INTERNATIONAL CONFERENCE ON ENGINEERING DESIGN
ICED 03 STOCKHOLM, AUGUST 19-21, 2003-01-31

A DETAILED COMPARATIVE ANALYSIS OF TWO MECHANICAL PRODUCTS WITH A VALUE ANALYSIS APPROACH

ZWOLINSKI Peggy, PRUDHOMME Guy

Abstract

This paper presents a comparative analysis of two mechanical systems with a value analysis approach. This approach is used to characterise mechanical products functions and to evaluate if the associated costs are acceptable. With this approach, we have a model which supports all the generated information during the design process: from design requirements to detailed solutions. Our research objective has been to test value analysis tools in order to verify if they are really usable for manufacturers. In this paper, it is shown that the approach is useful in helping designers to compare and to make a choice concerning a solution, but some improvements have to be done to increase the tools usability.

Keywords: design optimisation, functional modelling, product models, evaluation of design

1 Introduction

All designers have, at one time in their approach of design, a vision of the needs for the product. But they keep it in their mind and the problem is not written down. Nevertheless, functional and value analysis give them tools and an organized approach to express the needs. These methods are defined in norms [1] and are based on functional and costs aspects. A function is then described as the action of a product or one of its constituent parts. It is expressed, only in terms of finality, by a verb followed by a complement. The norms distinguish : - external functional analysis (or the functional analysis of need), which help to list the services the product is required to provide irrespective of the means available to it to provide them, - and internal functional analysis (or technical functional analysis), which help to analyse the resources required and the way they are allocated to provide the service required. We have already shown certain limits of such an approach [2] but, according to the norm, external analysis has to be done before internal analysis and without survey on solutions. The concept of function, as interesting as it may be, is not sufficient to characterise the needs. Functional Analysis proposes to add the concepts of assessment criteria, level and flexibility. The assessment criterion is defined as a characteristic which is used to evaluate the performance expected of a product, the level is the position on the scale of measurement of the assessment criterion, and flexibility is an indication expressed by the buyer as to the possibilities of modulating the level required for a given assessment criterion, thus showing what is explicitly considered as being negotiable in the formulation of a problem. Therefore, the act of characterising a function involves identifying all the assessment criteria. Then designers have to define level and flexibility which will serve as references in the course of the design phase of the product. Value is then defined like a ratio which grows when the satisfactory of the user's needs increase and/or the expenditure related to the product decrease. Analysis value links functional analysis, through user's needs, and cost or resources.

To understand what can be made with this approach and how designers can appropriate these tools, we have made a study to test the approach and the tools of the functional and value analysis. In a first step, we have the intention by using this approach to establish a model of product to lead a comparative survey of two products that are competitors. Our objective is then double: in one hand we have to compare and optimize the two products, and in the other hand we want to show in what extent the tools and the functional analysis approach can be used with efficiency by designers to do it.

The two products and the working group are described in section 2. Then we present the functional and value analysis approach, according to its temporal progress while presenting the used tools, and how designers used them during work and section 3. It will lead us to conclude on the results of the comparative study and on the use of the value analysis approach in such a process of assessment in section 4.

2 The project and the approach

2.1 The company and the product

The French company, that has asked us to make this study in order to compare solutions, make various products for the transportation with cable for winter sports: ski tows, chairlifts, Gondola lifts, …, This company has just bought their Italian competitor and they try to optimise their association with a common objective "Higher, faster, further, but always with the comfort and safety of users in mind". For certain parts of their products, there is a real difference between the costs and the technical solutions. So, they try to compare the services given by the different solutions and their corresponding costs in order to select or to redefine the best solution. The mechanical system under study is called "beam of wheels". It is the name for the mechanical structure (figure1) which accelerates or slows, without discomfort for the passengers, the components that are transported with cable. This beam of wheels is composed of wheels that are aligned along the beam. Each wheel has its own rotation speed. When the wheel is in contact with the components (cabs, chairs …), a linear speed is transmitted to them. Then, the component is transferred to the following wheel that has a different speed. It is the reason why the component can be accelerated or decelerated.

