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VALUE ANALYSIS AND ENGINEERING FOR 3D PRINTING EQUIPMENT

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Abstract: Value analysis and engineering (AIV) aims to reduce production costs, manufacturing costs and increase the use value of the analyzed product. Also, AIV establishes the analyzed object functions, as a result of the user's requirements in order to have proportionality between the performances of each function and the consumption of means necessary for their accomplishment. In this paper, the AIV study is applied to the Z310 Plus 3D printing equipment which uses a high-performance composite material. A functional analysis of the product was performed, the functions were identified and their sizing was performed from a technical and economic point of view. Following the study, it was possible to formulate design directions for the component parts of the analyzed equipment that will ensure for each function a correct ratio between the realization expenses and the use value of the product. Four critical functions of the Z310 Plus equipment have been identified and several measures have been imposed to resize them in order to maximize the ratio between the manufacturing cost and its utility.

Key words: AIV, 3D printing, systemic analysis.

1. INTRODUCTION

Value analysis is a systemic and creative research and design method that, through the functional approach, aims to design and perform the functions of the studied object with minimum costs in terms of quality, reliability and performance, to meet user demands, [1].
Value analysis (AV) is applied to existing objects, is a systematic process of improving them by eliminating unjustified costs and acts on the basis of the feedback mechanism.
Value engineering (IV) is applied in the case of new objects, is a systematic process of prevention and elimination of unnecessary costly causes by performing functions with a minimum cost without neglecting performance, is applied from the conception and design phases and acts based on the feed-before mechanism, [2].
In conclusion, value analysis and engineering (AIV) aims to achieve the functions of an object (functions being a result of user requirements) so that there is a proportionality between the usefulness of each function and the consumption of means to achieve it, and as a logical result to maximize the ratio between the utility of the product and its cost.
The object of study of value engineering can be: a product made on the basis of a patent or according to a model; an existing product for its modernization; component parts (modules) of a product or parts of a manufacturing technology; serving or auxiliary processes; work processes etc.
The main objectives of value engineering are as follows, [2]:
- Elimination of unjustified expenses and those determined by possible unnecessary functions and thus reducing the production cost;
-Reduction of the production cost in other ways than those mentioned above (organological redesign, other methods of performing functions).
-Improving the workplace, etc.
In summary, the objective of an IVA study can be expressed by the relation (1), [1, 3]:

$$AIV \rightarrow \max VI_G/CP \qquad (1)$$

where: VIG represents the global use value of the studied object; CP is the production cost of the studied object.
In the paper, the AIV study is applied for the Z310 Plus 3D printing equipment, whose component parts are presented in Table 1.

Table 1. Main components of the Z310 Plus 3D printing equipment

No.	Component	Description
1	Roll laminator	Its role is to apply the powder layer and compact it. It is provided with 1 roller that helps to support and guide the material.
2	Print head	Its role is to apply the binder and solidify the cross section of the piece.
3	Adhesive tank	It is a plastic container in which the adhesive is stored.
4	Powder supply box	Store the powder to be used.
5	Unused powder storage box	Store the remaining unused powder and recycle it.
6	Electrical equipment	Consists of electric motor, USB cables: ensures the performance of working movements.
7	2 trays (trays) provided with a piston	The pistons help to index the trays, on which the piece is located, thus depositing the layers.
8	Control panel	Displays information, helps make auxiliary settings.
9	Cover	Provides protection for the equipment.

