Volume : 3 | Issue : 3 | March 2014 • ISSN No 2277 - 8160

Research Paper | Material Science

# Value Analysis and Optimization a Machining Process

**Chichernea Florin**

Transilvania University of Brasov, Department of Materials Science, Blvd. Eroilor, Nr. 29, postal code 500036, Brasov,

**ABSTRACT**

*This paper presents a modern method for optimizing the selection of a manufacturing process for a part, for maximizing its performance and minimizing its cost.*

*The work strategy involves setting the functions of the product, applying the value analysis method in order to obtain an optimal design – machining process, to optimize the product's value / cost ratio.*

*For the automation of calculations, the author has developed calculus programs that perform all calculations and draw all the necessary diagrams.*

**KEYWORDS: value, modelling, value analysis, optimizing the design, machining process**

## INTRODUCTION

Based on our experience, on the relevant examples of applying the Value Analysis method [1-3], the author proposes a method for optimizing the selection of design manufacturing technologies for various parts.

The optimization is achieved by setting the functions of the constituent elements, of the operations that lead to changing the structure of the design – machining technological processes accompanied by a reduction in costs without altering the performances.

The pressure casting dies are devices used in the foundry sector in order to obtain cast semi-products in large series.

The technology of these devices is complex due to the complex shapes of the active part and is carried out mostly manually, thus requiring a large volume of work and highly skilled workers.

## TECHNOLOGICAL PROCESSES

The metal moulds, the pressure casting dies are usually manufactured from cast steels (OT 45, OT 55) whose technology and manufacturing difficulty resemble those for the forging dies, except for the fact that the metal moulds are not treated thermally [4].

In the manufacture of dies, the first technology that was used was based on the manual engraving method using chisels.

Preliminarily there was performed a roughing processing for the die slot using various technological procedures (milling, drilling, turning, etc.).

This procedure was replaced with other technologies when the copying milling and the electro erosion processing machines appeared.

Depending on the equipment existing in the workshop, there can be adopted one of the technological processes presented below.

For the pressure casting dies there are used the variants of technological processes presented in tables 1 a, b, c and d.

Finishing the slot (obtained by copying milling), using electro erosion and then manually, allows for smaller shape and dimension deviations, and a continuous surface is obtained.

Complete machining, roughing and finishing the slot, using electro erosion, offers the highest dimensional accuracy but requires appropriate machines and using at least two electrodes, for roughing and finishing.

The method is used to manufacture small and medium high precision dies [4].

**Table 1 a – variant 1**

| No. | Operation |
|---|---|
| 1 | Steel ingot casting 34MoC15 |
| 2 | Cutting heads (feeders) |
| 3 | Free forging in two or three directions |
| 4 | Primary heat treatment (annealing) |
| 5 | Roughing processing of semi dies interface |
| 6 | Die ultrasonic control |
| 7 | Processing exterior surfaces and dovetail profile |
| 16 | Closing the two semi-dies and obtaining the final control part. Checking the control part. Checking the other dimensions of the die |

**Table 1 b – variant 2**

| | |
|---|---|
| Same as first variant, including operation 13, then may follow operations | |
| 14 | Processing and finishing using electro erosion, until a machining allowance of 0,1 – 0,25 mm remains to polish the surface |
| 15 | Die slot surface polishing |
| 16 | Closing the two semi-dies and obtaining the control part. Final check |

**Table 1 c – variant 3**

| | |
|---|---|
| Same as first variant, including operation 13, then may follow operations | |
| 14 | Roughing processing using electro erosion for the die slot until a machining allowance of 0,3 – 0,5 mm remains |
| 15 | Finishing machining using electro erosion in an operating mode appropriate for obtaining the quality of the die surface ($R_a$ = 0,2 – 0,4 mm) |
| 16 | Final control |

**Table 1 d – variant 4**

| | |
|---|---|
| Same as first variant, including operation 7, then may follow operations | |
| 8 | Roughing machining milling, drilling, turning, for easing the electrode operation |
| 9 | Secondary heat treatment for improvement |
| 10 | Roughing machining using electro erosion of the die slot |
| 11 | Manual grinding of the die slot |
| 12 | Final control |

## SELECTING THE MACHINING PROCESS USING VALUE ANALYSIS

There shall be selected the optimal technological process for machining a pressure casting die, made of different semi-products and there shall be presented the implications of selecting each semi-product from the point of view of mechanical processing and costs.

