VALUE ANALYSIS AND VALUE MANAGEMENT IN DESIGN OF INDUSTRIAL EQUIPMENT

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REZUMAT. Managementul prin Valoare (MV) este un demers sistematic care îmbunătăţeşte „valoarea" echipamentelor industriale sau produselor şi serviciilor folosind o examinare funcţională. Valoarea este raportul funcţiilor şi a costului. Managementul prin Valoare este un proces structurat exclusiv pe noţiunea de funcţie. Managementul prin Valoare foloseşte raţionamente logice şi analiza funcţiilor pentru a identifica relaţionările care cresc valoarea. Managementul prin Valoare se bazează pe elementele demersului Analizei Valorii.

Cuvinte cheie: Managementul prin Valoare, analiza valorii, valoare, variantă optimă.

ABSTRACT. Value Management (VM) is a systematic method to improve the "value" of industrial equipments or products and services by using an examination of function. Value is the ratio of function to cost. Value Management follows a structured thought process that is based exclusively on "function. Value Management uses rational logic and the analysis of function to identify relationships that increase value. The elements on which it is based Value Management are the elements of Value Analysis approach.

Keywords: Value management, value analysis, value, optimum variant.

1. VALUE ANALYSIS

Value Analysis is a method that provides an operating technique utilizing a creative and organized approach.

It is managed by a group, each of them selected by their expertise in specific subjects and coordinated by a Value Analysis expert.

The Value Analysis group activity is managed in seven stages: 1) formation and functional analysis; 2) creativeness; 3) evaluation and selection of the proposals; 4) the creative phase; 5) development of the selected proposals; 6. presentation of the selected proposals; set in order by priority; 7) implementation phase.

An example of Value Analysis is presented, applied to the re-design of a jaw crusher used for primary crushing of a wide variety of materials in the mining, iron and steel and pit and quarry industries.

Next the establishing mode of the optimum constructive solution is presented from the technical and economic viewpoint for *two parts participating in two functions with a high cost:*

1) the Flywheel who contribute at the function F7 (ensure uniformity of the movement);

2) the Bearing who contribute at the function F4 (supports the assembly).

2. ESTABLISHING THE LIST OF FUNCTIONS AND DIMENSIONS

Table 1 presents the list of functions of the jaw crusher.

3. ESTABLISHING THE LEVELS OF IMPORTANCE OF THE FUNCTIONS – STEP 1

Figure 1 shows the studied jaw crusher.

Table 2 presents the value weighting of the functions.

The following percentage values of the functions value weighting result:

X_{F1} = 20%, X_{F4} = 17,8%, X_{F3} = 15,6%, X_{F7} = 13,1%, X_{F5} = 11,1%, X_{F6} = 8,89%, X_{F2} = 6,67%, X_{F10} = 4,44% and X_{F9} = 2,22%.

The product value is equal to the sum of the functions levels and is equal to 45.

Table 1. **List of functions**

Symbol	Function	Type of function	Technical dimension of function		
			Name	UM	Value
*F*1	Ensure milling	FS*	blast degree	-	3 - 12
*F*2	Ensure protection of machinery	FC**	moment, force	daN*m, daN	200, 100
*F*3	Ensures adjustment	FC	length	mm	10 - 25
*F*4	Supports the assembly	FS	weight	daN	20000
*F*5	Aesthetics	FE***	colour, form	-	7
*F*6	Supplies working energy	FS	moment	daN*m	100
*F*7	Ensure uniformity of the movement	FS	revolution pulsation	rpm, rad/sec	

*FS – Service function **FC – Constraint function ***FE – Estimation function.

