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Cognitive Virtual Exploration for Optimization Model Reduction

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***Abstract*—**In this paper, a decision aid method for pre-optimization is presented. The method is called "negotiation", and it is based on the identification, formulation, modeling and use of indicators defined as "negotiation indicators". These negotiation indicators are used to explore the solution space by means of a class-based approach. The classes are subdomains for the negotiation indicators domain. They represent equivalent cognitive solutions in terms of the negotiation indictors being used. By this method, we reduced the size of the solution space and the criteria, thus aiding the optimization methods. We present an example to show the method.

***Keywords*—**Optimization Model Reduction, Pre-Optimization, Negotiation Process, Class-Making, Cognition Based Virtual Exploration.

I. Introduction

WITHIN a product development process context, the transition between the "embodiment design" and "detailed design" (Pahl and Beitz [1] design process in figure 1) is one or the final transitions to product production launch. It is in this transition that most of this subjectivity must be solved. Preference satisfaction must be guaranteed before proceeding to a "detailed design phase". Generally, the process followed uses classical optimization methods. But these are limited by:

- The number of criteria that can be considered simultaneously
- The size of the solution search space, which influences on computing time and precision.
- The solution search space density, which determines as well the computing time.

So, in order to aid in the preparation of a solution space for it to be optimized easier, we have developed a method which we call "negotiation". It aims at reducing the criteria to be considered by filtering it and using only the most pertinent. Also, it aims at structuring the solution space into classes of "equivalent solution", so each class can be analyzed separately. In this way, the solution search space to be optimized is smaller, aiding in computing time and precision.

The method proposed in this paper positions itself within a "routinely design" context. This means the product being developed is already known. Specifically, we work in the transition between the "Embodiment Design" and "Detailed Design" phases. The "Embodiment Design" phase has as output a product whose general components, most of its geometry, as well as the materials have already been defined. We consider retrieving information out of the previous stages of "Requirement analysis" and "Conceptual Design".

In terms of requirements, several methods exist to analyze them. Amongst the most common there are the FAST (Function Analysis System Technique) Method [2], the "subtract and operate" method [3]. They can be used in a routinely design process to define all the functions a product must have and the constraints it will encounter. The FAST method has a top-down approach, which starts on an overall function and then decomposes it. It usually combines with the "subtract and operate" method to find the importance of a certain function. The "subtract and operate" method is made on an existing product, similar to the one being developed, to understand the influence of each function in terms of product operation.

In terms of product concept, it is developed after having determined the functions, via several types of search methods. Among them, we can mention the "morphological matrix", the "creative brainstorming", the application of TRIZ principles to satisfy the requirements, etc. An extensive review of these methods can be found in [3]. We propose a product decomposition following the guidelines of the *technical flowchart*. It is a tool that enables the description of any system in terms of its functional components.

II. Decision Support for The Best Choices in design

A. Process Based Approach for the Right Solution Search

Selecting the best configuration or final characteristics of a concept is linked to product requirement satisfaction. In product design the right solution search process strongly depends from the actors involved in the process. Since cognitive aspects are highly important in design, a lot of

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works have provided methods for rapidly achieving right solutions. They've focused on a suitable process organization and knowledge exploitation as of the first phases. As Shupe [4], Hazelrigg [5], and Stoll [6] expose, the key is retrieving information to decide on the best solution. For this, several methods have been developed. Multi-attribute decision analysis [7], [8], [9] and the classical utility theory [10] have also been used to select options. Pugh's method, a simplified version of the utility theory, requires a reference concept to be taken in account, where as the evaluation is limited to three states (o, -, +) [11]. Other methods establishing criteria importance in order to manage it in terms of concept refinement, or solution space search, are defined by the Analytical Hierarchy Process [12], Taguchi Loss Function [13], and Suh's Axiomatic design [14]. These methods have been used in the preliminary stages of product development, whose classic flow approach can be appreciated in figure 1. The application is usually made from the transition stage between "concept search" on. Yet, one common characteristic to all of them is the need of guidance to give importance to the criteria by which the product concept is being evaluated. This has been solved by the attribution of a "weight" *w* that can be found not only in these methods, but also as early as the requirement analysis.

All this importance and hierarchy attributes are targeted at aiding the development team in better guiding their solution

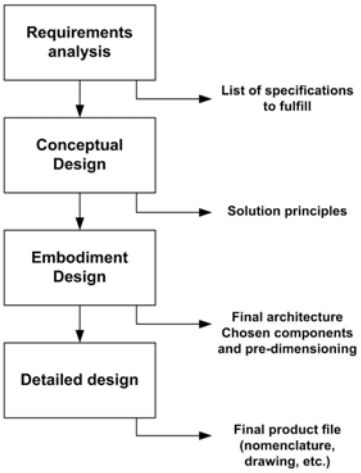


Fig. 1 Classic product development process (Pahl et Beitz.[1]).

space search process. Yet, this importance is often derived from human points of view. These can result then in conflictive criteria, or criteria of different nature that carries a similar importance in terms of human preference.