The functional shape of the part is represented by: dimensions, shape tolerances and the position of surfaces, dimensional tolerances, and quality of the surfaces, the hardness and the operating conditions.

Product functions are the following:

– the main function is: Provides mold manufacture,

– Service Functions
FS1 – Provides semi manufacturing production,
FS2 – Ensure heat treatment,
FS3 – Provides machining,

– Constraint Functions
FC1 – Provides reliance on press / hammer,
FC2 – Allows easy assembly, disassembly
FC3 – Allows control,
FC4 – Resist environmental actions,
FC5 – Provides imposed parameters (hardness, wear resistance, shock resistance, ...),
FC6 – Provide assemblies,
FC7 – Allows restoration,
FC8 – Provides user security,

– Estimation Functions
FE 1 – Provides the user interface,

The object of the Value Analysis is the activity, product or its subassemblies / components. The product is the only one bearing value and its subassemblies or components contribute to its utility.

In this article the Value Analysis product is considered to be the technological process for machining a pressure casting die. The components of this Value Analysis product are the stages/operations of the technological process for machining a pressure casting die. There shall be presented the iterations and conclusions drawn from applying the Value Analysis method in the assumptions described above.

Table 2 shows the classification of the functions starting from the functional analysis of the product – respectively – the process of machining a pressure casting die.

**Table 2 – The classification of the functions**

| Functions | *Type of functions |
|---|---|
| F4 - Provides machining | FS |
| F2 - Provides material composition | |
| F1 - Provides semi manufacturing production | |
| F3 - Provides structural changes | |
| F6 - Provides imposed parameters | FC |
| F7 - Resist environmental actions | |
| F9 - Allows restoration | |
| F8 - Allows control | |
| F5 - Provides user security | |
| F10 - Provides the user interface | FE |

***FS – Service Function; FC – Constraint Functions;**
FE – Estimation Function

## ITERATION 1
### value weighting of the functions

Throughout the two iterations of the Value Analysis there shall be kept the 10 functions outlined in table 2. Table 3 shows the value weighting of the functions.

The authors have developed a software that calculates all the values from the shown tables and draws all the diagrams necessary for presenting the findings, in all the iterations of the method. The calculus is made using the least squares method.

Value weighting of the functions are the values from the last row of table 3.

**Table 3 – Value weighting of the functions (*coordinate X)**

| Functions | F4 | F2 | F1 | F3 | F6 | F7 | F9 | F8 | F10 | F5 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of points | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 | 1 | 55 |
| Ratio | 0.18 | 0.16 | 0.14 | 0.12 | 0.10 | 0.09 | 0.07 | 0.05 | 0.03 | 0.01 | 1 |
| *Percentage% | 18.2 | 16.4 | 14.5 | 12.7 | 10.9 | 9.09 | 7.27 | 5.45 | 3.64 | 1.82 | 100 |

Economic dimensioning of the functions

The allocation of costs to functions was performed in table 4.

In the first iteration processing is as follows:

- alloying elements an average,
- obtaining semi manufactured (cast),
- primary heat treatment,
- grinding (milling, drilling, milling copying, electro erosion),
- secondary heat treatment (improvement, thermochemical nitro–ferrox treatment),
- hand semi finishing,
- hand finishing (grinding, ...),
- manual control (with template, ultrasonic),
- test pieces obtaining and repairs.

Cost weighting of the functions are the values from the last row of table 4.