2. FUNCTIONAL ANALYSIS OF THE PRODUCT. FUNCTIONS AND THEIR SIZING

2.1 Functions

The function is the first fundamental notion with which value analysis and engineering operate.
In order to establish the functions of an object, it is recommended to perform the following categories of complementary analyzes:
a) Use sequence analysis: it is necessary to know the use sequences, i.e the logical steps that must be followed for the correct operation of an object in order to comply with certain technical conditions.
b) Analysis of the efforts and movements that the object must withstand: This analysis is an extension of the previous one and can be performed simultaneously in certain situations.
c) Analysis of the environment: Analyzing the relationship between the studied object and the environment will result in a suite of functions.
d) Analysis of a standard product: It is recommended the analysis of a similar object of the competition, the analysis of a family of objects of which the studied object could be part, etc.
e) Analysis of some norms: The study of some laws, standards, norms, rules, etc. will determine a number of ecological functions. This analysis can be performed in close connection with the analysis in point c.
By function nomenclature is meant the list of all the functions necessary for the respective object.
The nomenclature of functions is the starting point of value engineering studies. A nomenclature of functions must not omit any function, contain the correct classification and the technical dimensions (maximum and minimum limits) set correctly for the respective functions. Any function can have one or more technical dimensions. The specialists who deal with the elaboration of the nomenclature of functions must correctly interpret the notion of function, have a thorough knowledge of social needs (customer demand, directions for development of the technique) and have a good knowledge of the AIV methodology, [2, 4].
The success of the action of identifying the functions and the elaboration of the nomenclature depends on the training and professional qualities of the specialists in AIV, as well as on the production culture of the interlocutors participating in this action.
Table 2 shows the function nomenclature for the Z310Plus.

Table 2. Function nomenclature for the Z310 Plus Equipment

Symbol	Function name	Function type					
		Main	Secondary	Objective	Subjective	General	Specific
F_1	Ensure the deposition of the powder layer	x		x			x
F_2	Ensure the application of the binder	x		x			x
F_3	Allow indexing of the part	x		x			x
F_4	To provide dimensional flexibility	x		x			x
F_5	Provide automatic cleaning	x		x			x
F_6	Ensure pre-processing of the part	x		x			x
F_7	Ensure dust recovery for recycling	x		x			x

F_8	To ensure the realization of the auxiliary structure for stability	x		x			x
F_9	Ensure quiet operation	x		x			x
F_{10}	Allow easy operation	x		x			x
F_{11}	Provide programming flexibility	x		x			x
F_{12}	Be reliable	x		x		x	
F_{13}	Be ergonomic	x		x		x	
F_{14}	To ensure electrical safety	x		x			x
F_{15}	To carry information	x		x		x	
F_{16}	Display information	x		x			x
F_{17}	Be maintainable	x		x		x	
F_{18}	Be aesthetic	x			x	x	
F_{19}	Provide corrosion protection	x		x			x

2.2 Technical and economic sizing of functions

Determining the levels of importance and the weights of the functions for use

The determination of the levels of importance and the weights of the functions for use is based on the results of a survey of opinions among real and potential users of such equipment, [2].

Table 3 shows for each function:

- the scores that each respondent entity (B_1 .... B_7) gave;
- the total number of points obtained from all respondents N_j;
- level of importance n_j;
- the share in the use value qj which is calculated with relation (2), [2].

$$q_j = \frac{n_j}{\sum_{j=1}^{N} n_j} \tag{2}$$

Table 3. Function values for the surveyed entities

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	n_j	q_j	N_j
F_1	19	18	15	14	16	14	18	114	0.0770	2
F_2	18	17	19	16	15	17	19	121	0.0817	1
F_3	17	16	12	13	11	16	17	102	0.0689	5
F_4	15	17	14	13	18	12	15	104	0.0702	4
F_5	11	9	10	7	15	12	8	72	0.0486	16
F_6	10	12	8	11	8	9	7	65	0.0439	17
F_7	12	14	13	10	9	7	8	73	0.0493	15
F_8	13	15	12	11	9	9	8	77	0.0520	11
F_9	15	16	10	11	14	13	12	91	0.0614	8
F_{10}	18	15	19	13	14	11	10	100	0.0675	6
F_{11}	12	11	13	10	9	10	11	76	0.0513	13
F_{12}	19	15	18	16	14	12	17	111	0.0750	3
F_{13}	11	12	9	14	16	17	13	92	0.0621	7
F_{14}	12	10	8	4	7	6	5	52	0.0351	18
F_{15}	10	11	9	12	14	13	9	78	0.0527	10
F_{16}	14	15	10	11	12	9	13	84	0.0567	9
F_{17}	10	12	15	9	11	10	8	75	0.0506	12
F_{18}	11	10	11	10	12	11	10	74	0.0500	14
F_{19}	5	8	6	4	5	6	7	17	0.0114	19
							Total N_j	1480		

Technical sizing of functions

The functions of a product are elementary use values, components of the global use value of the product, homogeneous in content and having technically measurable qualities. The dimension of these qualities has been called the technical dimension of functions, [2].

