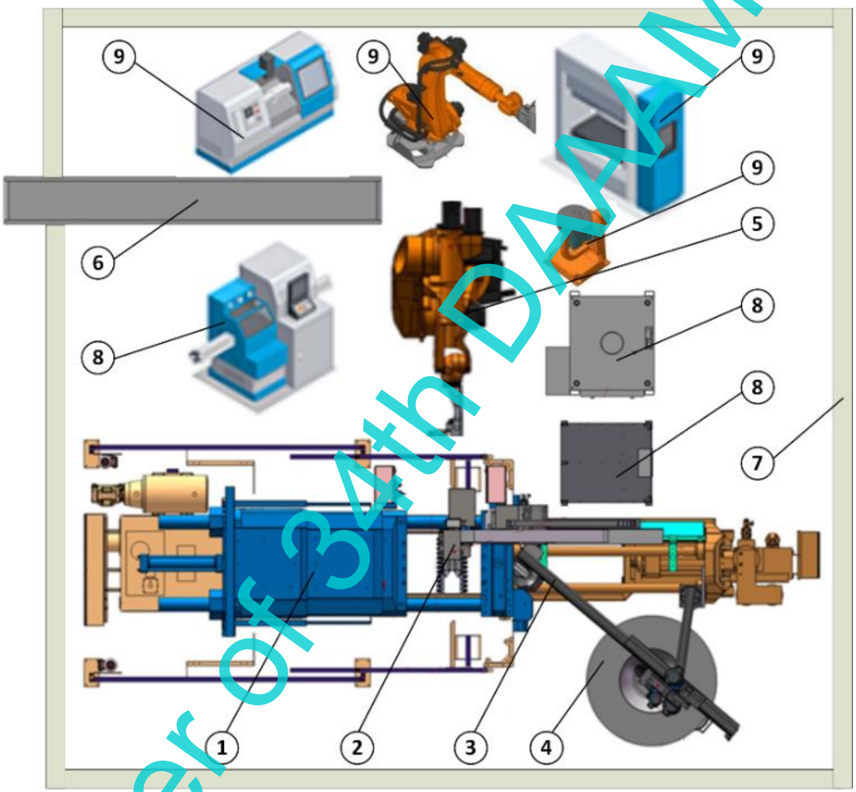



Fig. 1. Die casting cell

These components are:

1. Die casting machine
2. Sprayer robot for lubricating of Die - Sprayer
3. Robot for supplying molten metal - Feeder
4. Melting furnace
5. Robot for extracting the casting from the Die - Extractor
6. Conveyor for removing the casting from the cell
7. Protective fences
8. Components for primary processing of the resulting casting - cooling, trimming, control
9. Components for additional processing of the resulting casting - industrial robots, processing machines, reorienting devices, etc.

Many publications are devoted to methodologies and algorithms for the design of various products [3], [5] and cells for Die casting [4], [6], [7]. They examine the main stages of design, the relationship between these stages and the possibilities for optimizing the designed products.

The main stage in the design of the cell is the selection of the necessary components, determining their location in space and the functional connections between them. This requires a clear formulation of the tasks that will be solved with the help of the designed cell since changing the already selected components at a later stage of the design is associated with significant losses of time and money.

## 3. Using the quality function deployment method in the design of die casting cells

To solve the tasks related to the selection of the necessary components in the Die casting cell structure, the QFD method is proposed, which uses a series of matrices to define the customer's requirements to be embodied in the final product.

The first proposed matrix Fig. 2 aims to determine what are the necessary components in the structure of a Die casting cell, depending on the level of automation that is desired by the customer.