Table 2. **Value weighting of the functions (*X coordinate)**

Functions	*F*1	*F*4	*F*3	*F*7	*F*5	*F*6	*F*2	*F*10	*F*9	Total
No. of points	9	8	7	6	5	4	3	2	1	45
Ratio	0,2	0,178	0,156	0,133	0,111	0,089	0,067	0,044	0,022	1
***Percentage, %**	20	17,8	15,6	13,3	11,1	8,89	6,67	4,44	2,22	100

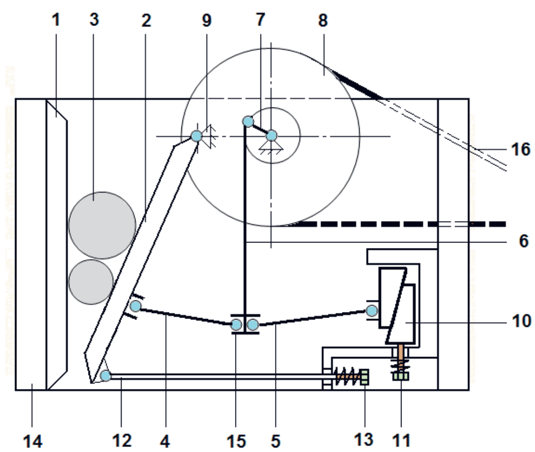


Fig. 1. Jaw crusher:
1 – fixed crushing jaw; *2* – moveable crushing jaw (moving jaw); *3* – materials; *4, 5* – toggle; *6* – pitman; 7 – eccentric shaft; *8* – flywheel; *9* – axle; *10, 11* – the adjustable wedge system; *12* – the bar; *13* – cylindrical spring; *14* – walls of the crushing zone; *15* – joint; *16* – belting.

4. ECONOMIC DIMENSIONING OF THE FUNCTIONS

Costs were assigned to the various functions by means of the functions-costs matrix shown in table 3.

The percentage values of the functions participation in the total cost are:

Y_{F1} = 16%, Y_{F4} = 14,3%, Y_{F3} = 15,2%, Y_{F7} = 14,4%, Y_{F5} = 11,7%, Y_{F6} = 7,83%, Y_{F2} = 11,2%, Y_{F10} = 4,79% and Y_{F9} =4,6%.

The value – costs relationship needs to identify:

1) the functions that are very expensive in relation to the others;

2) the functions that are too expensive in relation to their contribution to the value of the product;

3) the functions that are too expensive in relation to the existing technical possibilities of achievement.

5. DIAGRAMS

The construction of the diagrams is presented.

Based on the values for coordinates x_i and y_i presented in table 4 the diagrams of figures 2, 3 and 4 are plotted.

The parameters have the following computed values: $a = 0,93$, $\alpha = 42,9^{o}$, $S = 49,57$, $S' = 0$.

Table 4 provides the necessary values for constructing the following types of diagrams:

1) in figure 2, the diagram of the value weighting of functions;

2) in figure 3, the diagram of the cost weighting of functions;

3) in the figure 4, the diagram of the value and cost weighting of functions.

Figure 2 shows the ranking of the functions by their value.

Figure 3 shows the ranking of the functions by their functional cost.

The diagram reveals a Pareto type distribution, meaning that 20 - 30% of the total number of functions include 70 - 80% of the total costs of the functions.

These functions are *F*1, *F*4, *F*3 and *F*7.

In the case of such a distribution, the first functions in the order of costs, representing 20 - 30% of the total number of functions (in the above example functions *F*1, *F*4, *F*3 and *F*7) are considered to be very expensive functions.

The real situation is represented by the shape of the straight line in figure 4, plotted by means of the smallest squares method, and showing disproportions in the distribution of costs and in the contribution of the various functions to the value of the product.

Table 3. **Distribution of costs on functions**

No.	Parts	Functions									Cost part**
		F1	F4	F3	F7	F5	F6	F2	F10	F9	
...											
7	Flywheel	20			15			30	10	25	100
...											0
17	Bearing	250	30					70	20	30	400
...	...	550	700	750	720	500	400	410	215	175	4420
Total cost		820	730	775	735	600	400	570	245	235	5110
Ratio		0,16	0,14	0,15	0,14	0,11	0,07	0,11	0,04	0,04	1
Cost of functions, %		16	14,3	15,2	14,4	11,7	7,83	11,2	4,79	4,6	100

* *Y* coordinate, ** monetary units.