For an existing product, the technical dimensions are expressed by the technical parameters of the respective product, provided in the technical documentation or determined by direct measurements. For a new product, the technical dimensions are established by comparison with reference products, based on the requests of the

beneficiaries, depending on the cost-performance ratio and must reflect as accurately as possible the features expressed by the product functions.
Table 4 presents the results of this phase for the studied product.

Table 4. The phases of the Z310 Plus product studied

Function name	Technical dimension			q_j
	Parameter	UM	Value, [mm]	
Ensure the deposition of the powder layer	Layer thickness	[mm]	0.089-0.203	0.0770
Ensure the application of the binder	Density	[g/cm^3]	43	0.0817
Allow indexing of the part	Step	[mm]	0.089-0.203	0.0689
To provide dimensional flexibility	L · l · h	[mm]	203 · 254 · 203	0.0702
Provide automatic cleaning	Cleaning time	[min]	5	0.0486
Ensure pre-processing of the part	Processing time	[min]	2	0.0439
Ensure dust recovery for recycling	Percentages	%	80	0.0493
To ensure the realization of the auxiliary structure for stability	Yes/No	------	-----	0.0520
Ensure quiet operation	Noise level	[dB]	43	0.0614
Allow easy operation	Learning time	[h]	4	0.0675
Provide programming flexibility	Types of software	No	AutoCAD SolidEdge CATIA SolidWorks	0.0513
Be reliable	Average operating times. Normal service life.	[h] [year]	720 20	0.0750
Be ergonomic	Equipment dimensions	[mm]	740 · 860 · 1090	0.0621
To ensure electrical safety	Equipment dimensions. Control voltage. Electrical resistance. Covers.	V/A MΩ Yes	115/4.3 30	0.0351
To carry information	Categories of information	No	Product type	0.0527
Display information	Yes/No	------	------	0.0567
Be maintainable	Average repair times (MTR)	h	25	0.0506
Be aesthetic	Symbiosis shape, color	Appreciation note	9	0.0500
Provide corrosion protection	Time	[year]	20	0.0114

Economic sizing of functions

The economic sizing of functions aims to determine the cost of each function and its share in the cost of the product. This stage requires a very good knowledge of the constructive-functional solution of the product, of the AIV techniques and a very intense work. In addition, it offers the first solutions to reduce the cost of the product, by identifying the costs of unnecessary functions and unjustified expenses.
In relation to the possibilities we have to know these components of the cost, the time available for conducting the study and the interest shown for further study, the economic dimensioning of the functions can be done globally or in detail.
The global method of economic dimensioning of functions involves the use of global values (c_i) of parts costs, not requiring the detailing of material, salary and overhead components. The following are the steps of this method [1, 2, 5]:
a) Elaboration of the diagram / matrix of part-function relations.
For the elaboration of the diagram / matrix of part-function relations, it is very useful to know the assembly diagram of the studied product, which will also facilitate the determination of the costs that will be operated in

the continuation of the study. The matrix can be elaborated only on the basis of the logical, engineering reasoning, on the functionality of each component of the analyzed object (subassemblies, parts etc.). The relationships between the components of the studied object and its functions are conventionally marked with a symbol, for example with *x*.

b) Establishing the weights with which each component Ri participates in the materialization of the functions F_j [g_{ij}, %]

Deepening the process of analysis of the part-function relations, the quantitative appreciation of the participation of the parts R_i in the materialization of the functions F_j is performed. As we have already pointed out, this assessment is made on the basis of a good knowledge of the object of study, of an engineering reasoning, answering questions such as: to what extent, in what proportion, does the component R_i participate in the function F_j?

c) Allocation of parts costs (c_i) by functions F_j;

d) Calculation of the costs of the functions.