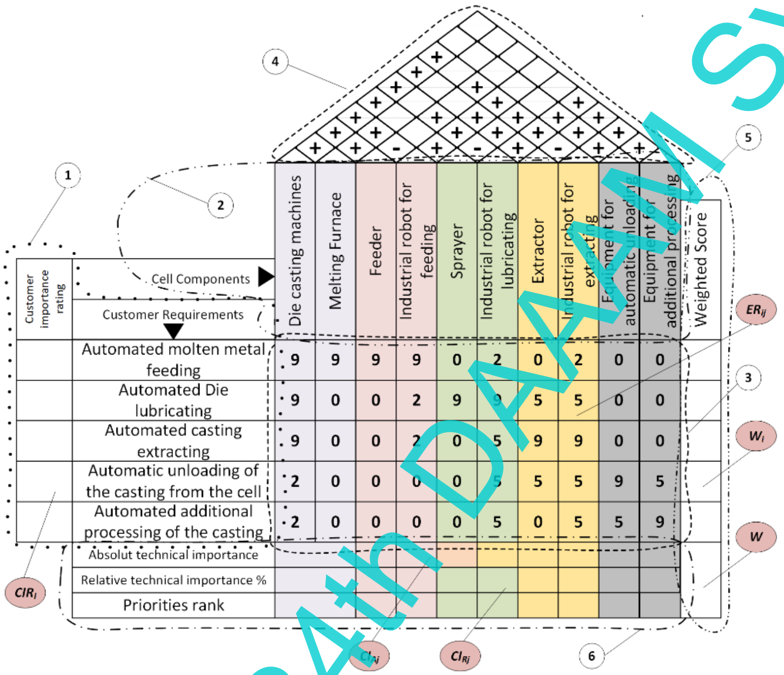



Fig. 2. The first proposed matrix

The individual sections in this matrix are:

- **Customer Requirements (1)** - all the options for automating the operation of the Die casting machine discussed above are recorded here. The customer gives an assessment of these possibilities, according to the desired degree of cell automation. Customer ratings range from ***5*** (mandatory automation of the relevant process) to ***0*** (no need to automate the relevant process).
- **Cell Components (2)** - here are written the groups of components that make up an automated Die casting cell, according to the scheme shown in Fig. 1.
- **Relationships between customer requirements and cell components (3)** - here an expert assessment of the importance of individual components to satisfy customer requirements is given (***ER***). A scale from ***9*** (the component is mandatory for the implementation of the corresponding function) to ***0*** (the component has no connection with the implementation of the corresponding function) was used.
- **Interaction between the components of the cell (4)** - here the defined relationships between the components necessary to realize the customer's requirements are shown. Possible connections are:
  - (+) - positive - possible integration of the components and harmonization of the functions performed by them;
  - (-) - negative - mutually exclusive components performing the same function;
  - (**empty**) - lack of interaction between components.
- **Comparing components (5)** - here, based on the client's desire and the given expert assessments, the weight of realizing the degree of automation desired by the client with the necessary components is determined. Equation (1) is used for this purpose:

$$W_i = CIR_i * \sum_{j=1}^{10} ER_{ij} \tag{1}$$

where:

$W_i$ - Weight of realization of the $i^{-th}$ degree of automation desired by the client;

$CIR_i$ - Customer Importance Rang of the $i^{-th}$ degree of automation desired by the customer;

$ER_{ij}$ - Expert Rating of the importance of achieving the $i^{-th}$ degree of automation desired by the customer with the $j^{-th}$ component.

The total weight for achieving the degree of automation desired by the customer is determined by (2):

$$W = \sum_{i=1}^{5} W_i \tag{2}$$

where:

$W$ - Total weight of realizing the degree of automation desired by the client;

$W_i$ - Weight of realization of the $i^{-th}$ degree of automation desired by the client.

- **Importance (6)** - here, based on the degree of automation desired by the client and the given expert assessments, the absolute and relative importance of individual components to achieve the client's wishes is determined. Equations (3) and (4) are used for this purpose:

$$CI_{Aj} = \sum_{i=1}^{5} CIR_i * ER_{ij} \tag{3}$$

where:

$CI_{Ai}$ - Absolut technical importance of the $j^{-th}$ component.

$$CI_{Rj} = \frac{CI_{Aj}}{W} * 100\% \tag{4}$$

where:

$CI_{Ri}$ - Relative technical importance of the $j^{-th}$ component.

Based on the relative importance value obtained ($CI_{Ri}$), the components of the cell are ranked, which allows to determine their importance for realizing the user's desire.

