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CONFIGURATION OF PRODUCT FAMILIES USING FUZZY SET APPROACH

Eugeniu DECIU, Egon OSTROSI, Michel FERNEY, Marian GHEORGHE

Abstract

Globalisation, market saturation and fragmentation, and rapid innovation are redefining the way that many companies are doing business. Designing configurable products families provides efficient and effective means to realise the product variety that satisfies the market demands. However, the development of configurable products increases the complexity of the design process. One way to reduce this complexity is to formalise the configurable product families and their design process. In this paper, fuzzy set theory was applied to deal with the configuration design problem. This study proposes a *multiple-fuzzy models* approach that supports the development of a configurable product family throughout the design process. The multiple-fuzzy models are the following: requirement-function model, fuzzy functional network, function-physical solution model and constraint-physical solution model. The fuzzy functional network maps the relations between the product functions. Having the multiple fuzzy models, the properties of the fuzzy relationships and their corresponding operations, final valid product configurations can be generated. An example illustrates the proposed approach.

Keywords: product families, product platforms, product structuring, fuzzy techniques

1 Introduction

Today's companies are confronted with new challenges from the market. Globalisation, market saturation and fragmentation, and rapid innovation are redefining the way that many companies are doing business. The new challenge for the companies is to produce as much product variety for the marketplace as possible with as little variety between products as possible. The dynamic customer needs demand a quick response from the companies. Companies that can provide customisation and increased product variety improve customer satisfaction and enjoy significant competitive advantage of those that cannot [1].

Designing *products families* provides an efficient and effective means to realise the product variety that satisfies the market needs. A product family is a group of related products that shares a set of common features. *Configurable products* represent a special class of product families and are the result of the *configuration process* [2]. The configurable products are the products, which can be selected from a set of components using a set of constraints so that the customer requirements are fulfilled [3]

The configuration is a process, which based on a configuration model, generates a set of possible product configurations and is characterized by the *configuration task*. Given a set of components, the configuration task consists in finding a set of complete and valid product configurations [4]. Theoretically, the number of product configurations can be unlimited. To validate these product configurations, a set of constraints and requirements is defined at the beginning of the process. Some systems for the computer-aided development of product configurations have been developed as for example in [5].

Working with a large number of product variants proves to be difficult. The development of configurable products increases the complexity of the design process. One way to reduce this complexity is to formalise the configurable product families and their design process.

In this research, fuzzy set theory was applied to deal the configuration design problem.

The fuzzy set approach introduced by Zadeh [6] is particularly suitable for handling imprecise information by providing a set of solutions with different degrees of preference [7]. Bahrami & Dagli proposed a fuzzy associative memory (FAM) paradigm in order to map fuzzy functional requirements to a crisp design [8]. Feng developed a methodology of fuzzy mapping of requirements onto functions and fuzzy mapping of functions to features in detail design [9]. Mutel & Ostrosi used manufacturing features and fuzziness in order to configure manufacturing cells [10]. Zhang proposed a fuzzy-set-based approach for representation and optimisation of design objects using the concept of the fuzzy shape. An evolutionary computation is used here to obtain fuzzy solutions to the fuzzy shape optimisation problem [6]. To develop new products that can satisfy the consumer's physical and psychological requirements, Hsiao proposed a semantic and shape grammar based approach using fuzzy operations [11].

This paper proposes a *multiple-fuzzy models* approach that supports the development of a configurable product family throughout the design process. The multiple-fuzzy models are the following: requirement-function model, fuzzy functional network, function-physical solution model and physical solution-constraints model. The fuzzy functional network maps the relations between the product functions. The final product configuration is obtained by associating the fuzzy functional network model to the other fuzzy models.

In the second section of the paper the multiple fuzzy models are defined and presented. They represent the core of our configuration model. Having the multiple fuzzy models, the properties of the fuzzy relationships and their corresponding operations, final valid product configurations can be generated. An example illustrates the proposed approach.

Finally, the conclusions and the perspectives are presented.