**Table 4 – Cost weighting of the functions (**coordinate Y, cost $)**

| Parts | Cost | Functions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | F4 | F2 | F1 | F3 | F6 | F7 | F9 | F8 | F10 | F5 |
| Alloying elements | 200 | 10 | 100 | 10 | 40 | 20 | 20 | 0 | 0 | 0 | 0 |
| Casting | 90 | 4.5 | 4.5 | 72 | 4.5 | 4.5 | 0 | 0 | 0 | 0 | 0 |
| … | | | | | | | | | | | |
| Test pieces | 30 | 3 | 0 | 0 | 0 | 3 | 0 | 6 | 15 | 1.5 | 1.5 |
| Repairs | 30 | 3 | 0 | 0 | 0 | 7.5 | 1.5 | 10.5 | 1.5 | 3 | 3 |
| Total Cost | 975 | 215 | 104 | 82 | 117 | 153 | 54.5 | 51.5 | 91.5 | 53 | 50.7 |
| Ratio | | 0.22 | 0.10 | 0.08 | 0.12 | 0.15 | 0.05 | 0.05 | 0.09 | 0.05 | 0.05 |
| **Cost of Functions % | | 22.1 | 10.7 | 8.41 | 12.0 | 15.7 | 5.59 | 5.28 | 9.38 | 5.43 | 5.20 |

## COMPARISON / WEIGHTING FUNCTIONS IN VALUE AND COST

The check of this comparison is performed using regression analysis by determining the linear function (the regression line) that represents the average proportionality.

The regression line passes through the origin, as it is considered that a function with "0" value costs "0". The line has the shape: y = a * x (1), where y is the cost weighting of the functions and x is the value weighting of the functions.

In the case of perfect proportionality all points are on the line (1). In order to simplify, the calculation is tabulated. The coordinates $x_i$ and $y_i$ are given in tables 3 and 4 and based on the data calculated in this table the diagrams from figures 1, 2 and 3 are drawn:

– the value weighting of the functions (figure 1),
– the cost weighting of the functions (figure 2),
– the cost and value weighting of the functions (figure 3).

The diagram in figure 1 shows the value ranking, prioritization and weighting of the functions. The assessment of the functions which is shown in figure 2 highlights the most expensive functions.

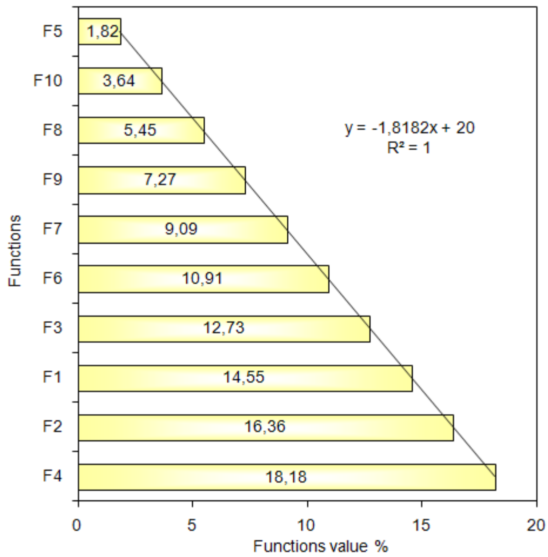


**Figure 1 – Value weighting of the functions**

The diagrams allow comparisons between the total costs of the functions and, within the total costs, there are highlighted:

- the very expensive functions, with the highest weighting in the total cost of the product,
- the functions whose implementation requires disproportionate costs as compared with other functions.

These functions are shown in the example from figure 2, functions F4, F3 and F6.

Regression equation describing this distribution is y = − 1.3029 * x + 17.166 with R – squared value on chart $R^2$ = 0.5118. If there is such a distribution, the first functions in the order of costs, representing 20 – 30% from the total number of functions, the functions are considered expensive.

The diagram in figure 3 shows:

- the equation line y = x (the first bisector) the line that averages the weighting of functions in value and cost, expresses the ideal situation of the disparity between the two weightings, the weighting of functions in value and costs.
- the regression line of equation y = 0.7874 * x + 1.9324, which approximates the arrangement of the points, expresses the real situation of the disparity between the two weightings, the weighting of functions in value and costs,