B. Numerical Optimization for the Best Solution Set

Along with the previous, other methods being strongly based on numerical processes have proposed ways to manage conflictive criteria. Optimization techniques have been widely studied and developed for supporting pre-dimensioning operations in design. The various provided tools are commonly dedicated to the detailed design phase.

Optimization techniques have been rapidly deployed for supporting dimensioning activity at the stage of detailed design. Those techniques are not adapted to the support during early phases of the process. This is because they are based on accurate mathematical models and require a complete and advanced definition of the design problem.

However, more recently, some numerical processes combining evolutionary, combinatory and qualitative approaches (examples in [15],[16], and [17]) have allowed fuzzy problems to be considered. With the aim of supporting pre-dimensioning in embodiment design (where the problem is still ambiguous, not clear, and under development), a specific way allow to virtually explore solution spaces has been also proposed in [18]. However, the criteria search definition; the ways by which knowledge is considered and domains are explored remain difficult.

Weight attribution depending only on implicated actors' point of view can't always prove to be effective, as Olewnik and Lewis show in [19], especially regarding the Quality Function Deployment [20]. In terms of a general hierarchy establishment, Bahill, and Eden and Ackerman have reported respectively in [21], [22] how relying on points of view and people knowledge is not so straightforward.

But the problem of representation of solution set is not integrated in previous techniques

C. Virtual Representation of Right Solution Set

Although designers obtain a set of right product alternatives, the problem of best choice is still present. Pareto-set is a known approach to this problem, as applications found in [23], [24], [25], [26] show. However, Pareto representation can only be employed if optimal solution set is already defined. In the end, it is a good way for virtually representing multi-dimensional solution spaces.

D. Preference Based Virtual Exploration

Our approach intends the combination of cognitive process and virtual exploration techniques at the embodiment design stage. It is preparation for optimization (pre-optimization).

This pre-optimization approach consists in reducing a model of optimization having the standard form presented in equation 1.

$$\begin{cases} \{\mathcal{M}(\{x\})\} = 0 \\ \{C(\{x\})\} \le 0 \\ \forall i \in \{1,\dots,n\},\ x_i \in D_i \\ \mathrm{Max}(\{\mathcal{F}\}) \end{cases} \quad (1)$$

- {x} is the set of n variables of the design problem, linked through the model by knowledge,
- {M} is a function of a function vector defining the model of the design problem issued from knowledge,
- {C} is a function of function vector defining the constraints linked to the design problem,
- Di is the domain of values for the variable xi; the domain can be either discrete or continuous,

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- {F} is the set of criteria to optimize.

The previous model includes limits such as:

- All the knowledge can not be modeled and so not be considered in the optimization process, by necessarily forgetting good solution during the process,
- time processing depends on the size of value domain although some values not cognitively suitable are tested,
- the form of numerical techniques limits the maximum number of criteria to be maximized (2 or 3).

Our approach consists in the combination of the cognitive and numerical processes to:

- consider and integrate all discriminative knowledge even if it can not be modeled,
- reduce the domain of values by keeping only the values having a chance to integrate an alternative solution,
- identify a reduced set of criteria and handling it even if it exceeds 4 elements,
- allow experts to virtually explore and represent solution spaces,
- lead quickly to best design alternatives even if we are in the embodiment design phase.

In order to achieve such goal we propose:

- firstly, to reduce value domain from a cognitive approach by identifying what we define as negotiation indicators,
- secondly, to reduce a set of alternatives. This by better considering all of the expert's knowledge through a choice process,
- thirdly, to reduce the number of criteria by avoiding lack of information and allowing designers a virtual exploration of best alternatives (this is a decision process).

We thus propose a method to aid negotiation. We propose a crosslink between the concept's decomposition and the criteria. Key parameters defining the criteria can then be used to find the best configuration of the product.

This paper is organized as follows. First, we explain the basis of our proposal, and why we call it "negotiation". Then, the input, method, and output are outlined. Criteria defined as "negotiation indicators" will be determined throughout the method. A set of rules to use the indicators will be established as well. The application of the method will be made on the solution space of a simple case study.

III. Optimization Model Reduction Based on Cognition

A. Negotiation: from the Definition to the Goal

We introduce Negotiation as a specific method supported by original tools which allow engineers to prepare and render the optimization process easier in routinely design. Our method permits designers:

- To easily define the criteria used to explore solution spaces,
- To reduce the search space (or value domains).