2 Configuration approach based on multiple fuzzy models

In this research we propose an approach based on the fuzzy set theory to deal with the configurable product family design. The configuration design is a process that generates a set of possible product configurations. Also this process is characterised by many degrees of freedom. Fuzzy models are integrated in the configuration design to deal with this uncertainty. Our approach consists in the followings stages:

- *Building the requirement-function model*
- *Building the functional network model*
- *Building the function-physical solution model*
- *Building the physical solution-constraint model*

The chart depicted in figure 1 shows the architecture of this approach. A set of relational databases, which contain all the data needed for the configuration process, is used to build the corresponding fuzzy models. The fuzzy models define a set of fuzzy relationships used to configure a product family.

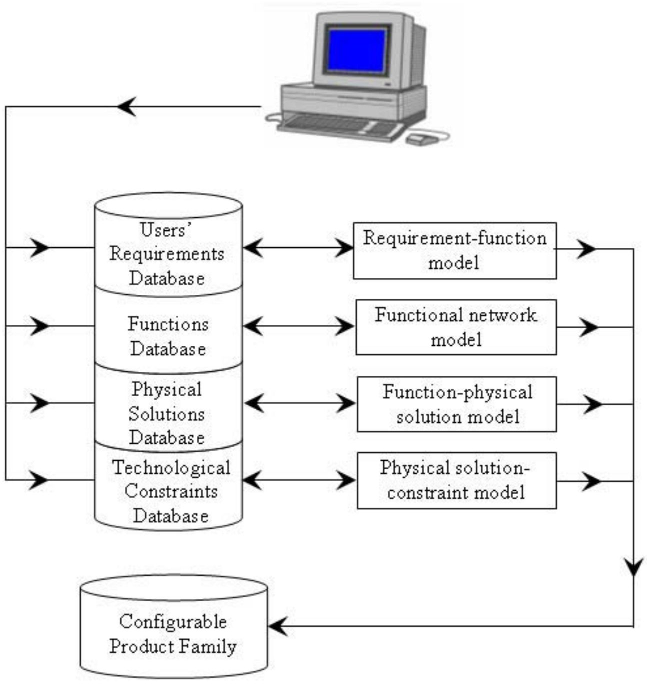


Figure 1. The multiple fuzzy structure platform

2.1 Building the requirement-function model

The design problem starts by specifying the set of users' requirements and the set of product functions. Many degrees of freedom exist in the statements describing the design specifications. The fuzzy users' requirements model is developed to deal with this problem.

The requirement-function model is carried out in two stages. In the first stage, we define the fuzzy relationship between the requirements and the functions. In the second stage, considering the user's requirements and using the fuzzy operators, the degrees of satisfaction of each function are inferred.

Stage 1: Definition of Requirement-Function Fuzzy Relationship. Linguistic statements enable both users and designers to define the degree of importance for each requirement and product function. For example a chair "*more*" or "*less*" *comfortable* can be accomplished in different degrees by each product function.

The uncertainty of the statements means the existence of a fuzzy relationship $\widetilde{\mathbf{R}}_1$ between the set of users' requirements R and the set of product functions F. This fuzzy relationship, noted $\widetilde{\mathbf{R}}_1$, is a subset of the Cartesian product $R \times F$ with the membership function $\mu_{R_1} \in [0,1]$ and it can be noted: $r_i \widetilde{\mathbf{R}}_1 f_j \quad r_i \in R,\ i = 1,2,\cdots m; \quad f_j \in F,\ j = 1,2,\cdots n$. The relation is represented by a sagittal diagram (figure 2.a). The nodes of the diagram represent the elements of the set *R* and the set *F*.

When related universes, in our case *R* and *F*, are finite [12], the fuzzy relation $\widetilde{\mathbf{R}}_1$ on $R \times F$ can be represented as a membership matrix $[R_1]$, whose generic term $[R_1]_{ij}$ is $\mu_{R1}(r, f) = a_{ij}$, $i = 1,\ m;\ j = 1,\ n$.

Let us consider the configuration design of a chair family. The users' requirements and the main functions of the chair are listed respectively in table 1 and in table 2. It can be seen that the requirements have different nature. Two different categories of requirements can be considered: *quantitative* requirements and *qualitative* requirements. The first category refers to physical requirements, as for example the *size* and the *weight,* and to economical requirements, as for example the *cost*. The second category refers to the types of chairs and to the different criteria of evaluation (*comfortability, durability*…etc.).