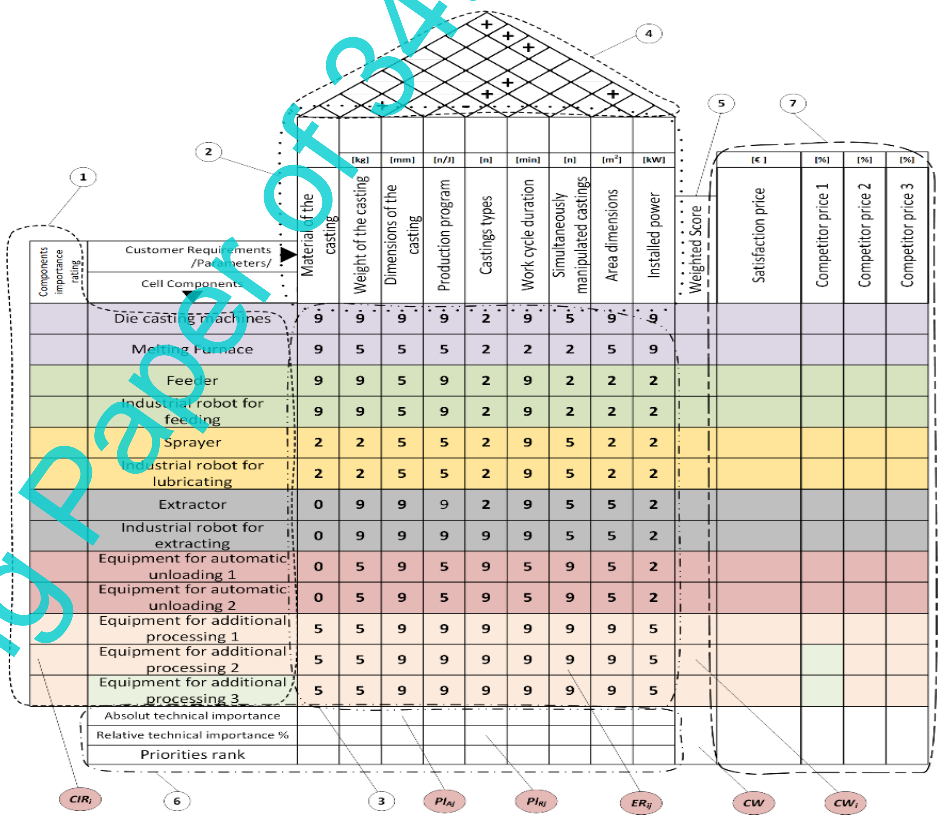



Fig. 3. The second proposed matrix

The second proposed matrix, Fig. 3, aims to determine the influence of the working parameters of the cell desired by the customer on the components of the cell determined with the help of the first matrix.

The individual sections in this matrix are:

- **Cell components (1)** - here are recorded the cell components determined using the first matrix. The assessment of the importance of these components (Component's importance rating)is according to their ranking in the first matrix (Priorities rank Fig. 1). Ratings range from ***5*** (component ranked first) to ***1*** (component ranked last).
- **Customer requirements (2)** - here are recorded the operating parameters of the cell desired by the customer, and their specific values are indicated.
- **Relationships between customer requirements and cell components (3)** - here an expert assessment of the relationship between the cell components and its operating parameters required by the customer is given (***ER***). A scale from ***9*** (the parameter determines the selection of the corresponding component) to ***0*** (the parameter does not influence the selection of the corresponding component) is used.
- **Connection between cell parameters (4)** - here are shown the defined connections between the working parameters of the cell required by the customer. The possible connections are:
  (+) - positive - changing of one of the parameters does not complicate the construction of the cell;
  (-) - negative - changing of one of the parameters leads to the complication of the cell construction;
  (**empty**) - lack of interaction between parameters.
- **Comparing components (5)** - here, based on the assessment of importance for the respective component and the given expert evaluations, the weight of the individual components is determined. Equation (5) is used for this purpose:

$$CW_i = CIR_i * \sum_{j=1}^{9} ER_{ij} \tag{5}$$

where:
$CW_i$ - Weight of the $i^{-th}$ component;
$CIR_i$ - Customer Importance Rang of the $i^{-th}$ component;
$ER_{ij}$ - Expert Rating of the relationship of the $i^{-th}$ component with the $j^{-th}$ cell parameter
The total weight of the components to achieve the customer's wishes is determined by (6):

$$CW = \sum_{i=1}^{13} CW_i \tag{6}$$

where:
$CW$ - Total weight of the components to realize the wishes of the client;
$CW_i$ - Weight of the $i^{-th}$ component.