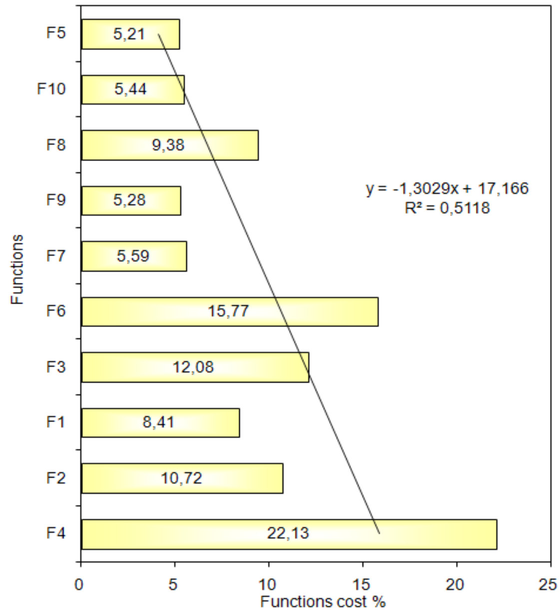


**Figure 2 – Cost weighting of the functions**

- functions F4, F6, F8, F10 and F5 are situated above the lines aforementioned. The weighting of the cost is larger than the weighting of the value of these functions. These functions are deficient and attention should be focused on them. The cost of these functions should be reduced.

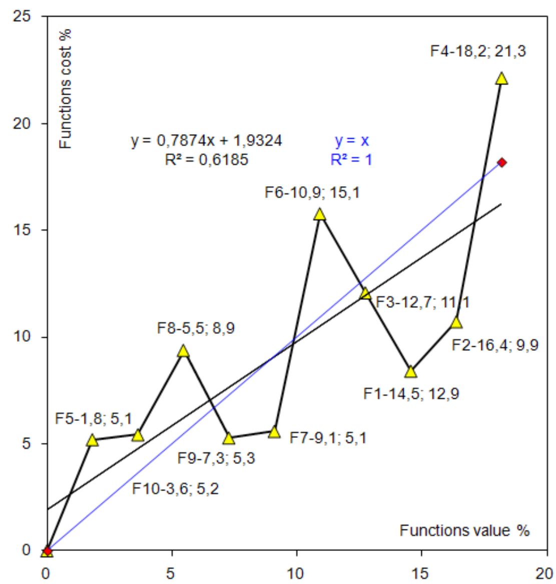


**Figure 3 – Weighting of the functions in value and cost**

**ITERATION 2**
Economic dimensioning of functions

In the second iteration of the Value Analysis method there shall be considered the functions situated above the ideal regression line (1): F4 – Provides machining, F6 – Provides imposed parameters, F8 – Allows control, F10 – Provides the user interface and F5 – Provides user security.

For the second iteration there shall be presented only the results in tabulated form. The weighting of the functions in value is the same as for the first iteration as no functions were added or removed from the system (table 2).

As the functions that cost more are highlighted in figure 3, solutions shall be suggested for reducing the cost of these functions.

The cost of these functions can be reduced by answering the following questions:

- can there be used less expensive semi-products?
- can the thermal regimes of the heat treatments be reduced (duration and temperature)?
- can there be eliminated / used another a heat treatment operation?
- can the die be milled at a lower cost?

These questions must be answered in such manner so that the properties, characteristics and performance of the die's alloy are not affected, but improved if possible!

In the second iteration, actions were taken for the following cost elements, manufacturing process are the follows:
– alloying elements to the maximum,
– obtaining semi manufactured (cast),
– primary heat treatment steps,
– grinding (milling 3D),
– secondary heat treatment (improvement)
– hand finishing (grinding, ...),
– 3D control (ultrasonic),
– obtaining test pieces and repairs.

The allocation of costs to functions was performed in table 5.

In table 5 the cost is distributed on the function/functions it is part of.

Cost weighting of the functions are the values from the last row of table 5.

**Table 5 – Cost weighting of the functions (**coordinate Y, cost $)**

| Parts | Cost | Functions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | F4 | F2 | F1 | F3 | F6 | F7 | F9 | F8 | F10 | F5 |
| Alloying elements | 230 | 11.5 | 11.5 | 11.5 | 46 | 23 | 23 | 0 | 0 | 0 | 0 |
| Casting | 90 | 4.5 | 4.5 | 72 | 4.5 | 4.5 | 0 | 0 | 0 | 0 | 0 |
| ... | | | | | | | | | | | |
| Total Cost | 805 | 148 | 119 | 83.5 | 98.7 | 108 | 56.2 | 33.5 | 86 | 34.5 | 36.5 |
| Ratio | | 0.18 | 0.14 | 0.10 | 0.12 | 0.13 | 0.07 | 0.04 | 0.10 | 0.04 | 0.04 |
| **Cost of Functions % | | 18.4 | 14.8 | 10.3 | 12.2 | 13.4 | 6.9 | 4.1 | 10.6 | 4.2 | 4.5 |