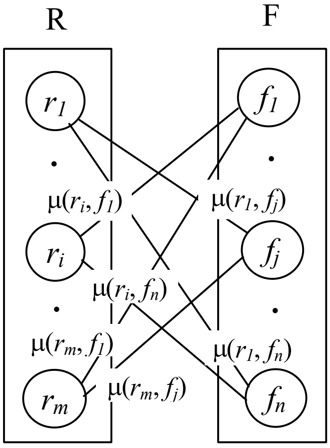
Table 1. The users' requirements

Quantitative requirements	I	r_1	*Size*
		r_2	*Weight*
	II	r_3	*Cost*
Qualitative requirements	III	r_4	*Office*
		r_5	*Classroom*
		r_6	*Home*
		r_7	*Bar*
	IV	r_8	*Comfortable*
		r_9	*Practical*
		r_{10}	*Durable*
		r_{11}	*Distinctive*
		r_{12}	*Soft*
		r_{13}	*Stable*
		r_{14}	*Elegant*

Table 2. The main functions of chair

f_1	*support the lower-body weight of a person in a sitting position*
f_2	*support the back of a person in a sitting position*
f_3	*support the arms of a person in a sitting position*
f_4	*offer movement space for the legs of a person in a sitting position*

The membership matrix representing the requirement–function fuzzy relationship is illustrated in figure 2b.



a)

Function No. 1 2 3 4

$$\left[M\left(r_i\,\tilde{R}_1\,f_j\right)\right]=\left[R_1\right]=\begin{bmatrix} 0,7 & 0,7 & 0,3 & 0,8 \\ 0,7 & 0,7 & 0,2 & 0,5 \\ 0,7 & 0,8 & 0,3 & 0,6 \\ 1,0 & 0,9 & 0,8 & 0,8 \\ 1,0 & 0,7 & 0,3 & 0,8 \\ 1,0 & 0,8 & 0,7 & 0,5 \\ 1,0 & 0,2 & 0,1 & 0,8 \\ 0,9 & 0,9 & 0,8 & 0,6 \\ 0,9 & 0,7 & 0,4 & 0,9 \\ 0,9 & 0,8 & 0,2 & 0,9 \\ 0,9 & 0,9 & 0,7 & 0,9 \\ 0,8 & 0,4 & 0,1 & 0,7 \\ 1,0 & 0,8 & 0,2 & 0,4 \\ 0,6 & 0,9 & 0,8 & 0,3 \end{bmatrix}\begin{matrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 12 \\ 13 \\ 14 \end{matrix}$$

Requirement No.

b)

Figure 2. a) Sagittal diagram; b) Requirement-function membership matrix

Stage 2. Users' requirements mapping onto functions. The goal of this stage is to map the requirements of one specific user onto product functions.

Mathematically, this means to induce the fuzzy function set F from the fuzzy requirement set R through the fuzzy relationship $\widetilde{\mathbf{R}}_1$

$$F = R \circ \widetilde{R}_1 \quad (1)$$

The composition of R through $\widetilde{\mathbf{R}}_1$ [12] can be written as

$$\mu_F = \mu_{R\circ\widetilde{R}_1}(f) = \max_r \min\left[\mu_R(r), \mu_{\widetilde{R}_1}(r, f)\right], \quad \forall r \in R,\ \forall f \in F \quad (2)$$

Let us consider our example. The set of requirements of one specific user is given by the requirement vector. For instance, the user prefers *rather* an *office* chair. So the requirement r_4 takes the value $\mu_R(r_4)$ = 0,8. In the same manner, the other values are determined for each requirement represented in the table 1.

$$\begin{array}{lcccccccccccccc} \textit{Requirement No.} & 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 \\ [\mu_R(r)] = & [0,5 & 0 & 0,3 & 0,8 & 0 & 0 & 0 & 0 & 0,9 & 0 & 0,8 & 0,3 & 0 & 0] \end{array} \quad (3)$$