We define the negotiation as the mean to reach an agreement satisfactory to all the parties implicated in the product development process. By taking in account their preferences, the satisfaction of all the implicated parties leads to the design space sub-classes making.

For achieving previous goal, we support the development of the "negotiation indicators". They serve as preference criteria to virtually explore solution spaces and lead to product alternatives. Being the reason behind design space sub-classes, they describe similar cognitive representations for the product.

In this paper, the authors detail the negotiation method and its relevance. A general presentation of negotiation process is made. Then the most significant instruments enabling the negotiation indicators to be created, as well as the virtual exploration to be implemented are described.

B. Location of the Negotiation Process

Our approach is located in Embodiment Design. The input of our method comes from the preceding phases of the product development process:

The product requirements. We consider a list of functions divided into "service" and "constraint" functions, depending on the purpose they serve. The "service" functions describe the product operation, as well as its relation to the environment and the user. The constraints will be those product characteristics that limit the configuration possibilities). The first available input consists in (Table I):

- function list,
- function importance (K): refers to the designers' opinion,
- Measure: defines the type of measurement scale suitable for valuing the function,
- Level: refers to the acceptable measure for the function or constraint,
- Flexibility: refers to the fluctuations the measure can have, and which can still be acceptable

The existing product concept. We receive a concept definition in term of functioning and using. The concept configuration and basic characteristics of a product is provided through an organic decomposition. The "technical

TABLE I
PRODUCT REQUIREMENT INPUT.

No.	Description	K	Measure	Level	Flexibility
1. Service Functions					
1 SF	Description				
2 SF	Description				
3 SF	Description				
...	SF ...				
2. Constraint Functions					
1 CF	Description				
2 CF	Description				
3 CF	Description				
...	CF ...				

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flowchart" considers several levels of decomposition, as can be appreciated in Fig. 2. The first level, considered "level 0" includes the product as a whole, and the external environment with which it interacts. The next levels go down from sub-assembly to component. The characteristic that's taken in account to separate each sub-assembly is the product operation. Each part of the product that accomplishes an operation or a group of similar operations can be considered as a "operational block" and then be subdivided into assemblies, components and even subcomponents (if the product is detailed enough).

From product concept and requirements we provide a series of tools based on the principle of negotiation which lead to the

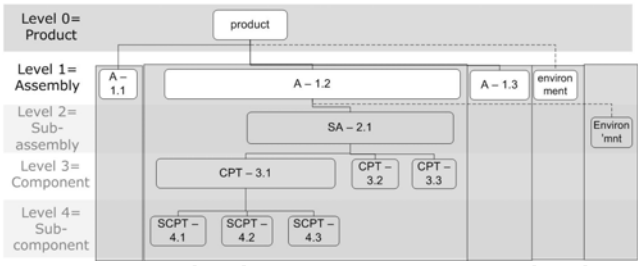


Fig. 2 Conceptual product representation input: "Technical Flowchart".

creation of negotiation indicators. Major functions are identified, qualified and transformed into "negotiation indicators" (onwards also named criteria), to build classes within the solution space.

Our method consists of the following stages (figure 3):

- Criteria identification: among the available list of functions we identify those being discriminant in a decision making process,
- Criteria formulation: the criteria are established as "negotiation indicators" with certain properties. The way to handle them is also defined,
- Criteria modeling: for each criterion, a model respecting a standard representation is provided,
- Criteria qualification: for each negotiation indicators the significance and danger is detailed with specific standard parameters.

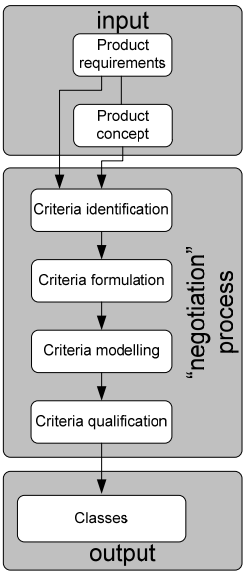


Fig. 3 Negotiation method.

The output for the "negotiation" method consists in sub-spaces of solution spaces. All product alternatives are arranged in classes where inner solutions have the same cognitive significance. These "classes" are the guidelines to explore and reduce the solution space This is made in terms of the cognitive representation the actors has of the product and the analysis of their relation to the tangible object. These classes can be analyzed separately, thus rendering the further optimization simpler and easier to handle.

IV. Negotiation Indicator Development

A. Negotiation Indicator Identification

The main tool proposed to achieve Criteria Identification is the crosslink between product functions and the product concept decomposition. Its objective is to find in what terms "a component or a functional block satisfies a function", or "a function is major for the product and discriminant during decision making". Finally, each function contains a power of negotiation

The power of negotiation of a function is identified through the Organic Function Graph (Figure 4).