**COMPARISON / WEIGHTING FUNCTIONS IN VALUE AND COST**

Coordinates $x_i$ and $y_i$ are given in tables 3 and 5 and, based on the data calculated and presented in this tables, the diagrams from figures 4 and 5 are drawn:

- the diagram of weighting functions in value (identical with figure 1 – iteration 1),
- the diagram of weighting functions in cost (figure 4),
- the diagram of weighting functions in value and cost (figure 5).

The critical assessment of the functions presented in figure 4 highlights the most expensive functions. Regression equation describing this distribution is $y = -1.3838 * x + 13.6116$ with R – squared value on chart $R^2 = 0.72491$.

The diagram in figure 5 represents the regression line drawn using the least squares method and presents the comparison of functions in terms of value and cost.

In the diagram from figure 5 there can be seen the following lines:

- the equation line $y = x$ (the first bisector), the line that averages the weighting of functions in value and cost, expresses the ideal situation of the disparity of the two weightings, the weighting of functions in value and cost,
- the regression line, of equation $y = 0.8208 * x + 1.629$, which approximates the arrangement of the points, expresses the actual situation of the disparity of the two weightings, the weighting of functions in value and cost,
- functions F6, F8 and F5 are situated above the lines aforementioned.

The weighting of the cost is larger than the weighting of the value of these functions. These functions are deficient and attention should be focused on them. The cost of these functions should be reduced.

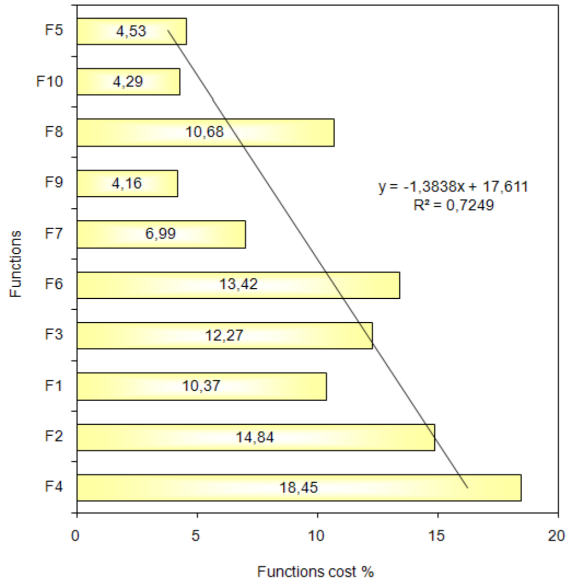


**Figure 4 – Cost weighting of the functions**

**RESULTS**

Following the second iteration there can be seen in figures 3 and 5 that the value of some functions increased, of other functions decreased, but the cost of those that increased eventually decreased due to the decrease of the cost of the "product".

In the second iteration the functions F6, F8 and F5 are situated above the regression line. There can be seen comparatively to figure 3 (iteration 1) in figure 5 (iteration 2) that the functions are grouped closer to the ideal regression lines. Below are presented comparatively the equations of the regression lines (the real situation):

iteration 1: $y = 0.7874 * x + 1.9324$, $R^2 = 0.6185$,
iteration 2: $y = 0.8208 * x + 1.629$, $R^2 = 0.7933$.