In this case, the fuzzy function set F (j=1,4) is induced by the composition of the fuzzy requirement set R (i=1,*14*) through the fuzzy relationship $\widetilde{\mathbf{R}}_1$. The composition can be viewed as a matrix product

$$\mu_F(f_j) = [R \circ \widetilde{R}_1]_j = \sum_i a_{ij}\, \mu_R(r_i),\ i = \overline{1,14};\ j = \overline{1,4} \quad (4)$$

where Σ corresponds to *max* operation and product to *min* operation.

$$\mu_F(f_j) = \max_i\left[\min\left(\mu_R(r_i), a_{ij}\right)\right] \quad (5)$$

According to (3), (5), the fuzzy function vector results

$$\begin{array}{lcccc} & f_1 & f_2 & f_3 & f_4 \\ \mu_F(f) = & [0,9 & 0,8 & 0,9 & 0,9] \end{array} \quad (6)$$

The function vector $\mu_F(f)$ represents the functional structure of the *office* chair. Next, we consider the α-level, α = 0,5. The set of product functions that belongs to the fuzzy set $\widetilde{F}$ at least to the degree α, is called *α-level product functions set.*

$$F_\alpha = \left\{ (f, \mu_F(f)) \mid \mu(f) \geq 0,5 \right\} \quad (7)$$

The significance of (7) is that functions with the membership value $\mu_F(f) < 0,5$ are considered not so important in the product functional structure. According to (7) the set of chair functions defined by (6) remains unchanged.

2.2 Building the fuzzy functional network

The fuzzy functional network is used to represent the functional structure of a product. Currently, crisp representations of products' functional structure are used. In these representations the product functions are symbolised by nodes and are interconnected. Each connection is characterised by a membership function, which takes the value of 1 if there is a relation between the two considered functions, or the value 0 if there is no relation.

The interactions between the functions have different intensities. Fuzzy sets enable designers to establish the intensity of each relation between the product functions in order to evaluate different product solutions. This is the reason we consider that relationships between functions are fuzzy. The fuzzy relationship $\widetilde{\mathbf{R}}_2$ between the elements of F is characterised by the membership function $\mu_{R2} \in [0,1]$. The membership function, μ_{R2}, represents the degree of intensity of the interactions between each couple of functions (f_i-f_j).

A fuzzy relation can also be interpreted as defining a fuzzy binary graph [12]. Let F be the crisp set of functions (the nodes of the graph), then the fuzzy graph of the chair's functional structure is defined as

$$\widetilde{R}_2 = \left\{ \left(\left(f_i, f_j \right), \mu\left(f_i, f_j \right) \right) \middle| \left(f_i, f_j \right) \in F \times F \right\}, \ \mathrm{i} = \overline{1,4}; \ \mathrm{j} = \overline{1,4} \qquad (8)$$

The fuzzy functional network presented in figure 3, is a graph representation of the fuzzy relationships existent between the functions of a chair (configurable product). The nodes of the graph represent the functions, the arcs represent the relationships between a random pair of functions and the labels along the arcs represent the membership grade.

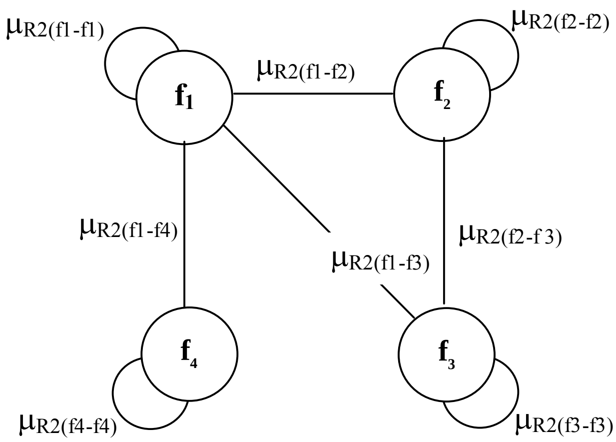


Figure 3. The fuzzy functional network of a chair

The following hypotheses are made:

- when i = j, $\mu_{R2(fj\text{-}fj)} = 1$;
- the functional binary graph or network is undirected, that is the fuzzy relation representing the graph is symmetric.