Figure 1. A beam of wheels under assembly

The drive shaft with wheel (DSWW) is the mechanical system that receives the wheel and transmits the necessary effort. Some DSWW have a rotation due to electrical motors. The two compared DSWW have a rotation due to bands and to pulleys (figure 2). According to the different radiuses of the pulleys, there is a variation of the rotational speed to decrease the linear speed of the transported components. The part that receives the roll bearings is linked to the beam of wheels with an assembly to adjust the strain of the band.

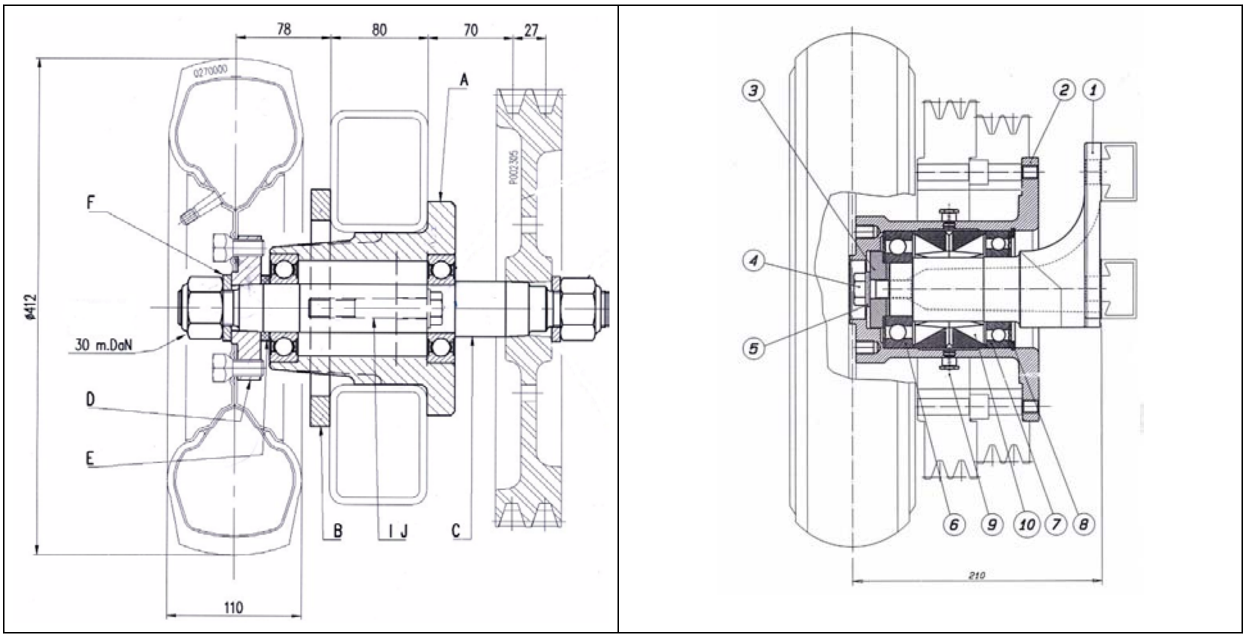

Figure 2. The two compared DSWW (drive shaft with wheel)

2.2 The working group

The project team was composed with: an engineer of the company, an expert in the value analysis (he is specialist in the animation of teams), five students in the mechanical (fourth year at the university) who are working for a course called “engineering mechanical project” and two teachers / researchers in the mechanical. To realize the study, there has been twenty half days of meeting, during six months. The company has given all the information on the products, organised the visits on the sites of production or on the sites of exploitation, and permitted contacts with all experts who are involved in the project. Our first objective was to construct the design specification of the two solutions, because the existing information about these products was not very developed [3]. This work was necessary, while keeping in mind that comparisons have to be made with a maximum of points of view. So, we have used various tools from the value analysis approaches that will be detailed in this paper.