The distribution of the costs of the components R_i on the functions F_j is done with relation (3).

$$c_{ij} = c_i \cdot g_{ij} \tag{3}$$

The economical sizing of functions for the Z310 Plus equipment is presented in Table 5 and was done based on the global economical sizing method.

Table 5. Economical sizing of functions for the Z310 Plus

No.	Component element	Cost (C_j) [thousand RON]	F_1	F_2	F_3	F_4	F_5	F_6	F_7	F_8	F_9	F_{10}
1	Electric motor	15.000	30% 4.500	30% 4.500	3% 450		2% 300				8% 1200	
2	Roll laminator	20.000	80% 16.000								1% 200	
3	Printing head	15.000		75% 14.800							1% 200	
4	Piston plates	2.000			45% 900	35% 700					5% 100	
	Binder tank	1.500		72% 1.080								3% 450
6	Powder supply box	1.500	76% 1140									2% 30
7	The box for storing the rest of the powder	750					42% 315		58% 435			
8	Cleaning accessories	550					64% 352		30% 165			
9	Control panel	700	3% 21	2% 14				30% 210		2% 14		40% 280
10	The cost of functions	C_j 61.811	22.411	20.394	1.350	700	967	210	600	14	1.250	760
11	Weigh in cost	P_j	0.3625	0.3299	0.0218	0.0113	0.0156	0.0033	0.0097	0.0001	0.020	0.0116

Table 5. Economical sizing of functions for the Z310 Plus (continued functions F11-F19)

No.	Component element	Cost (Cj) [thousand RON]	F_{11}	F_{12}	F_{13}	F_{14}	F_{15}	F_{16}	F_{17}	F_{18}	F_{19}
1	Electric motor	15.000	5% 750	7% 1.050	3% 450	5% 750			7% 1.050		
2	Roll laminator	20.000		14% 2.800					5% 1.000		
3	Printing head	15.000		20% 3.000					4% 600		

4	Piston plates	2.000		12% 240					3% 60		
5	Binder tank	1.500		5% 75							
6	Powder supply box	850		16% 240							
7	Box for storing the rest of the powder	850									
8	Cleaning accessorie s	550								6% 33	
9	Control panel	600	5% 30					10% 60		8% 48	
10	Carcase	800		10% 80		20% 160				25% 200	45% 360
11	The cost of functions	C_j 61.811	30	7485	450	910	80	60	2710	281	360
12	Weigh in cost	P_j	0.0017	0.1210	0.0729	0.0147	0.0012	0.0006	0.0438	0.0045	0.0058

3. SYSTEMIC ANALYSIS OF FUNCTIONS

The object of the systemic analysis of the functions is the identification of the critical / oversized functions from the economic point of view, ie of the functions whose costs are much higher than their use value, [1].
In order to achieve this objective, the two categories of weights determined at the previous stages and the weight in use value (q_j) are compared for each function with the weight in the production cost (p_j).
In relation to a q_jOp_j coordinate system, all the functions of an ideal product will be located on the regression line (Λ1) inclined at 450.
In a real product its functions can be located in the q_jOp_j plane both on the regression line (Λ2) and in its vicinity, a line that will no longer be inclined at 450. By means of such a function we can evaluate to what extent there are disproportions between the costs of the functions and their contribution to the value of the product, [2].
The equation of the line (Λ2) is $p_j = b \cdot q_j$ and the angular coefficient (b) is determined by the least squares method. To represent an average proportionality, the line (Δ_2) must deviate as little as possible from the real points, a condition expressed by the following relation:

$$S = \sum_{j=1}^{N} (p_j - b \cdot q_j)^2 \longrightarrow \min \tag{4}$$

From the condition:

$$\frac{\partial S}{\partial b} = 0 \tag{5}$$

Results:

$$b = \frac{\sum_{j=1}^{N} p_j \cdot q_j}{\sum_{j=1}^{N} q_j^2} \tag{6}$$

$$\alpha = arctg\, b \tag{7}$$

where: S is the entropy of the system, shows the degree of scattering of the points F_j in the q_jOp_j plan.