Table 4. **Computational elements (the smallest squares method) for plotting the diagrams**

No	Computational elements	Functions									Total value
		*F*1	*F*4	*F*3	*F*7	*F*5	*F*6	*F*2	*F*10	*F*9	
1	X_i	20	17,8	15,6	13,3	11,1	8,89	6,67	4,44	2,22	100
2	Y_i	16	14,3	15,2	14,4	11,7	7,83	11,2	4,79	4,6	100
	$y = x$	20									
3	$(X_i)^2$	400	316	242	177	123	79,0	44,4	19,7	4,93	1407
4	$X_i * Y_i$	320,9	254	235	191	130	69,5	74,3	21,3	10,2	1309
5	$(Y_i - a*X_i)^2$	6,493	5,03	0,49	3,94	1,99	0,19	24,5	0,43	6,41	49,57
6	S' *	101,9	79,7	-21	-52	-31	7,76	-66	-5,8	-11	0

$*S' = 2 * a * (X_i)^2 - 2 * X_i * Y_i$.

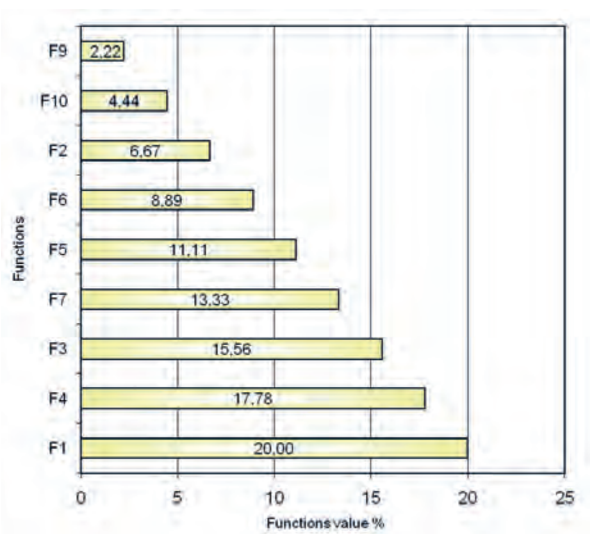


Fig. 2. Diagram of the value weighting of functions.

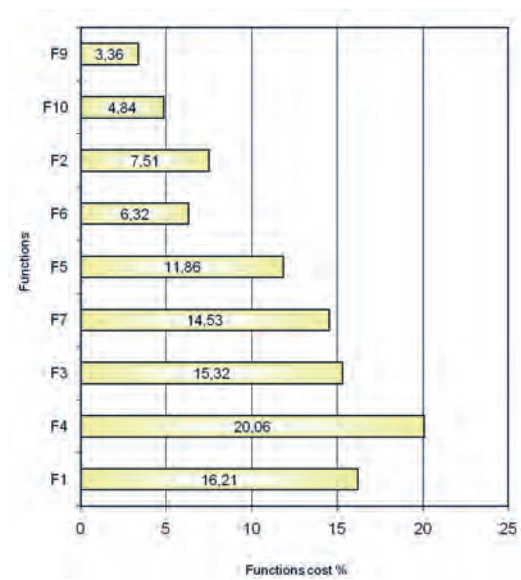


Fig. 3. Diagram of the cost weighting of functions.

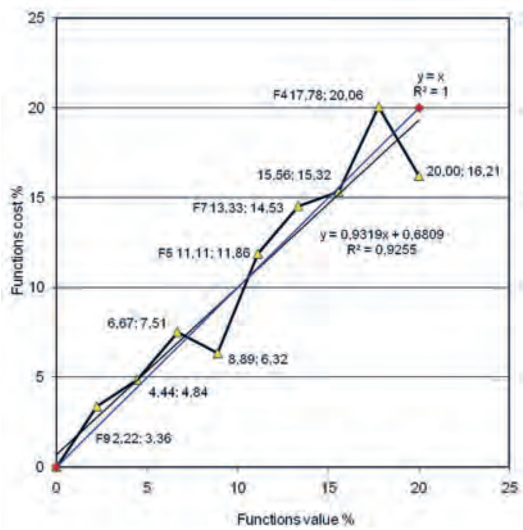


Fig. 4. Value and cost weightings of functions.