3 The approach

The researches that consider the product with a functional point of view, [4] [5] [6], present numerous methods with different semantics. Our first approach was to apply the French norm [1], so we have tried to define the functions of the product that could satisfy the needs. We have started with the global analysis of the beam of wheels, which has served us to delimit the system in its totality as well as its interactions with the surrounding middle. Thus, we have used the tool: “graph of interactions”.

3.1 The graph of interactions

The graph of interactions (figure 3) represents the product as a black box, that is able to satisfy the needs of the customer and the needs of the professionals involved in its realisation.

At this stage, it is important to identify all these needs because minor changes in this first specification could induce important changes in the optimisation of the principle and then for the solution [7].

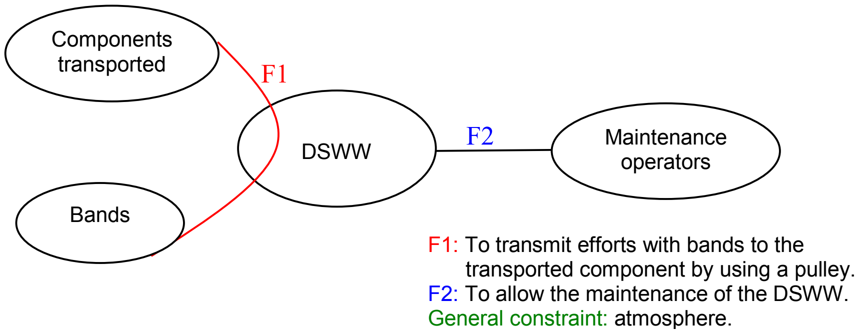

Figure 3. The graph of interactions for the DSWW in usage phase

For each phase of the life cycle of the product, it is necessary:

1- To define the “outer” environments of the products: C*omponents Transported, bands and maintenance operators,* and to determine the frontier of the study.

2- To define external functions and constraints: *To transmit efforts with bands to the transported components by using a pulley, To allow the maintenance of the DSWW and the constraint linked to the atmosphere.*

Then we have to define each assessment criterion associated to the functions with its expected level and its flexibility. At this stage we have not succeeded in recovering each level and flexibility that had been used during the design phases. Designers had not written this information and they were not able to reformulate it. Then we have decided to express the technical functions for each mechanism using the FAST tool describe in the following section. Then we hoped to better understand the external needs while analysing the technical functions achieved by these different solutions.

3.2 The FAST (Function Analysis System Technique):

This tool is available to structure the technical functions that could potentially fulfill the external functions and then to make matching up those technical functions with solutions. Then, it is necessary to define the internal functions (technical functions), their criteria and their expected levels. Some researches study the decomposition of these technical functions to formulate function from a standard of verbs [8]. The fast is used by the norm for the design: In this case, one identifies the external function and one looks for how to decline it until solutions. It can also be used for the redesign. In our case, we have rather used it in an analysis way that is to say that, while leaving from the technical solutions, we have formulated and structured the different technical functions that achieve the external functions (Figure 4). The expression in technical functions is not simple. It requires many round-trips between the solutions and the FAST. The technical knowledge of the work team has allowed the definition of a large number of criteria relative to the definition of the technical functions. But the definition of the identified functions remained too general (one doesn't go enough on the right of the FAST). It led us to use another tool: the blocks diagram, in order to define more precisely some technical functions. We present (figure 4) the final result of the FAST obtained after the utilization of the block diagram.