For different categories of products, the membership function degree, which characterises each couple of functions in the fuzzy functional network, can vary in the interval [0,1]. This variation of intensity generates different "configurations" of functional networks. Due to the relationship between the set of product functions and the set of physical solutions, the different variants of fuzzy functional networks that are generated allow the designers to obtain a variety of product structures.

Let us consider our example. Here, four types of chairs have been considered. Each type is characterised by its own fuzzy functional network. The functional network is composed by four functions (table 2), determined in the *function-requirement model*. Ten relationships are established between the product functions (table 3). Each relationship is characterised by the membership function $\mu_{R2(fi\text{-}fj)}$, i = 1, *4*; j = 1, *4*.

Table 3. Product functions fuzzy relationships

Relations \ Types		*Office*	*Classroom*	*Home*	*Bar*
1.	f_1-f_1	1,0	1,0	1,0	1,0
2.	f_1-f_2	0,9	0,8	0,9	0,6
3.	f_1-f_3	0,8	0,6	0,9	0,2
4.	f_1-f_4	0,9	0,9	0,8	0,9
5.	f_2-f_2	1,0	1,0	1,0	1,0
6.	f_2-f_3	0,7	0,5	0,8	0,1
7.	f_2-f_3	0,1	0,1	0,1	0,1
8.	f_3-f_3	1,0	1,0	1,0	1,0
9.	f_3-f_4	0,1	0,1	0,1	0,1
10.	f_4-f_4	1,0	1,0	1,0	1,0

For instance, the membership function $\mu_{R2(f1\text{-}f3)}$ which characterises the couple f_1-f_3 takes the values: 0,8 for an *office* chair; *0,6* for an *classroom* chair; 0,9 for an *home* chair; 0,2 for a *bar* chair. The values 0,8 and 0,9 show that couple f_1-f_3 has a great intensity in the functional network of *office* and *home chairs*; 0,6 indicates a medium intensity of the couple for the *classroom chair*; while the 0,2 means that couple f_1-f_3 has a low intensity in the *bar chair* functional network.

2.3 Building the function-physical solution model

Each function in the set of product functions corresponds to different chair components. Each component on its turn has some alternative solutions. It is assumed that product components are defined at the beginning of the design process. Searching the physical solutions set that materializes the set of functions does not make the subject of this study.

Physical solutions represent the physical structure of the product components and set up the physical solutions set. Each physical solution can satisfy in a certain degree the set of functions *F*. This aspect implies that the relationship between the set of functions *F* and the set of physical solutions *S* has a fuzzy character. The fuzzy relationship $\tilde{\mathbf{R}}_3$ defined between the two sets *F* and *S* is a subset of the Cartesian product $F \times S$ characterised by the membership function μ_{R3}. It takes values between 0 and 1, and denotes the satisfaction degree of a function by the set of physical solutions.

Let us consider our example. Based on the set of functions determined in the functions-requirements model, some components of a chair and their different variants are presented in morphological chart (table 4). Each component performs a single function or more, according to the case, and similarly a single function can be performed by a single component or more.

The membership matrix representing the function–physical solution relationship is illustrated in the figure 4.

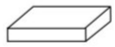
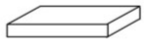
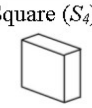
Solutions No. 1 2 3 4 5 6 7 8 9 10 11 12 13 14

$$\left[\mathrm{M}\left(f_j \tilde{R}_3\, s_k\right)\right] = \left[\mathrm{R}_3\right] = \begin{bmatrix} 0{,}9 & 0{,}7 & 0{,}9 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0{,}7 & 0{,}7 & 0{,}8 \\ 0 & 0 & 0 & 0{,}7 & 0{,}9 & 0{,}9 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0{,}8 & 0{,}8 & 0{,}7 & 0{,}2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0{,}8 & 0{,}7 & 0{,}7 \end{bmatrix} \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \end{matrix}$$

Functions No.