- **Importance (6)** - here, based on the cell parameters desired by the client and the given expert assessments, the absolute and relative importance of the individual parameters on the cell construction is determined. Equations (7) and (8) are used for this purpose:

$$PI_{Aj} = \sum_{i=1}^{13} CIR_i * ER_{ij} \tag{7}$$

where:
$PI_{Ai}$ - Absolut technical importance of the $j^{-th}$ parameter.

$$PI_{Rj} = \frac{PI_{Aj}}{CW} * 100\% \tag{8}$$

where:
$PI_{Ri}$ - Relative technical importance relative of the $j^{-th}$ parameter.

- **Price (7)** - here, based on market research, an estimate is given of the price of marketed components necessary for the construction of the cell and the funds that the customer has foreseen for these components.

Based on the values obtained for the relative importance ($PI_{Ri}$), the parameters of the cell are ranked, which allows to determine their influence on the construction of the cell.

Analyzing the data on the cost of the components currently offered on the market, necessary to build the cell and the determined influence of the working parameters of the cell desired by the customer, on its construction, the assignment for the design of the cell is prepared.

The proposed method allows, before the start of the actual design of die casting cells, to clarify the wishes of the client related to the degree of automation, working parameters and expected cost of the cell.

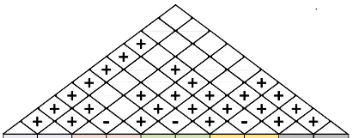
The correct definition of the customer's wishes significantly reduces the risk of changes in the basic structure of the cell, at a later stage of the design process, and the associated costs.

## 4. Examples of using the quality function deployment method in the design of die casting cells

Exemplary applications of the proposed method for two cases of Die casting cells design with different degrees of automation are given below. The price data of the cell components used in the compilation of the matrices are illustrative and do not correspond to the actual ones.

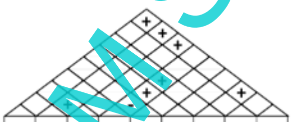
### *4.1 Partial automation of the operation of Die casting machine*

The first of the proposed matrices is shown in Fig. 4.a. Taking into account the customer's wishes for the automatic loading of molten metal into the machine and automatic lubricating of the Die, the components necessary for building the cell were determined and ranked.



| Customer importance rating | Cell Components ▶ / Customer Requirements ▼ | Die casting machines | Melting Furnace | Feeder | Industrial robot for feeding | Sprayer | Industrial robot for lubricating | Extractor | Industrial robot for extracting | Equipment for automatic unloading | Equipment for additional processing | Weighted Score |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | Automated molten metal feeding | 9 | 9 | 9 | 9 | 0 | 2 | 0 | 2 | 0 | 0 | 200 |
| 5 | Automated Die lubricating | 9 | 0 | 0 | 2 | 9 | 9 | 5 | 5 | 0 | 0 | 195 |
| 0 | Automated casting extracting | 9 | 0 | 0 | 2 | 0 | 5 | 9 | 9 | 0 | 0 | 0 |
| 0 | Automatic unloading of the casting from the cell | 2 | 0 | 0 | 0 | 0 | 5 | 5 | 5 | 9 | 5 | 0 |
| 0 | Automated additional processing of the casting | 2 | 0 | 0 | 0 | 0 | 5 | 0 | 5 | 5 | 9 | 0 |
| | Absolut technical importance | 135 | | 45 | 55 | 45 | 55 | 25 | 35 | 0 | 0 | |
| | Relative technical importance % | 34,2 | | 11,4 | 13,9 | 11,4 | 13,9 | 6,3 | 8,9 | 0 | 0 | 395 |
| | Priorities rank | 1 | | 3 | 2 | 3 | 2 | 5 | 4 | - | - | |

a)