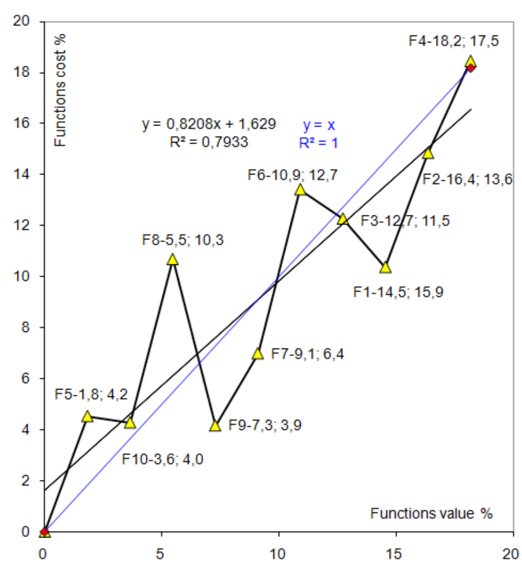


**Figure 5 – Weighting of the functions in value and cost**

There can be seen an increase in the value of the correlation coefficient $R^2$ in the second iteration as compared to the first iteration, thus resulting that the dispersion of the points decreased in relation with the regression line.

The iterations continue until the correlation coefficient $R^2$ tends to value 1 and the regression line (the real situation) tends to y = x (the ideal situation).

In two iterations of the Value Analysis study the machining technology for the pressure casting die was redesigned and optimized from the point of view of:

1 – engineering:
- the die machining process was changed,
- the percentages of the alloying elements were modified from a minimum, in first iteration to a maximum, in second iteration,
- the nitro–ferrox heat treatment was eliminated without changing in any way the properties required to such steel,
- the primary continuous heat treatment was replaced with a heat treatment in stages,
- the classic milling process (less expensive) of the die print was replaced with high velocity milling, using 3D processing machines (workmanship, more expensive equipment but higher productivity and precision),
- the manual control process, using templates (less expensive) was replaced with a 3D machines control process (workmanship, more expensive equipment but higher productivity and precision)
- as the machining processes are more precise in the 2-nd iteration, the final remedies are fewer than in the first iteration,

2 – economics:
- the cost of the product decreased from 975 $, in the first iteration to 805 $ in the second iteration, a 17,43 % decrease,
- the cost of functions F4, F6, F9 and F5 decreases in the second iteration compared to the first iteration (table 6).

**Table 6 – the cost of functions**

| Functions | F4 | F6 | F9 | F5 |
|---|---|---|---|---|
| First iteration (%) | 22.13 | 15.77 | 5.28 | 5.21 |
| Second iteration (%) | 18.45 | 13.42 | 4.16 | 4.53 |
| Decreases (%) | 16.62 | 14.90 | 21.51 | 13.05 |

In the third iteration of the Value Analysis study there shall be analysed the functions situated above the regression line y = x, (F6 – Provides imposed parameters (hardness, wear resistance, shock resistance, ...), F8 – Allows control and F5 – Provides user security), there shall be analysed the "components" participating to achieving these functions and solutions shall be proposed for reducing the costs. For functions F4 and F3 there shall be searched alloying and thermal treatments elements that decrease their cost, but maintain the qualities and the properties of the die material.

## CONCLUSIONS

The Value Analysis is a work whose objective is to find the "compromise" between cost and functionality of a product, all ensuring aoptim level of quality.

With this method are identified:
- very expensive functions,
- they highlight the technical components that cost very much,
- show where a technical solution must be changed,
- in this way does not go on attempts, in engineering design,
- it goes directly to solutions that cost very much, all this constituting the Value Analysis benefits.

This method can be used for optimizing the value/cost ratio for different types of machining technological processes for various parts.

Designing an economic model for making decisions regarding the optimization of the technological processes for machining parts in terms of the Value Analysis method is an absolute novelty in the field. This modelling has an important role because it opens a wide range of engineering applications.


## REFERENCES

[1] Chichernea, Fl., Chichernea, Al., Value Management, ISBN 978-973-598-852-4, Editura Universităţii Transilvania Braşov, 2011 | [2] Chichernea, Fl., Chichernea, Al., Iterations of the Value Analysis, ISBN 978-606-19-0040-4, Editura Universităţii Transilvania Braşov, 2012 | [3] Chichernea, Fl., Chichernea, Al., Value Analysis from theory to practice, ISBN 978-606-19-0039-8, Editura Universităţii Transilvania Braşov, 2012 | [4] Bejan, V., Technology for manufacturing and repair of technological equipment, vol.I, II, ISBN 973-95458-7-4, Bucureşti, 1991 |