The Organic Function Graph (OFG) is a systematic method that aims at the definition of a function's presence and technical origin at a given systemic level of the global product. By crossing both inputs of the embodiment design stage (the conceptual and requirements definitions), the OFG highlights the links between organic parts of the product and the function presence. The influence parameter $r(i,j)$ defines the link between the function i and the organic part j:

- if $r(i,j)=1$, the function i needs the organ j in order to exist; in other words, the organ j allows the function i to be achieved,
- if $r(i,j)=0$, there is no relation between the function i and the product organ j.

The parameter $r(i,j)$ intends to highlight the design and dimensioning intent for each function. For each systemic level p, the whole set of influence parameters are arranged in the Influence Matrix (IM) $[K^{(1)}]$ (see equation 2 for the influence matrix of systemic level 1 linked to Figure 4).

$$\left[K^{(1)}\right] = \begin{bmatrix} 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 \\ 0 & r(i,j) & 1 & 1 \\ 0 & 1 & 1 & 0 \end{bmatrix} \quad (2)$$

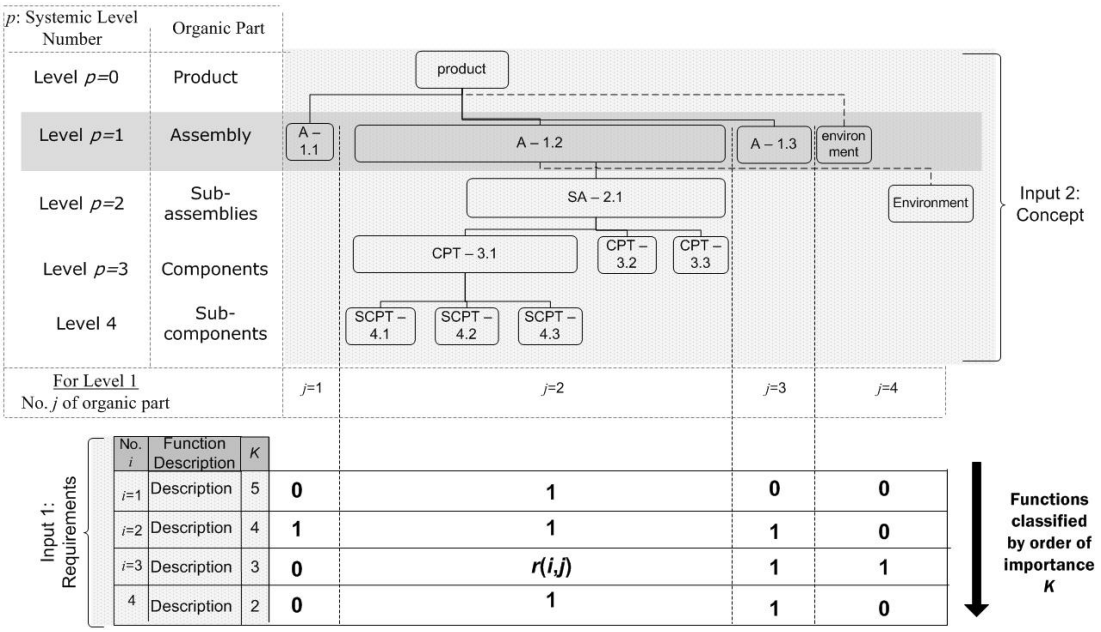


Fig. 4 Organic Function Graph for the systemic level 1

From the IM, we propose to calculate the Organic Functional Rate (OFR) $R_{OF}^{(i)}$ that defines the significance of the function *i* in design. This is achieved by detailing its power of discrimination for solution choices. The OFR calculation respects the following properties:

- when a function depends from a great number of organs, it becomes a strong criteria of decision,
- when a function is located in a high systemic level, it becomes major.

On one hand, the soundness of a function *i* at a systemic level *p* is valued by the Function-Organic Vector (FOV) $\{F^{(p)}\}$. It highlights the function's influence power over the design parts (see equation 3)

$$\left\{F^{(p)}\right\} = \begin{Bmatrix} \sum_m K_{1m}^{(p)} \\ \sum_m K_{2m}^{(p)} \\ \vdots \end{Bmatrix} \quad (3)$$

On the other hand, the function's systemic level of application is valuated by means of the Systemic Level Weight (SLW). It depends on the level *p* of application and the full number of known systemic levels *L* (equation 4).

$$w_p = L - p \quad (4)$$

For all the functions, the OFRs are arranged in a vector $\{R_{OF}\}$ (equation 5).

$$\left\{R_{OF}\right\} = \sum_p w_p \left\{F^{(p)}\right\} \quad (5)$$

The ROF will help us choose the functions in the product specifications which will be transformed into design criteria (also called negotiation indicators).