An analysis of the diagram of figure 4 shows that functions F9, F5, F7 and F4 are located above the regression line, indicating high costs, not justifiable in relation to the value.

These aspects allow the assumption that these functions are deficient, hence the solutions to be identified are to focus on those assemblies, parts, materials and technological operations that contribute, within the general structure of the product, to the achievement of these functions.

A basic criterion of Value Analysis is obtaining a minimum value for S'.

In order to diminish estimator S' the points need to be aligned as perfectly as possible along the straight line $y = a * x$, with a tilt of 45°.

Firstly, in order to diminish costs those functions will be re-designed that are located above the straight line.

For the points below the line the problems is more complicated. By diminishing the cost of the functions above the straight line, it may change its tilt and the points initially located below the line may appear above it.

It is also evident, that by diminishing the cost of certain functions the total costs of the product decreases, the weighting of the functions that were not modified increasing implicitly. This is another cause for some points relocating from below the straight line to above it, without, however, any modification occurring in the absolute value of the costs of these functions.

Secondly, the minimization of *S*' needs to be understood in the sense of growth the value/cost ratio as much as possible, and not in the sense of imposing *S*' = 0.

Thirdly, Value Analysis also admits the increase of the costs of some functions, provided their value increases at a faster rate than the costs.

Practically, the criterion of minimization of S' leads most often to cascading Value Analysis studies, the optimisation of the constructive solution being thus an iterative process.

At first the functions above the regression straight line are analyzed and their costs reduced, then the regression line is re-plotted and the functions relocated above it are noted; these functions too are analyzed in view of reducing their costs, followed by the re-plotting of the regression line etc. etc.

Hence the constructive solution is improved from one iteration to the other.

6. ESTABLISHING THE FUNCTIONAL-TECHNOLOGICAL FORM OF THE PARTS IN VIEW OF COST REDUCTION FOR THE FLYWHEEL

An analysis from the technical and economic viewpoint will be carried out in order to select a technically optimum variant for *two selected pieces of equipment: the flywheel and the bearing.*

Four constructive variants of flywheel will be studied and eventually the most cost effective and the most competitive one from the technical and economic viewpoint will selected.

Figures 5 and 6 presents a flywheel made from the welded semi-products.

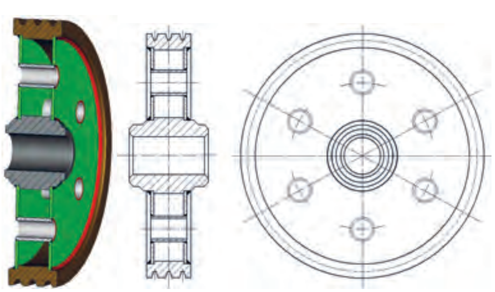


Fig. 5. Flywheel made from the welded semi-products.

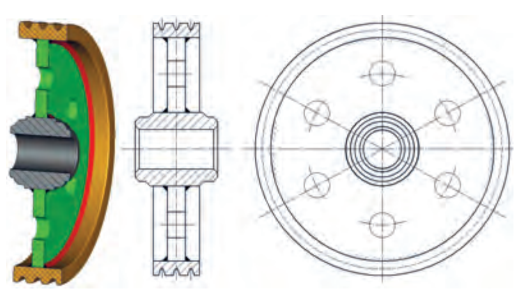


Fig. 6. Flywheel made from the welded semi-products.

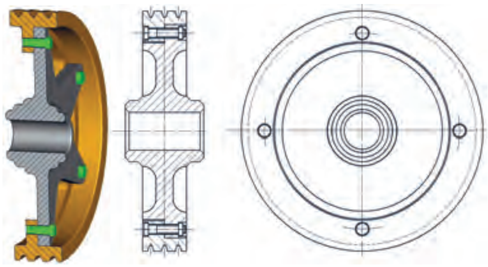


Fig. 7. Flywheel screw assembled.