Obviously, the smaller S, the closer the points F_j are to the right (Δ_2). An object can be considered well designed if $S \leq 0.01$.
The research directions that must be adopted later for the improvement of an object, can be clearly identified having as benchmark the fundamental objective of value analysis and engineering benchmark the fundamental objective of value analysis and engineering.
Figure 1 shows the Systemic Analysis for the Z310 Plus Equipment.

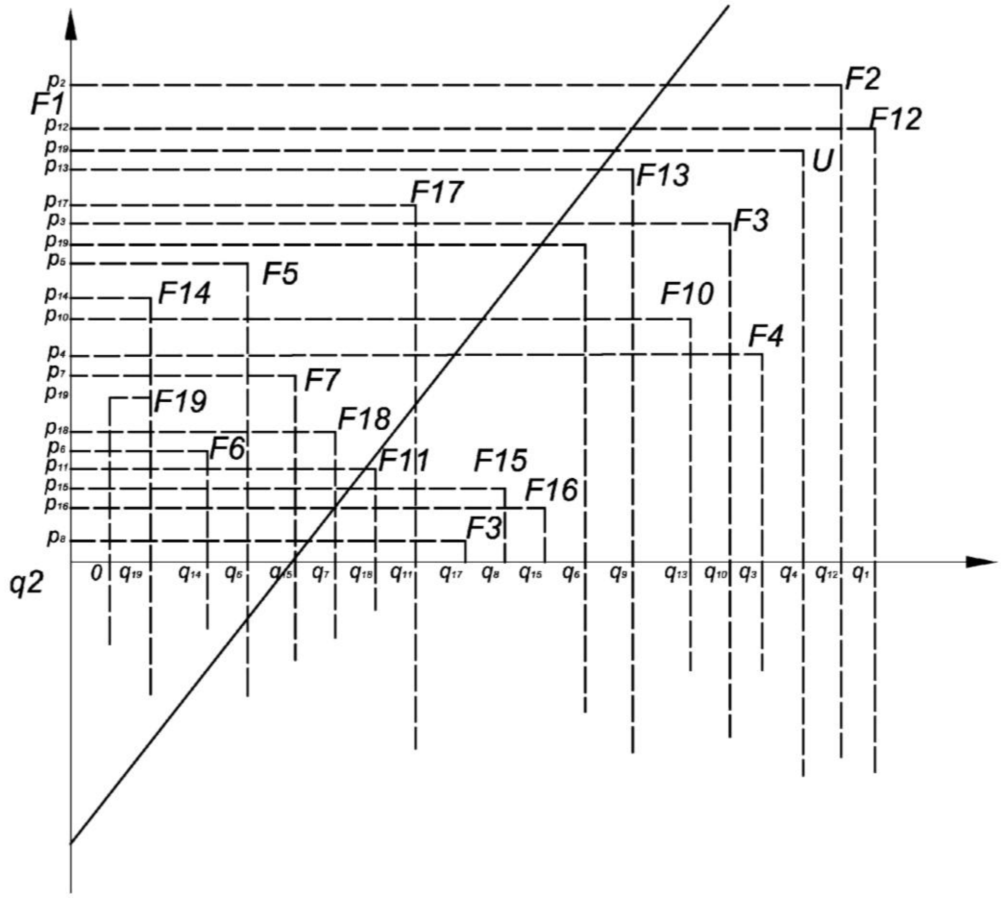

Fig.1. System analysis for the Z310 Plus

After performing the specific calculations, the following results:

$$b = \frac{\sum_{j=1}^{N} p_j \cdot q_j}{\sum_{j=1}^{N} q_j^2} = 0.852; \quad \alpha = arctg\, b = \text{arctg } 0.852 = 40^0\, 43^{`} \qquad (8)$$

Figure 1 shows that the economically oversized functions are:

- F_{19} Provide corrosion protection;
- F_{17} Be maintainable;
- F_5 To ensure automatic cleaning;
- F_{14} Ensure electrical safety.