Once all the R_{OF} for all the functions have been calculated, their average $\overline{R}_{OF}$ and standard deviation $\sigma(R_{OF})$ values are calculated.

We identify what function is used as criteria in the design (negotiation indicators):

- if the OFR function is greater than $\overline{R}_{OF} + \sigma(R_{OF})$, the function is strategic and discriminant in design, being a negotiation indicator,
- if the OFR function is lower than $\overline{R}_{OF} - \sigma(R_{OF})$, the function is not an element for supporting decision making,
- if the OFR function has a value in the interval $\left[\overline{R}_{OF} - \sigma(R_{OF}), \overline{R}_{OF} + \sigma(R_{OF})\right]$, the function could be a negotiation indicator. Its labelling depends on the cognitive vision of the design group.

From a huge list of functions, the previous proposal allows designers to rapidly identify a reduced set of strong design criteria that supports choices and solution qualification. Our approach is completely based on cognitive approach in order to avoid lack of information. In the following section we propose the means to model such indicator.

B. Negotiation Indicator Formulation and Modeling

Criteria having ROF values greater than $\overline{R}_{OF} + \sigma(R_{OF})$ are transformed into negotiation indicators. The negotiation indicators are chosen among the functions, depending on their influence on the product.

A negotiation indicator is an element that allows distinguishing or assimilating different alternatives. Each negotiation indicator formulates how to regard a set of design choices applied on a specific organ of the product.

An indicator is formulated from (Table II):

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- A number and a mathematical denomination for the variable,
- Its objective in design, or how is it handled in terms of the design solutions,
- The systemic level where it is more important,
- The linked technical knowledge and the models where it is included.

TABLE II
NEGOTIATION INDICATOR FORMULATION SHEET

Negotiation Indicator Number	1	Designation	N_i
Systemic Level to Be Applied		Systemic Level where design choices influe on the function	
Objective in Design		Definition of the design aim related to the function	
Related Technical Knowledge		Implicit available Models implying the criteria	

Each model of negotiation indicator N_i details (equation 6):

- The scale of measure m,
- the wide domain of possible values Di being taken by the criterion: this comes from own design actors know-how , the domains may be continuous or discrete,
- the ideal character of this criterion f_i.

$$\begin{cases} N_i \in D_i \\ [N_i] = m_i \\ \lim_{\infty}(N_i) = f_i \end{cases} \quad (6)$$

Previous model information comes from negotiation process inputs.

A way to evaluate design is enabled by these negotiation indicator model and formulation. However, we suggest also a qualification of each criterion. This will make the exploration of design issues more cognitive and flexible.

C. Negotiation Indicator Qualification

The criterion qualification aims at detailing the significance for criterion handling. This qualification also guarantees the description of the relevance for the captured cognition being consequently used in solution spaces exploration.

A negotiation indicator N_i is qualified with two parameters:

- its level of confidence λ_i – measured in % - expressed in equation 7: it comes from a comparison between the Organic Functional Rate $R_{OF}^{(i)}$ negotiation criteria,

$$\lambda_i = \frac{R_{OF}^{(i)} - \left(\overline{R}_{OF} + \sigma\left(R_{OF}\right)\right)}{\max_k\left(R_{OF}^{(k)}\right)} * 100 \quad (7)$$

- the systemic level s (among n systemic levels) where it is more relevant

$$\forall p \in \{1,\cdots,n\}\ \exists s, s = p \ with \ \max_p\left(F_i^{(p)}\right) \ is \ true \quad (8)$$

Previous elements allow designers to value their analysis, yet remaining flexible and strongly based on a cognitive approach.

However, thanks to the reduced list of criteria and their qualification, we supply a technique for supporting design space exploration, which is the aim of negotiation.

V. COGNITION BASED VIRTUAL EXPLORATION OF SOLUTION SPACES

A. Virtual Exploration from Negotiation

In virtual exploration from negotiation, each negotiation indicator N_i has its domain D^i partitioned into subdomains called classes C_j^i, none of which overlap. This means there's no intersection between the intervals defined for each class.

These classes represent equivalent solutions from a cognitive point of view, in terms of the negotiation indicator being considered. An agreement among the design actors is reached in order to determine the subdomains of a domain D^i for a negotiation indicator N_i. The quantity and limits of these domains are based on the experts' knowledge and agreement.

The cognitive approach by classes enables the establishment of an "ideal" combination as well. It is defined by the combination of the class in each N_i that's considered as having the best values.