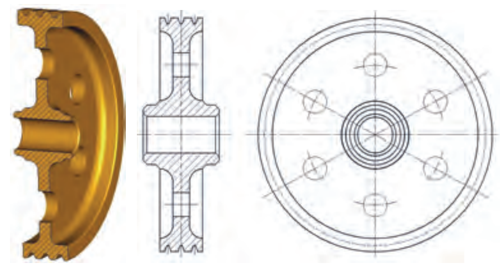


Fig. 8. Flywheel made from a cast semi-product.

The functional characteristics for this type of part, are the following:

1) maximum diameter, diameter of egagement, geometrical elements of connecting gear,

2) internal diameter of wheel hub, concentricity between flywheel axis and diameter of egagement,

3) wearing resistance, reconditioning method.

Figure 7 presents a flywheel screw assembled and figure 8 presents a flywheel made from a cast semi-product.

All variants are technological and the selection of one of them depends on the level of endowment of the company.

The constructive variant of figure 8 obtained from a cast semi-product ensures the best functional characteristics, if the technical conditions for heat treatment are provided. It has, however, the disadvantage that it allows only one solution for reconditioning: build-up welding and re-machining to the initial functional dimensions.

7. COMPARISON OF THE VARIANTS FOR FLYWHEEL

Table 5 presents the denoting by 9 assessment criteria of the analyzed constructive variants of a flywheel. The variant of figure 8 has obtained the highest score, and will thus be selected as the constructive solution within the assembly of the jaw crusher.

Table 5. **Synthetic table with the analyzed constructive variants for flywheel**

No.	**Analysis criteria**	**Figure 5**	**Figure 6**	**Figure 7**	**Figure 8**
					
1	Functional characteristics	4	4	4	4
2	Semi-product	1	2	3	4
3	Mechanical machining	1	2	3	1
4	Mounting	4	4	4	4
5	Repair	4	4	4	4
6	Rigidity	3	3	2	4
7	Ergonomics	2	2	2	4
8	Aesthetics	3	3	3	4
9	Cost	1	2	3	4
	TOTAL	23	26	28	**33**

8. ESTABLISHING THE FUNCTIONAL-TECHNOLOGICAL FORM OF THE PARTS IN VIEW OF COST REDUCTION FOR THE BEARING

An analysis from the technical and economic viewpoint will be carried out in order to select a technically optimum variant for the bearing. Six constructive variants of bearings will be studied and eventually the most cost effective and the most competitive one from the technical and economic viewpoint will selected. The analysis of the constructive variants for the support (bearing) of figures 9, 10, 11, 12, 13 and 14 is presented on.

The figures 9, 10 and 11 shows three constructive – technological variants of the support (bearing): welded semi-product made of three, six and five modules, the figures 12 and 13 shows two constructive cast semi-product and figure 14 present a complex bearing.

The constructive variant of figure 13 obtained from a cast semi-product ensures the best functional characteristics, if the technical conditions for heat treatment are provided.

Fig. 9. Support made from welded semi-products.

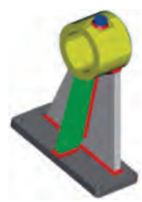


Fig. 10. Support made from welded semi-products.

Fig. 11. Support made from welded semi-product.

Fig. 12. Support made from cast semi-products.

Fig. 13. Support made from cast semi-product.

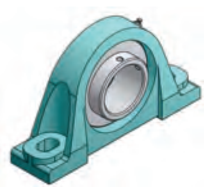


Fig. 14. Complex bearing.

It has, however, the disadvantage that it allows only one solution for reconditioning: build-up welding and re-machining to the initial functional dimensions. The difficulty in this case is applying a heat treatment subsequent to reconditioning.

9. COMPARISON OF THE VARIANTS FOR BEARING

Table 6 presents the denoting by 9 assessment criteria of the analyzed constructive variants of a bearing.