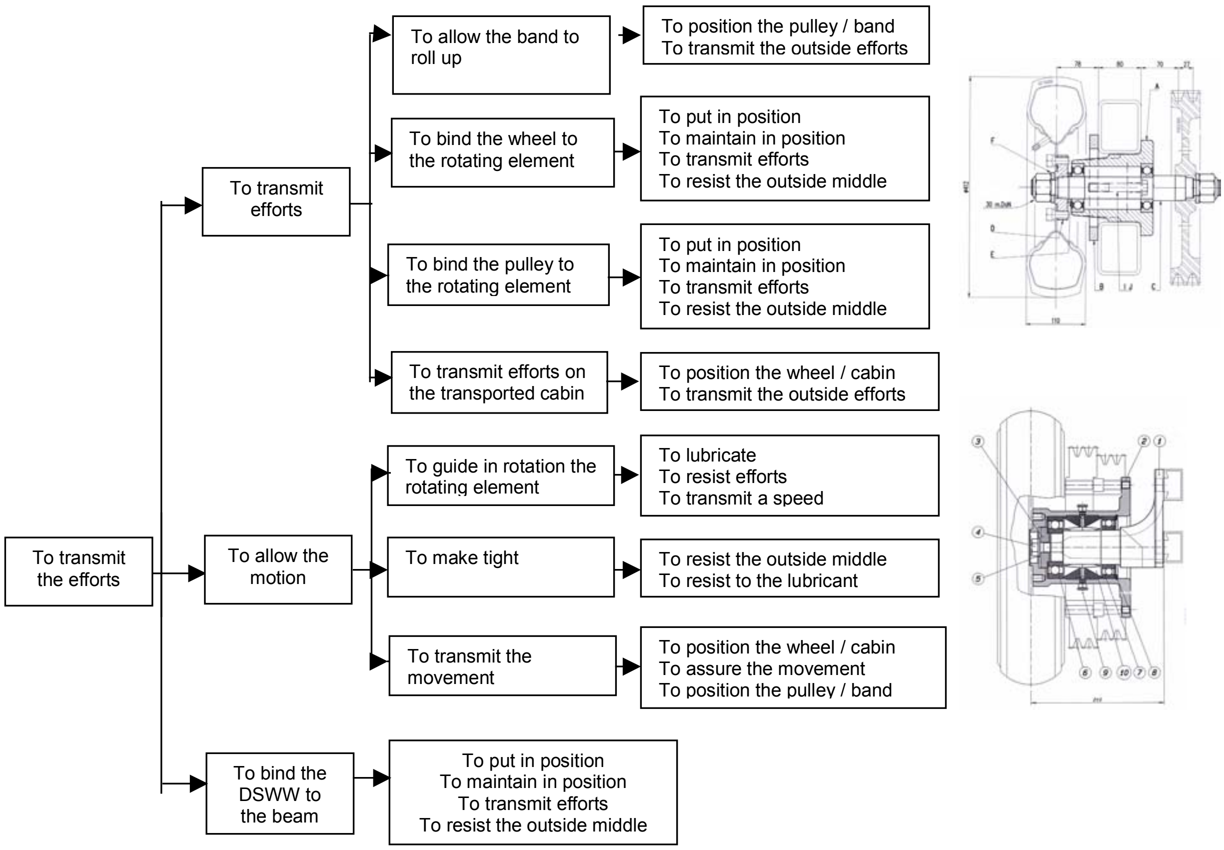

Figure 4. The FAST to define the following technical function: to transmit the efforts

3.3 The Block diagram

This tool is especially usable in the setting of projects to redefine some existing products. It shows the technical functions for the complex systems and it serves in the detailed design phase for the product optimization, when all the parts of the product are defined. On this diagram (figure 5), one represents:

- The components of the product, the border of the product and the “outer” environments
- The contacts between parts and the “outer” environments
- The fluxes linking parts and “outer” environments. These fluxes represent the external functions
- The buckles of design (BD). They characterize the design choices that satisfy some elementary technical functions.

With the characterization of the elementary technical functions we have detailed the characterization of technical functions with higher levels. Here, the two tools (FAST and blocks diagram) were well complementary. The upward analysis (solutions - blocks diagram – technical functions) and the downward analysis (External functional analysis and FAST) were necessary to define and to characterize the internal technical functions.

Having defined technical functions for the two mechanisms, we have made a comparison on the high-level technical functions. From this comparison, the two mechanical systems are similar. So, we have established the cost table for the two solutions to examine the functional aspects and the cost aspects of the product and then the value dimension.