| Components importance rating | Customer Requirements /Parameters/ ▶ / Cell Components ▼ | Material of the casting | Weight of the casting [kg] | Dimensions of the casting [mm] | Production program [illegible] | Castings types [n] | Work cycle duration [min] | Simultaneously manipulated castings [n] | Area dimensions [m²] | Installed power [kW] | Weighted Score | Satisfaction price [€] | Competitor price 1 [%] | Competitor price 2 [%] | Competitor price 3 [%] |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5 | Die casting machines | 9 | 9 | 9 | 9 | 2 | 9 | 5 | 9 | 9 | 350 | 100000 | 1.00 | 1.30 | 0.95 |
| 5 | Melting Furnace | 9 | 5 | 5 | 5 | 2 | 2 | 2 | 5 | 9 | 220 | 10000 | 1.20 | 0.95 | 1.00 |
| 3 | Feeder | 9 | 9 | 5 | 9 | 2 | 9 | 2 | 2 | 2 | 147 | 1000 | 1.00 | 0.86 | 0.95 |
| 4 | Industrial robot for feeding | 9 | 9 | 5 | 9 | 2 | 9 | 2 | 2 | 2 | 196 | 20000 | 0.90 | 1.00 | 0.95 |
| 3 | Sprayer | 2 | 2 | 5 | 5 | 2 | 9 | 5 | 2 | 2 | 102 | 1000 | 0.90 | 0.98 | 1.10 |
| 4 | Industrial robot for lubricating | 2 | 2 | 5 | 5 | 2 | 9 | 5 | 2 | 2 | 136 | 20000 | 0.90 | 1.00 | 0.95 |
| 1 | Extractor | 0 | 9 | 9 | 9 | 2 | 9 | 5 | 5 | 2 | 50 | 2000 | 1.05 | 0.98 | 1.10 |
| 2 | Industrial robot for extracting | 0 | 9 | 9 | 9 | 9 | 9 | 5 | 5 | 2 | 114 | 20000 | 1.05 | 1.25 | 1.10 |
| | Absolut technical importance | 167 | 174 | 167 | 195 | 68 | 208 | 99 | 113 | 124 | 1315 | | | | |
| | Relative technical importance % | 12.7 | 13.2 | 12.7 | 14.8 | 5.2 | 15.8 | 7.5 | 8.6 | 9.4 | | | | | |
| | Priorities rank | 4 | 3 | 4 | 2 | 8 | 1 | 7 | 6 | 5 | | | | | |

b)

Fig. 4. Example matrices in partial automation

The second of the proposed matrices is shown in Fig. 4.b. There the operating parameters of the cell desired by the client are shown. Taking into account the ranking of the components necessary for the construction of the cell, determined in the first matrix, the assessment of their importance is given (from ***5*** to ***1***). An estimate of the expected price of the cell is made.

The obtained data show that, in the specific case, the defining parameters for the structure of the cell, desired by the user, are ***1*** - duration of the work cycle; ***2*** - production program and ***3*** - casting weight.

### *4.2 Full automation of the operation of Die casting machine with additional processing of the resulting cast*

The first of the proposed matrices is shown in Fig.5.a. Taking into account the wishes of the client for full automation of the operation of the Die casting machine and the possibility of additional processing of the received castings, the components necessary for the construction of the cell have been determined and ranked.

The second of the proposed matrices is shown in Fig.5.b. There the cell operating parameters desired by the client are shown. The additional components of the cell are defined, which will use to:

- automated removal of the casting from the cell - a conveyor for moving the castings to other cells for further processing and an industrial robot for moving the castings between the positions of the cell;
- automated additional processing of the castings - cooling, trimming and control of the castings.

Taking into account the ranking of the components necessary for the construction of the cell, determined in the first matrix, the assessment of their importance is given (from ***5*** to ***1***). An estimate of the expected price of the cell is made. The obtained data show that, in the specific case, the determining parameters for the structure of the cell, desired by the user, are ***1*** - the size of the casting; ***2*** - the duration of the work cycle and ***3*** - the production program.

Analyzing the obtained results, the client defines the design task by determining which of the mutually exclusive components performing the same function (matrix 1) should be included in the cell structure.