But in many cases the bearing must be made of two parts, to facilitate quick installation and removal of all assembly (figure 15 and figure 16). The bottom can body with the cradle, can be incorporated into the cradle.

Given the option of figure 15 and 16 the Value Analysis study be repeated, for comparing the share value and cost functions and this is the next step of study and the table 7 presents the new denoting by 9 assessment criteria of the analyzed constructive variants of a bearing.

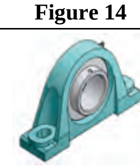
Variant of figure 13 obtained a score better than the version in figure 16, but in many cases the bearing must be made of two parts, to facilitate quick installation and removal of the assembly.

The score obtained by the variant of figure 16 is less than the cast version of figure 13, but choose the variant of figure 16, because the weight of the advantages is greater than the weight of disadvantages for variant of figure 13.

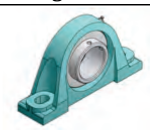
The version in figure 16 has the following advantages over the version in figure 13:

1) installation and removal are all much easier;
2) maintenance runs also easier;
3) The disadvantages of the variant of figure 16 to the variant of figure 13 are:
4) the process of obtaining semi – product: it can see in this choice the piece is composed of two
5) modules;
6) the machining by cutting: machining process is longer; more complicated and costly;
7) the functional cost of this variant is greater, but the difference is non significant.

Tabele 6. **Synthetic table with the analyzed constructive variants for bearing**

No.	**Analysis criteria**	**Figure 9**	**Figure 10**	**Figure 11**	**Figure 12**	**Figure 13**	**Figure 14**
							
		welded 3 modules	welded 6 modules	welded 5 modules	cast	cast	complex
1	Functional characteristics	6	6	6	6	6	6
...							
9	Cost	5	4	4	3	6	2
	TOTAL	45	40	42	39	*51*	41

Tabele 7. **Synthetic table with the analyzed constructive variants for Bearing**

No.	Analysis criteria	Figure 12	Figure 13	Figure 14	Figure 16
					
		cast	cast	complex	incorporated in cradle
1	Functional characteristics	6	6	6	6
...					
	TOTAL	42	*51*	41	***49***

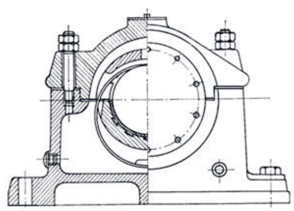


Fig. 15. Complex bearing.

Fig. 16. Bearing incorporated in cradle.

10. ESTABLISHING THE LEVELS OF IMPORTANCE OF THE FUNCTIONS – STEP 2

Table 8 presents the value weighting of the functions, in the second step of the Value Analysis study, the final situation.

By introducing the new data into table 9 the three diagrams of figures 17, 18 and 19 are plotted. These diagrams will be compared to those of figures 2, 3 and 4. The parameters have the following computed values:

$$a = 0{,}95,\ \alpha = 43{,}6^{o},\ S = 23{,}83,\ S' = 0.$$

It can be noticed that S and S' have smaller values than in the initial variant.

Table 9 provides the necessary values for the plotting of the following types of diagrams:

1) The diagram of the value weighting of the functions (figure 17). This diagram has not changes, as the value of the system and of the functions has remained the same and is similar to figure 2,

2) The diagram of the functions cost weighting (figure 18). The diagram of figure 18 presents the functional costs of the new variant, step 2.

3) The diagram of the cost weightings of the functions, step 2 (figure 19). Figure 19 presents the diagram of the cost weightings of the functions in step 2.

Only the costs are represented in order to not overload the diagram and to observe the decrease of the value of cost:

1) of function F4, from 20,06 %, in the first step of Value Analysis study to 17,44 % in the second step of Value Analysis study, with a decrease of 15 %.

2) of function F7, from 14,53 %, in the first step of Value Analysis study to 13,58 % in the second step of Value Analysis study, with a decrease of 7 %.