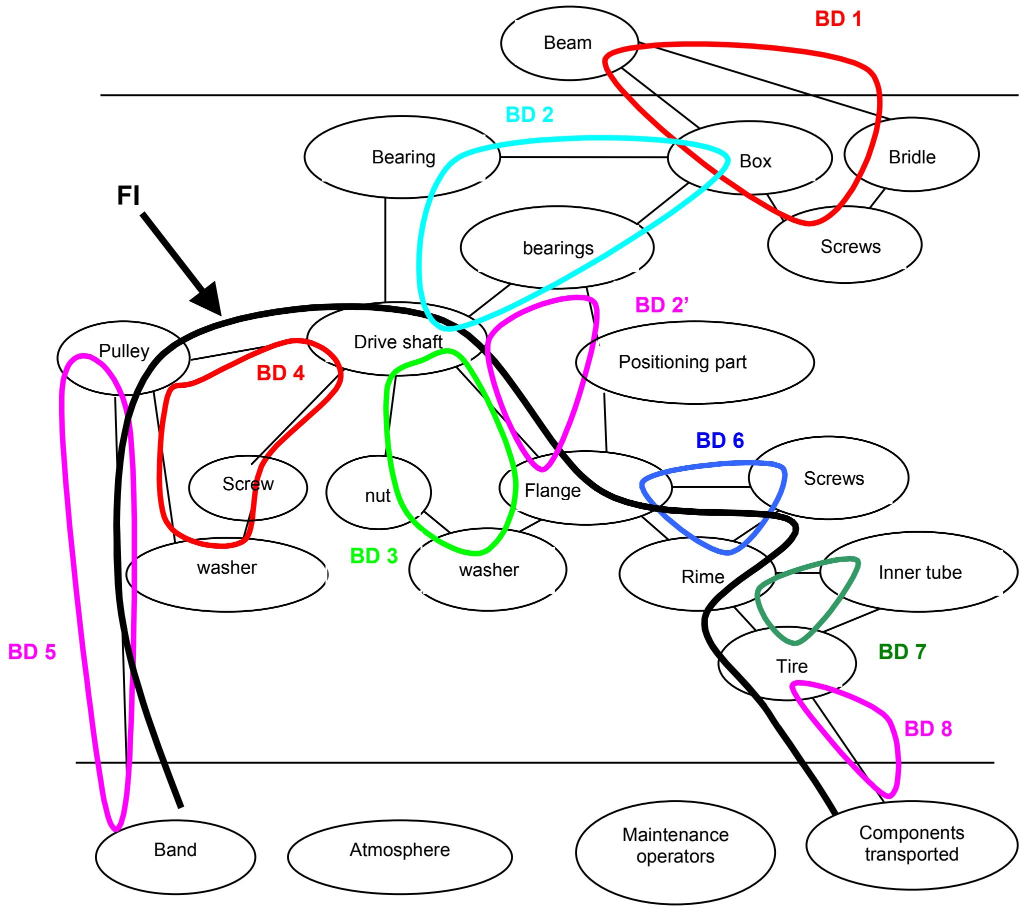

Figure 5. The Block diagram for a DSWW

We have identified a certain number of buckles of design, that have permitted us to complete the FAST therefore:

BD 1: Adjustable fixation on the beam
BD 2: Liaison for the rotation + lubricant.
BD 2': Bearings position.
BD 3: Fixation with disassembly for the flange.
BD 4: Fixation with disassembly for the pulley.
BD 5: Transmission of the efforts between the pulley and the band.
BD 6: Fixation of the Rime.
BD 7: Wheel.
BD 8: Transmission of the efforts between the wheel and the transported component.

3.4 The costs table

With the costs table we can make a comparative analysis of the two DSWW with a value point of view. This table list all the elementary functions that each part has to fill (table 1 : example for the drive shaft). Indeed, to do the comparative survey with the cost point of view, we have identified all the functional surfaces on the different parts (figure 6 : example for the drive shaft). We have identified if the functional surfaces participate to the realization of the technical function. Then, we have tried to distribute the machining costs of these functional surfaces between the different technical functions (table 1) taking into account the functional specifications (dimensional and geometric). This table was made with a costs specialist because it is very difficult to have the distribution of these costs [9]. The comparative survey with the cost point of view was made while adding all machining costs of every external and technical function for each of the two systems, and while comparing the costs between the similar external or technical functions of the two systems.