Figure 4. Function–physical solution membership matrix

Table 4. The morphological chart for a chair

Chair components	**Component variants (*Physical Solutions* – S_k)**			
	1	*2*	*3*	*4*
1. Seat	Square (S_1) 	Rectangle (S_2) 	Round (S_3) 	–
2. Back	Square (S_4) 	Trapezoidal (S_5) 	Ellipsoidal (S_6) 	No back component (S_7)
6. Armrest	"L-shape" (S_8) 	"T-shape" (S_9) 	Ellipsoidal (S_{10}) 	No armrest (S_{11})
7. Stand	Straight (S_{12}) 	Round (S_{13}) 	Slant (S_{14}) 	–

Considering the function–physical solution fuzzy relationship, the following set of physical-solutions has been found

$$\begin{array}{c} \qquad\quad Seat \quad\;\; Back \quad\; Armrest \;\; Stand \\ S_{R3} = \{(S_2, S_3), (S_5, S_6), (S_8, S_9), (S_{12}, S_{14})\} \end{array} \tag{9}$$

2.4 Building the physical solution-constraint model

The fuzzy constraints - physical solutions model is built to represent the fuzzy relation between the set of constraints and the set of physical solutions.

Design is generally defined as a process of creating a description of an artificial object that satisfies certain constraints. Multiple applications are integrated during the various phases of the product development. Due to the different nature of applications, the set of constraints to be used can be manufacturing constraints, assembly constraints, maintenance constraints etc. We name generically all these application constraints as the *set of technological constraints*.

The physical solution–constraint model is carried out in two stages. In the first stage, we define the fuzzy relationship between the physical solutions and the constraints. In the second stage, considering the constraints and using the fuzzy operators, the solutions that satisfy the given constraints are inferred.

Stage 1: Definition of Physical solution–Constraint Fuzzy Relationship. A fuzzy set of physical solutions has resulted from the application of product functions - physical solutions fuzzy relationship.

The set of physical solutions *S* must satisfy a set of technological constraints noted *C*. Each constraint can be satisfied in different degrees by the elements belonging to the set of physical solutions *S*. A fuzzy relationship $\widetilde{\mathbf{R}}_4$ is defined between the sets *C* and *S*. This relationship is a subset of the Cartesian product $C \times S$ and is represented by the membership function μ_{R4} that can take values in the interval [0,1]. These values indicate in what degree each constraint is satisfied by the set of physical solutions.

The fuzzy relation $\widetilde{\mathbf{R}}_4$ on $S \times C$ can be represented as a membership matrix $[R_4]$, whose generic term $[R_4]_{kp}$ is $\mu_{R4}(s,c) = b_{kp}$, $k = 1, x$; $p = 1, z$.

Let us consider the chair example. For the assembly case, the following constraints are considered

- ***C1**: Standardization*
- ***C2:** Proper spacing ensures allowance for a fastening tool*
- ***C3:** Maximize symmetry*
- ***C4:** Design mating features for easy insertion*

The membership matrix representing the constraint–physical solution fuzzy relationship is illustrated in figure 5.

$$\begin{array}{r} \textit{Solutions No.}\quad 1 \quad 2 \quad 3 \quad 4 \quad 5 \quad 6 \quad 7 \quad 8 \quad 9 \quad 10 \quad 11 \quad 12 \quad 13 \quad 14 \end{array}$$

$$\left[M\left(c_p \tilde{R}_4\, s_k\right)\right] = \left[R_4\right] = \begin{bmatrix} 0{,}9 & 0{,}9 & 0{,}6 & 0{,}9 & 0{,}7 & 0{,}4 & 0 & 0{,}8 & 0{,}6 & 0{,}6 & 0 & 0{,}9 & 0{,}7 & 0{,}9 \\ 0{,}9 & 0{,}9 & 0{,}7 & 0{,}9 & 0{,}8 & 0{,}6 & 0 & 0{,}8 & 0{,}7 & 0{,}5 & 0 & 0{,}9 & 0{,}8 & 0{,}6 \\ 0{,}8 & 0{,}8 & 0{,}7 & 0{,}8 & 0{,}7 & 0{,}7 & 0 & 0{,}8 & 0{,}7 & 0{,}6 & 0 & 0{,}7 & 0{,}7 & 0{,}7 \\ 0{,}8 & 0{,}8 & 0{,}7 & 0{,}8 & 0{,}8 & 0{,}4 & 0 & 0{,}9 & 0{,}7 & 0{,}5 & 0 & 0{,}8 & 0{,}8 & 0{,}8 \end{bmatrix} \begin{matrix} 1 \\ 2 \\ 3 \\ 4 \end{matrix}$$

Constraints No.