Table 8. **Cost distribution on functions**

No.	Parts	Functions									Cost part**
		F1	***F4***	***F3***	***F7***	***F5***	***F6***	***F2***	***F10***	***F9***	
1	Fix crushing jaw		60	24		90		50		4	228
...											0
7	Flywheel	10			15			25	5	22	77
...											0
Total cost		810	880	774	685	590	400	443	235	229	5046
Ratio		0,16	0,17	0,15	0,13	0,11	0,07	0,08	0,04	0,04	1
Cost of functions %		16,1	17,4	15,3	13,6	11,7	7,93	8,78	4,66	4,54	100

* *Y* coordinate, ** monetary units.

Table 9. **Computational elements for plotting the diagrams**

No.	**Computational elements**	**Functions**									**Total value**
		*F*1	*F*4	*F*3	*F*7	*F*5	*F*6	*F*7	*F*10	*F*9	
1	X_i	20	17,8	15,6	13,3	11,1	8,89	6,67	4,44	2,22	100
2	Y_i	16,1	17,4	15,3	13,6	11,7	7,93	8,78	4,66	4,54	100
3	$(X_i)^2$	400	316	242	177	123	79,0	44,4	19,7	4,93	1407
4	$X_i * Y_i$	321	310	238	181	129	70,4	58,5	20,6	10,0	1340
5	$(Y_i - a*X_i)^2$	8,97	0,25	0,27	0,76	1,23	0,29	5,90	0,18	5,86	23,74
6	S' *	119,	-18	-16	-23	-24	9,57	-32	-3,7	-10	0

* $S' = 2 * a * (X_i)^2 - 2 * X_i * Y_i$.

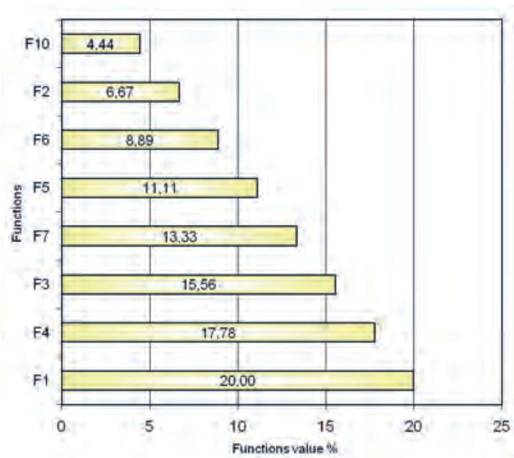


Fig. 17. Diagram of the value weighting of the functions.

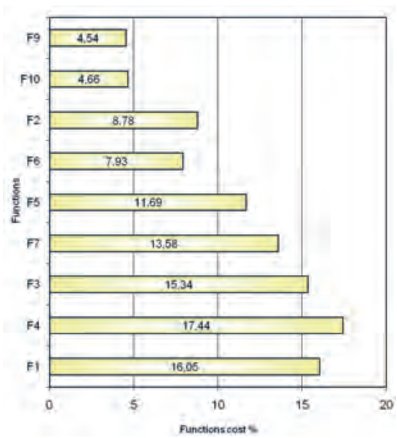


Fig. 18. Diagram of the functions cost weighting.

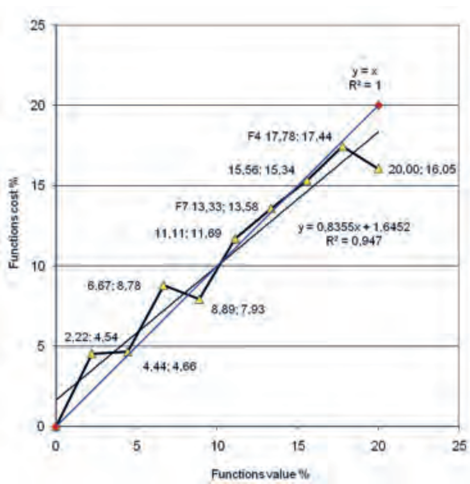


Fig. 19. The diagram of the cost weightings of the functions in step 2.