The functions presented above are critical functions, because their weights in the value of use are much lower than the weights in the cost of the product and must be redesigned.
In order to establish the redesign directions, the components that contributed to the greatest extent to the economic oversizing of the mentioned functions will be determined for the beginning, as follows:
- For the economic resizing of the F_{19} function (to ensure anti-corrosion protection) it is necessary to purchase a housing made of a replacement material with the same properties at a lower price;

- For the economic resizing of the F_{17} function (to be maintainable) it is recommended to purchase the electric motor at a lower price and reduce the material costs for the laminator, printhead, pistons and plates;
- For the economic resizing of the F_5 function (to ensure automatic cleaning) it is recommended to purchase cleaning accessories at a lower price;
- For the economic resizing of the F_{14} function (to ensure electrical safety) it is recommended to reduce the expenses for the electrical components and the housing.

The cause-effect links (between the high cost generating components and the critical functions) are presented in Figure 2 and Figure 3 according to the data in Table 4 of the economic dimensioning of the functions.

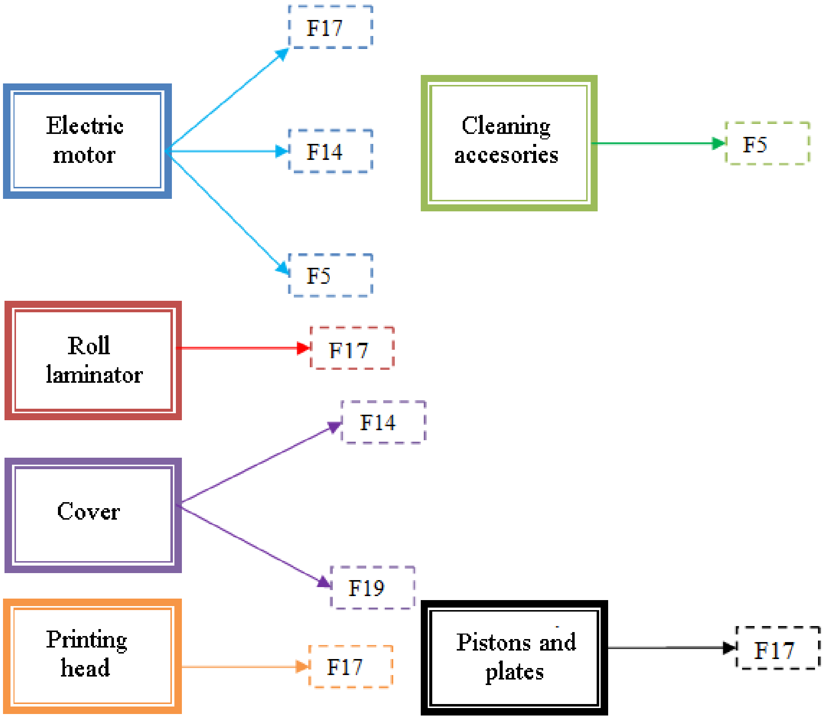

Fig. 2. Critical component-function relationship (cause-effect)