Table 1. The costs table for the “drive shaft”

		Functions		Buckles of design								
Parts	**Obtaining of the elementary surface**	**FI**	**C**	**1**	**2**	**2'**	**3**	**4**	**5**	**6**	**7**	**8**
Turning part (drive shaft)	Tapping M30 (x2) cost : T1						T_1	T_1				
	Cone turning - side of the wheel Cost : C1	$C_1/3$				$C_1/3$	$C_1/3$					
	Cone turning - side of the pulley Cost : C1	$C_1/2$						$C_1/2$				
	turning diameter 40n6 (x2) Cost : C2				$2C_2$							
	Shoulder diameter – roll bearing Cost : E1					E1						
	Raw material Cost : M1	$3M_1/8$	$M_1/8$		$M_1/4$		$M_1/8$	$M_1/8$				

The interest of this table is to carry efforts of optimization on the expensive functions and not only on the mastered functions. Thus, we can verify if levels of costs are coherent with needs and if buckles of design are coherent with the technical function to fulfill. It led us to work on the representations of the solution (figure 6) to recover indicators to formulate some new criteria and their levels. For example, when we have examined the conic surface that supports the pulley, we have formulated criteria concerning the transmission of the couple: the type of material, the diameter, the admissible pressure and the necessary couple for tightening.

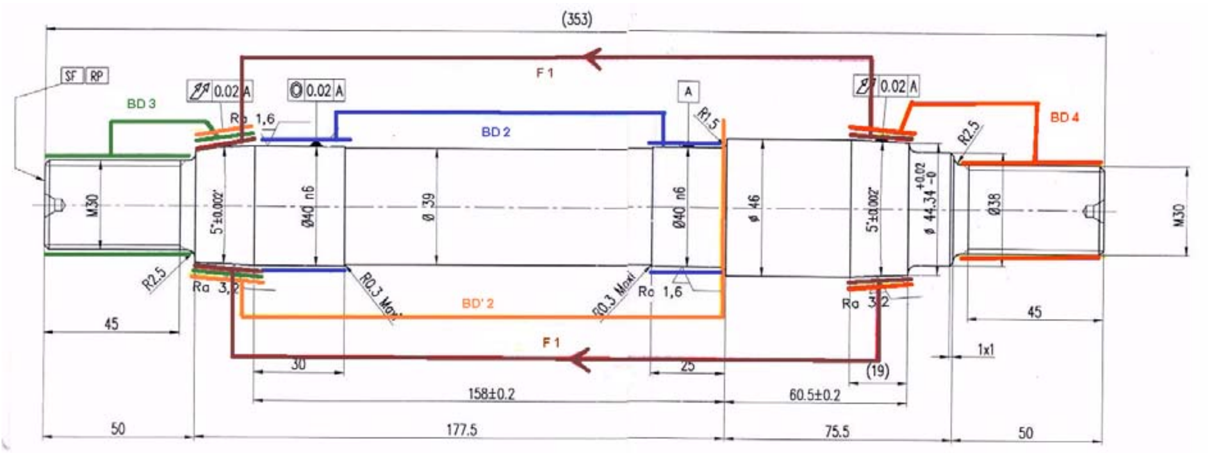

Figure 6. Representation of the drive shaft with its quotation

Thus, in the table (table 2), we have described an example of the elementary functions for the drive shaft. This work was necessary to achieve the analysis of costs. Then we have defined new criteria and identified some levels of criteria for the technical functions.

At this stage, we have identified the whole of the necessary elements to establish the comparison between the two devices. We have used all the criteria to finish the characterisation of the external functions (table 3) because it could be interesting to use this information in a future design study.