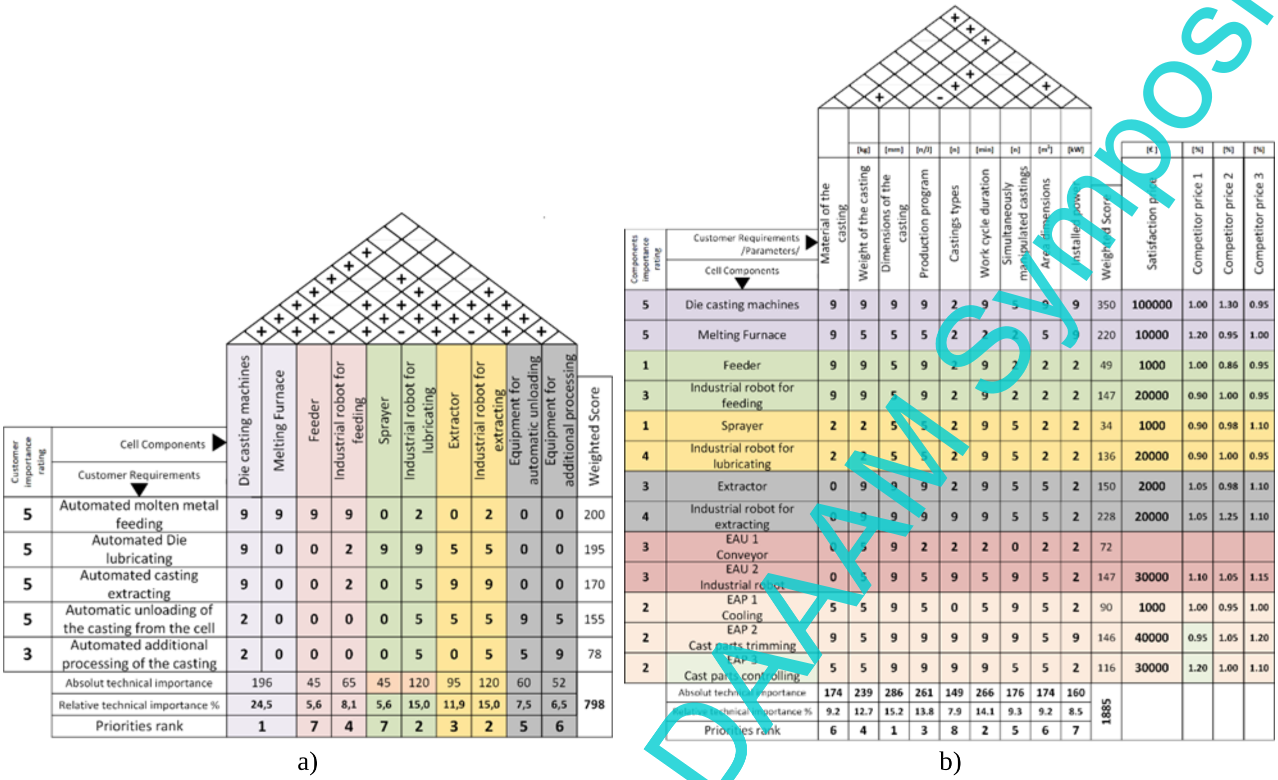



Fig. 5. Example matrices in full automation

In case of large discrepancies in the expected cost of the cell (components of the cell described in matrix 2 determine more than 70% of the cost of the cell) and the funds planned for investment by the customer, he can change the degree of automation or some of the parameters, to fulfil the financial restrictions.

## 5. Conclusions

The wide variety of currently available Die casting machines, industrial robots for automating various stages of the operation of these machines, and specialized cells for Die casting creates problems when choosing a solution for automating the production of metal and alloy parts with a low melting point, in the conditions of a specific company.

The method proposed here, of using two QFD matrices, at the task definition stage for the design of specialized Die casting cells, allows the creation of a task that most precisely corresponds to the degree of automation desired by the customer and his financial opportunities, taking into account the variety of solutions offered on the market.

For the application of the proposed method, expert ratings of the relationships between the degree of automation, the operating parameters and the components that make up the cell are given. The interactions between the cell components and the relationships between the customer's desired cell parameters are defined. The expert ratings and interactions between the cell components are based on a study of publications related to the design and operation of Die casting cells.

The cell's components price data used in the work is illustrative, as the actual prices depend on the current state of the market and are tied to a specific time period of delivery of the desired component.

The use of the proposed method significantly reduces the risk of changes in the basic structure of the designed Die casting cells and the associated costs, simultaneously reducing the time for designing, manufacturing and commissioning of the cell.

It is possible to develop the method through the development of type matrices (the second matrix), in which various options for additional processing of the obtained cast can be offered, such as drilling holes, milling, marking, etc.

## 6. Acknowledgments

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