B. Class making

A class C_j^i is a subdomain within the domain N_i, of each negotiation indicator N_i.

Each of those subdomains has the property expressed in equation 9, where the subindex j denotes the class denominator

$$\bigcup_j C_j^i \subseteq D^i \quad (9)$$

The lack of intersections between classes is a necessary condition expressed in equation 10, where t is the number of classes in a subdomain.

$$C_j^i \cap C_k^i = \varnothing, \forall j \neq k;\ j,k = 1,2,...,t \quad (10)$$

Where C_j^i and C_k^i are classes within the Negotiation Indicators N_i,; j, k are subindexes from 1 to t, where t is the number of classes in N_i (Table III).

TABLE III
INCLUSION OF CLASSES INTO NEGOTIATION SHEET

Negotiation Indicator Number	1	Designation	N_i
Systemic Level to Be Applied		Systemic Level where design choices influe on the function	
Objective in Design		Definition of the design aim related to the function	
Related Technical Knowledge		Implicit available Models implying the criteria	

Cognitive classes		
Designation	Ci	Values
	C...	

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C. Cognitive ideal combination

Firstly, we determine a class $C_{i\ best}$ for each negotiation indicator N_i according to the experts' knowledge and agreement.

The exploration of the solution space is made with the set of negotiation indicators N_i having as interval of possible values their $C_{i\ best}$. The model of the negotiation indicator for the Cognitive ideal combination is modified as detailed in equation 11

$$\begin{cases} N_i \in C_{i\ best} \\ [N_i] = m_i \end{cases} \quad (11)$$

This model is included in the Negotiation Indicator Formulation Sheet, within the Related Technical Knowledge box.

VI. Method Application: Nutcracker case

A. Product Description

The case study we will take will be a nutcracker, similar to the examples shown in figure 5. We consider then the product concept to have arrived to the following stage of development:

- The maximum general dimensions will be 8 x 2.5 x H 20 cm.
- The material will be aluminium with chrome finish.



Fig. 5 Nut cracker product type for case study.

B. Input

The input for our negotiation method, are the product requirements and the product decomposition. They are shown in figure 6 and Table IV.

C. Negotiation Indicators

Firstly, we identify the negotiation indicators by means of the Organic Function Graph (OFG) for the case study. Figure 7 shows the lowest level graph.

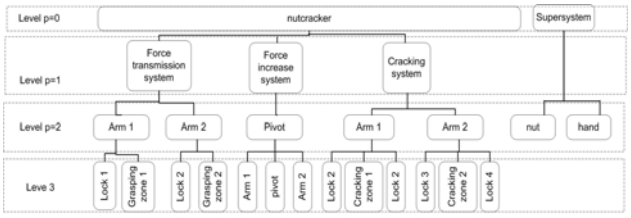


Fig. 6 Nutcracker study concept decomposition.

TABLE IV
Case Study Product Requirements

No.	Description	K	Measure	Level	Flexibility
1. Service Functions					
1 SF	trasmit force from hand to nutcracker	5	Force	10N	± 10%
2 SF	enable grasping	5	Ergonomics	95 percentile	± 10%
3 SF	resist deformation	3	Force	50N	-
4 SF	increase the applied force from the nutcracker to the nut	4	Force	25% increase between input et output force	± 10%
5 SF	transmit mouvement to hand	3	Sliding	100% of mouvement transmission	-5%
6 SF	adapt to the nut form	4	Form	90% of nut sizes (experimental testing)	±5 %
7 SF	adapt to user's hand form	4	Form	95 percentile	± 10%
8 SF	be handy	5	Force Weight	10N 0,400kg	± 10% ± 10%
9 SF	limit the nut's movement	4	Sliding	0 mm	+5 mm
10 SF	resist rusting	2	Aspect	90% acceptance*	-
11 SF	do not occupy too much space	2	Volume Dimensions	L :0,30m l :0,20m h :0,10m	± 10% ± 10% ± 10%
12 SF	enable cleansing	3	Acces	100% product accesibility	±5 %
13 SF	enable one-hand grasping	1	Ergonomics	95 percentile	± 10%
14 SF	be aesthetic	3	Aspect	90% acceptance* *	-
3. Constraint Functions					
1 CF	guarantee the security of the user	5	Protection	90% acceptance* * *	-
2 CF	do not present dangerous edges	3	Security	0 edges	-
3 CF	resist temperature variations	1	Temperature	+70° C, -20° C	± 10%
4 CF	guarantee the security of persons being near the product	3	Protection	90% acceptance* * *	-
5 CF	resist impact	2	Impact	90% acceptance* * *	-
6 CF	resist falls	1	Aspect Height	95% acceptance* * * 1,00 m	± 10% -
7 CF	resist cleansing products	2	Cleanliness	100% acceptance* * *	-2%

* D6294-98(2003) Standard Test Method for Corrosion Resistance.
** User experimentation with available prototypes or sketches.
*** Experts' requirements in the form of a standardized test

The Influence Matrixes K for each systemic level are shown in figure 8. They reflect the influence of each function over each organ of the product concept decomposition.