Table 2. Elementary functions and criteria for the "drive shaft"

Parts	Elementary functions	Criteria
Turning Part (drive shaft)	To permit the adhesion of the pulley	Coefficient of friction pulley/ drive shaft
	To permit the adhesion of the flange	Coefficient of friction flange/ drive shaft
	To transmit the couple	Admissible pressure on the cone - side of the pulley
		Admissible pressure on the cone - side of the flange
		Couple of tightening - side of the pulley
		Couple of tightening - side of the flange
		Material (Re)
		Section (diameter)
	To assure interior left contact of the rings	Life span (tolerance on position)
		Radial and axial acceptable efforts on rolling bearings
	To assure interior right contact of the rings	Life span (tolerance on position)
		Radial and axial acceptable efforts on rolling bearings
	To position the 2 surfaces for the rolling bearings	Ball and socket motion
		Concentricity
	To position the 2 reaches of rolling axially	Material (Re, thickness)
		Ball and socket motion
		Distance between the drive shaft shoulder and the reference for the cone- side of the pulley
		Distance between the drive shaft shoulder and the reference for the cone- side of the flange
	To assure the helical contact on the side of the flange	Shearing max. in the screw (length, Rg)
	To resist to efforts on the side of the flange	Tensile / compression max. (diameter of the screw)
	To position the flange	Position constraint
	To assure the helical contact on the side of the pulley	Shearing max. in the screw (length, Rg)
	To resist to efforts on the side of the pulley	Traction / compression max. (diameter of the screw)
	To position the pulley	Position constraint
	To resist to the corrosion	Temperature, humidity, ambient air, UV

Table 3. Characterisation of the external functions.

Function	**Criteria**	*Function*	**Criteria**
F1	Offset between the pulley axis and the beam axis Offset between the wheel axis and the beam axis Offset between the DSWW axis and the beam Coaxiality of the different part with the rotation axis (the reference) Speed max. for the rotating part Life span of the DSWW Total runout between the rotating part and the pulley Total runout between the rotating part and the wheel Material (Re, section) Minimum torque applied to the transported component Resistance (temperature, humidity, ambient air, UV) Lubricant	**F2**	Maximum weight for the DSWW
			Maximum volume for the DSWW
			Maximum distance for the DSWW /overpass
			Minimum Volume to intervene around the DSWW
			Kind and number of tools specific or not
			Frequency to oil

4 Results and discussion

4.1 Results concerning the comparative analysis

For the two systems, we show that:

- External functions are the same, with same criteria and same levels
- Internal functions are the same, with same criterions but with different levels
- Solutions are different, but they respect the initial requirements.

We demonstrated that, one system is really better than the other because it presents more advantages concerning the maintenance, the assembly and the disassembly, the number of parts, the standardisation, the relation with its environment… with the lowest cost! These results were not evident for designers at the beginning of the study, because:

- They have not the detailed history of the choices that have be done for the two mechanical systems.
- It is difficult to identify what could be called "too much quality" on a function, if you don't have the criteria and their levels. In fact, one system is optimized on numerous functions (certainly with too much quality) but we shown that the most important functions are not optimized.

So, this study demonstrates how essential is the notion of assessment criteria, in order to detail the description of the functions and then to really compare mechanisms. Then we can have two approaches: to optimize the product from a functional point of view or from a cost point of view. In our case, it was finally easy for the project team to retain the product that presents the better value (most functional advantages at the lowest price).