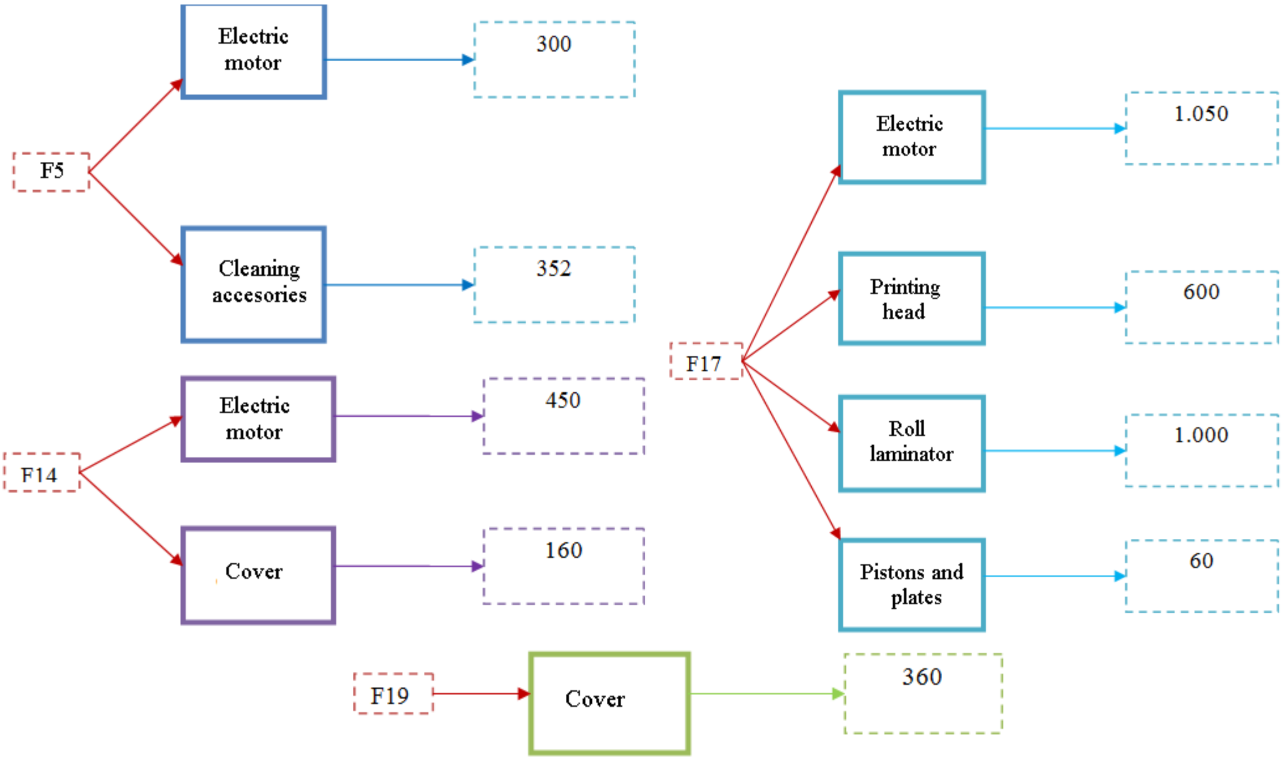

Fig. 3. Critical function-component-cost relationship (cause-effect)

3. CONCLUSIONS

This paper presented value analysis and engineering (AIV) for the Z310 Plus 3D printing equipment. Also, the main functions that this equipment should have, the technical dimensions of the functions (establishing the maximum and minimum sizes of the technical dimensions), determining the importance levels of the functions and calculating the weights of the functions in use value, the economic dimensioning of functions and the calculation of the weights of the functions by cost in the total cost of the product and the systemic analysis (identification of the critical-economically oversized functions).

Through the analysis and engineering method, applied to the Z310 Plus equipment, the aim was to achieve a proportionality between the functions presented by the equipment and their cost, at the same time creating conditions of quality, reliability and performance, which would satisfy the user's requirements. The AIV method aims to reduce as much as possible the production costs, reduce the manufacturing costs, increase the value of using the product, bringing satisfaction to both the manufacturer and the user.

Finally, the AIV formulates design directions that ensure each function a correct ratio between its contribution to the use value of the object and the expenses that are made (or should be made) with the accomplishment of the respective function.

Following the systemic analysis, 4 critical functions of the Z310 Plus equipment were identified, and certain measures were imposed for their resizing, so as to maximize the ratio between the utility of the product and its cost.

Thus, by resizing the 4 functions for the analyzed product, it will be possible to obtain a proportional ratio between the functions it holds and their cost.

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