Also in figure 8, we show the FOV (Function Organic Vector). This is calculated by following the equation 3 for each systemic level.

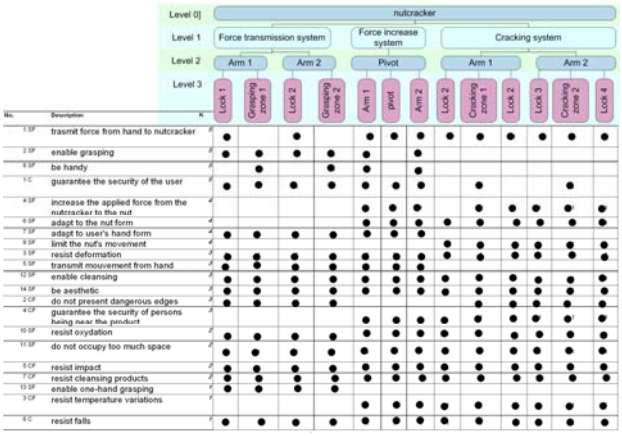


Fig. 7 Organic Functional Graph for lowest level in case study.

In terms of the Systemic Level Weight wp, we know the full number of levels L is 4, so we calculate according to the equation 4 the weights for each systemic level. The Organic Functional Rate can now be calculated, following the equation 5. The resulting vector {ROF } is shown as a line vector as follows

$$\{R_{OF}\} = \langle 7\ 4\ 0\ 7\ 4\ 5\ 7\ 4\ 14\ 7\ 14\ 14\ 4\ 1\ 7\ 12\ 14\ 14\ 4\ 7\ 14 \rangle \quad (12)$$

Then, we calculate the average value $\overline{R}_{OF}$, which is 7.14;

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and standard deviation $\sigma(R_{OF})$, which is 5.29. In consequence, and according to the negotiation indicator's identification, we choose among the functions i from the case study, those whose ROF value exceeds $\overline{R}_{OF} + \sigma(R_{OF})$. This results in the list shown in Table V.

The indicators formulation and modelling is shown in Table VI.

D. Virtual Exploration of Solution Spaces

Following class relations before, the experts decide on the classes built within the solution space. These are shown in Table VII.

Finally, the Ideal Cognitive Combination is conformed by the negotiation Indicators whose model is modified to substitute their domain of values by the interval of class belonging to their best class C_{best} (marked also in Table VII). The Ideal Combination is shown in Table VIII.

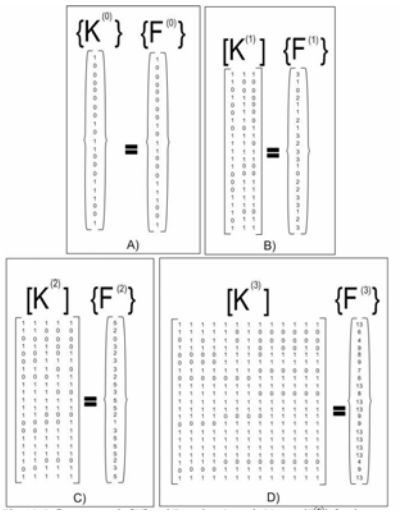


Fig. 8 Influence matrix [K] and Function Organic Vector $\{F^{(p)}\}$ for case study, in terms of each systemic level.

TABLE V
LIST OF FUNCTIONS TO BE TURNED INTO NEGOTIATION INDICATORS.

No.	Description	K	Measure	Level	Flexibility
1. Service Functions					
1 SF	trasmit force from hand to nutcracker	5	Force	10N	± 10%
9 SF	limit the nut's movement	4	Sliding	0 mm	+5 mm
11 SF	do not occupy too much space	2	Volume Dimensions	L :0.30m l :0.20m h :0.10m	± 10% ± 10% ± 10%
12 SF	enable cleansing	3	Acces	100% product accesibility	±5 %
3 CF	resist temperature variations	1	Temperature	+70° C -20° C	± 10%
4 CF	guarantee the security of persons being near the product	3	Protection	90% acceptance* * *	-
7 CF	resist cleansing products	2	Cleanliness	100% acceptance* * *	-2%