4.2 Discussion concerning the value analysis approach

The value analysis approach that we have used for the elaboration of the specifications of the product was not really the approach proposed by the norm. Indeed, this has been necessary to have a downward analysis to understand the context of the project as an upward analysis to find pertinent information on the existing mechanical systems. We have encountered difficulties all along the study because of the lack of information:

1. There is no description of the principles considered and retained during the conceptual phase of the mechanical systems. We show that the value analysis approach could give tools to help designers during the choice of principles.
2. The stage of technical functions definition that directly depends on the definition of principles appears to be very important during the project. The bloc diagram is an efficient tool to link the needs, the perceptions, the functions, and the products aspects [10]. But there is little information capitalised on these aspects. If the technical functions can be defined with their criteria and levels of criteria they could be linked to the external functions. Then the problem of too much quality could be examined with the external function criteria and the retained principles.
3. There is no capitalisation of the information that is used to optimise the solutions while examining the technical function definition. In this case, the information exists because designers need it for the optimisation of the solution, as mentioned in [11]. Considering that designers have not the time to capitalise all the information, we think that it is necessary to create a link between the existing tools, which define the solution, and the functional analysis tools.

5 Conclusion

We show in this study that design specifications can be written down using functional analysis and value analysis tools. These tools are particularly useful to compare existing solutions from customer and cost or resources points of views. But we show that an exclusive downward approach as proposed by the norms is not appropriated to define functions and assessment criteria. Downward and upward approach alternatively used is more efficient to reach these specifications. Then, this method and its tools enable us to compare two devices from functional and cost points of views and to realise an optimisation according to particular criteria. Our study also shows that functional and value analysis enable us to capitalize design knowledge, design information and decision about design experiences. So, the functional analysis must lead to the capitalization of knowledge within the firms concerning the definition of the functions, the constraints and their criteria. This form of memory of the firm will allow designers to decrease the time of development and to increase the quality for the future design projects.

References

[1] Normes NF X 50 – 100, "Analyse fonctionnelle, Caractéristiques fondamentales", AFNOR Paris, 1996.

Normes NF X 50 – 150, "Analyse de la valeur, Analyse fonctionnelle, Vocabulaire", AFNOR Paris, 1990.

Normes NF X 50 – 150-1, "Vocabulaire du management, de la valeur, de l'analyse de la valeur et de l'Analyse fonctionnelle", AFNOR Paris, 1996.

Normes NF X 50 – 151, "Expression fonctionnelle du besoin et cahier des charges fonctionnel", AFNOR Paris, 1991.

[2] Prudhomme G, Zwolinski P., Brissaud D., "Integrating into the design process the needs of those involved in the product life cycle" to be published in Journal of engineering design, vol.14, 2003.

[3] Malmqvist J., Schachinger P.,"Towards an implementation of the chromosome model focusing the design specification", Proceedings of ICED'97, Tamper, 1997.

[4] Stetter R., Aßmann G., Viertlböck M., "Functional Product Modeling – New Methods for the Generation of Product Functions", Proceedings of ICED'01, Glasgow, 2001, 8p.

[5] Maven D., "Engineering design models: context, theory and practice", Journal of engineering design, vol.9, 1998, pp.315-327.

[6] Hubka V., Eder W. E., "Functions revisited", Proceedings of ICED'01, Glasgow, 2001, 9p.

[7] Bracewell R.H., Wallace K.M.,. "Designing A Representation to Support Function – Means based Synthesis of Mechanical Design Solutions", Proceedings of ICED'01, Glasgow, 2001, 8p.

[8] Hirtz J. M., Stone R. B., Szykman S., McAdams D.A., Wood K. L., "Evolving a functional basis for engineering design", Proceedings of DETC'01, Pittsburgh, 2001, 11p.

[9] Schlink H., Schneider H., Höhne G., "The Determination of function costs in Engineering products", Proceedings of ICED'01, Glasgow, 2001,

[10] Yannou B., Petiot JF., "Needs, perceptions, functions and products : highlight on promising design methods linking them", Proceedings of IDMME'02, Clermont-Ferrand, 2002, 10p.

[11] Opran C., Armeanu A., "Elementary level in the functional-technological design", Proceedings of ICED'01, Glasgow, 2001, 9p.

Peggy Zwolinski Grenoble University, 3S Laboratory, DU, BP n°53, 38041 Grenoble Cedex 9, France
Tel : (33) 476825274 Fax : (33) 476827043 E-mail : Peggy.Zwolinski@inpg.fr
URL : http://www.3s.hmg.inpg.fr/