The economic dimension or the cost of the function represents the main criterion for the critical evaluation of functions.

These evaluations aim at identifying those functions, the too costly technical solutions of achievement of which affect the total manufacturing cost of the analyzed product.

A correctly completed critical evaluation will directly lead to the identification of what can be called the deficient functions of the analyzed product that is of those functions that include useless costs.

The deficient functions from the economic viewpoint appear as: very expensive functions in relation to the others.

11. CONCLUSION

In two steps of Value Analysis study two component of jaw crusher, the flywheel who contribute at the function *F*7 (*ensure uniformity of the movement*) and the bearing who contribute at the function *F*4 (*supports the assembly*) was redesigned and optimized:

• From engineering viewpoint (figures 20 and 21):

a) from variant of flywheel of figure 5 consists of five welded modules, one complicated part (many components, mechanical machining, turning of metal parts complicated, long and very expensive etc.) to the variant of figure 8 consists of cast semi-product (one component, mechanical machining, turning of metal parts simple, short and less expensive than the flywheel of figure 5 etc.).

b) from variant of bearing of figure 9 consists of three welded modules, one complicated part (many components, mechanical machining, turning of metal parts complicated, long and very expensive etc.) to the variant of figure 16 consists of cast semi-product (two component, mechanical machining, turning of metal parts simple, short and less expensive than the bearing of figure 9 etc.).

• From the economic viewpoint (figure 22):

a) the cost of function *F*7 (figure 19) decrease from 14,53 %, in the first step of Value Analysis study to 13,58 % in the second step of Value Analysis study (decrease with 7 %).

b) the cost of function *F*4 (figure 22) decrease from 20,06 %, in the first step of Value Analysis study to 17,44 % in the second step of Value Analysis study (decrease with 15 %).

• In the third step of Value Analysis study are analyzed other functions above the regression straight line (for exemple *F*1) and their costs reduced, then the regression line is re-plotted and the functions relocated above it are noted; these functions too are analyzed in view of reducing their costs, followed by the re-plotting of the regression line etc. etc.

• In the fourth step of Value Analysis study are analyzed other function above the regression straight line and their costs reduced, then the regression line is re-plotted and the functions relocated above it are noted; these functions too are analyzed in view of reducing their costs, followed by the re-plotting of the regression line etc. etc.

At the end of the Value Analysis study the points are aligned as perfectly as possible along the straight line $y = a * x$, with a tilt of 45^o, this is the optimal situation, the values weighting of functions and the functions cost weighting are equal.

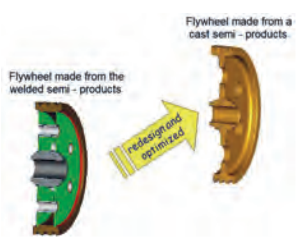


Fig. 20

Fig. 21

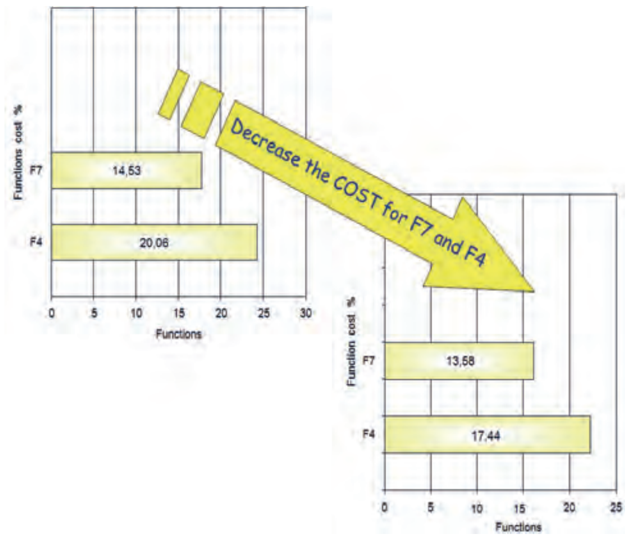


Fig. 22

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