*** Experts' requirements in the form of a standardized test

TABLE VI
FORMULATION AND MODELING OF NEGOTIATION INDICATORS FOR EACH CASE STUDY

Negotiation Indicator Number		1	2	3	4	5	6	7
Designation		N(1)	N(2)	N(3)	N(4)	N(5)	N(6)	N(7)
Systemic Level		0	0	0	0	0	0	0
Objective Design		Trasmit force from hand to nutcracker	limit the nut's movement	occupy less possible space	Enable cleansing	resist temperatur e variatons	Guarantee security	resist cleansing products
Related Technical Knowledge	domain	[9,11]	[0,5]	[0.004374,0.007986]	[0,90,1]	[83,99]	[0,90,1]	[0,90,1]
	measure	N	mm	mts^3	% accesibility	variation C°	% test acceptance	% test acceptance
	ideal character	10	0	0.006	1	90	1	1

TABLE VII
CLASSES WITH $CLASS_{BEST}$ MARKED.

Negotiation Indicator Number		1	2	3	4	5	6	7
Designation		N(1)	N(2)	N(3)	N(4)	N(5)	N(6)	N(7)
Related Technical Knowledge	domain	[9,11]	[0,5]	[0.004374,0.007986]	[0,90,1]	[83,99]	[0,90,1]	[0,90,1]
	measure	N	mm	mts^3	% accesibility	variation C°	% test acceptance	% test acceptance
	ideal character	10	0	0.006	1	90	1	1
Classes	C(1) subdomain	[9,9.5]	[0,2]	[0.004374,0.0047]	[0,90,0.92]	[83,87]	[0,90,0.92]	[0,90,0.92]
	C(2) subdomain	[9.6,10]	[2,5]	[0.0049,0.0053]	[0.92,0.96]	[90,95]	[0.92,0.96]	[0.92,0.96]
	C(3) subdomain	[10,5,11]		[0.0055,0.0058]	[0,97,1]	[96,99]	[0,97,1]	[0,97,1]
	C(4) subdomain			[0.0060,0.006]				

TABLE VIII
NEGOTIATION FORMULATION SHEET FOR COGNITIVE IDEAL COMBINATION.

Negotiation Indicator Number		1	2	3	4	5	6	7
Designation		N(1)	N(2)	N(3)	N(4)	N(5)	N(6)	N(7)
Systemic Level		0	0	0	0	0	0	0
Objective Design		Trasmit force from hand to nutcracker	limit the nut's movement	occupy less possible space	Enable cleansing	resist temperatur e variatons	Guarantee security	resist cleansing products
Related Technical Knowledge	domain	[9,11]	[0,5]	[0.004374,0.007986]	[0,90,1]	[83,99]	[0,90,1]	[0,90,1]
	measure	N	mm	mts^3	% accesibility	variation C°	% test acceptance	% test acceptance
	ideal character	10	0	0.006	1	90	1	1
cognitive ideal combination								
Classes	C(1) subdomain best	[9,9.5]	[2,5]	[0.0049,0.0053]	[0.92,0.96]	[90,95]	[0.90,0.92]	[0.90,0.92]

VII. SUCCESS AND FUTURE WORKS

In terms of pre-optimization, we achieve:

- A reduction for the optimization model. The solution space size has been reduced by establishing classes of identical alternatives (from a cognitive point of view).
- An inclusion of knowledge that could have been disregarded in classical optimization. This can lead to the exploration of new solutions that could have not been detected otherwise.
- A reduction in optimization calculation time. As a consequence of the optimization model reduction.
- Incoherence avoidance. Thanks to the fact that classes are not intersecting, and that each of them regroups equivalent solutions, optimization methods can avoid falling into incoherence.

The negotiation process we propose succeeds in reducing the solution search space of a product. Yet, thanks to its cognitive approach and its classing mechanism, it considers and integrates all discriminative knowledge. Also, it enables the reduction of the value domains, keeping only those that are relevant to the problem. We would eventually find the ideal combination of the different negotiation indicators classes, thus creating the "ideal" product. We propose the development of this option for the future.

VIII. CONCLUSION

We have shown how the crosslink of functions with the product concept can serve in the detection of key criteria. These key criteria can be used to select or refine a product concept. By means of this same crosslink, an importance for each indicator can be calculated. This importance will take in account the influence of each function or constraint onto the product concept and thus, help to balance the subjectivity given by the human interaction with the product.

The method presented in this paper is targeted to be a

decision-aid tool for the transition of a product concept from the phase of "embodiment design" and that of "detailed design". It assumes that the product has a certain level of definition. This means the general geometry and the material has been chosen. It is in this level where the evolution from subjectivity to objectivity is most obvious. It is between these two phases that the imprecision of the product must disappear as much as possible, and the function satisfaction guaranteed.

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