Figure 5. Constraint-physical solution membership matrix

Stage 2. Constraints mapping onto physical solutions. The goal of this stage is to map the constraints of one specific application onto physical solutions.

Let us consider our example. The set of constraints is given by the assembly constraint vector (10). The *standardization* and *symmetry* are very important and their membership values are $\mu_{R4}(c_1) = 0{,}9$, *designing mating features* is moderately important and *proper spacing for fastening tool* is unimportant.

$$\begin{array}{c} \textit{Constraint No.}\quad 1 \quad\ 2 \quad 3 \quad 4 \\ \left[\mu_C(c)\right] = \left[0{,}9 \quad 0 \quad 0{,}8 \quad 0{,}4\right] \end{array} \tag{10}$$

In this case, the fuzzy solution set S ($k=\overline{1,14}$) is induced by the composition of the fuzzy requirement set C ($p=\overline{1,4}$) through the fuzzy relationship $\tilde{\mathbf{R}}_4$. The composition can be viewed as a matrix product

$$\mu_S(s_k) = \left[C \circ \tilde{R}_4\right]_k = \sum_k b_{kp}\, \mu_C(c_p),\ k = \overline{1,14};\ p = \overline{1,4} \tag{11}$$

where Σ corresponds to *max* operation and product to *min* operation.

$$\mu_S(s_k) = \max_k \left[\min\left(\mu(c_p), b_{kp}\right)\right] \tag{12}$$

According to (10), (12), the fuzzy physical solution vector results

$$\begin{array}{l} \qquad\quad\ \ s1 \quad s2 \quad s3 \quad s4 \quad s5 \quad s6 \quad s7 \quad s8 \quad s9 \quad s10 \quad s11 \quad s12 \quad s13 \quad s14 \\ \mu_S(s) = \left[0{,}9 \quad 0{,}9 \quad 0{,}7 \quad 0{,}9 \quad 0{,}8 \quad 0{,}6 \quad 0 \quad 0{,}8 \quad 0{,}8 \quad 0{,}7 \quad 0 \quad 0{,}9 \quad 0{,}8 \quad 0{,}9\right] \end{array} \tag{13}$$

The function vector $\mu_S(s)$ represents the set of physical solutions of the *chair*. An α-level, can be considered, where $\alpha = 0{,}5$. The set of physical solutions that belongs to the fuzzy set $\tilde{S}$ at least to the degree α, is called *α-level physical solution set.*

$$S_\alpha = \left\{ \left(s, \mu_S(s)\right) \mid \mu(s) \geq 0{,}5 \right\} \tag{14}$$

According to (14) the set of physical solutions remains the same as defined by (13).

To find the final valid product configuration the α-level set S_α and the S_{R3} are intersected. The final product configuration is.

$$\{S\}_{\alpha \cap R3} = \{(S_2, S_3), (S_5, S_6), (S_8, S_9), (S_{12}, S_{14})\} \tag{15}$$

3 Conclusions

A configurable product family design approach using fuzzy set theory is proposed. The functional network, functions-requirements relationship, functions-physical solutions relationship and physical solutions-constraints relationship are built and used to configure a product family. Different product configurations are generated using a set of physical solutions defined at the beginning of the design process. This approach has been applied to configure one-of-a-kind product. Further research is concentrating on the development of an integrated platform based on the multiple fuzzy models, capable to assist the designers throughout the entire design process.

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Corresponding author: Eugeniu DECIU:
Université de Technologie de Belfort-Montbéliard, Laboratoire M3M, 90010 BELFORT Cedex, FRANCE / University "Politehnica" of Bucharest, Manufacturing Department, Splaiul Independentei 313, RO-77206, Bucharest, ROMANIA. Tel. : +33 (3) 84 58 33 37/ +40 (21) 402 9640. Fax : +33 (3) 84 54 00 62 / +40 (21) 402 9373. E-mail: eugeniu-radu.deciu@utbm.fr; eugen@coop.ueo.pub.ro.
URL: http://www.utbm.fr; http://www.pub.ro.