

A Model of Genetic Fuzzy System for the Design of New Products

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Abstract

In more and more uncertain environments, the companies find that the satisfying the needs of the consumers is not a strategic option but a strategic necessity. This paper presents a methodology based on Fuzzy Genetic Algorithm technique to the voice of consumer management in the Design of New Product problem.

Keywords: Fuzzy GAs, New Products

1 The Design of New Products Process

In a environment of changes in economic and technological conditions, together with an increased level of competition, both local and global, variations in consumer needs, the rapid obsolescence of products and the emergence of new markets, it is essential for firms to respond quickly in the design of new products [1] [4] [5].

The need to translate consumers' expectations into specifications for use within the business and to transmit such specifications faithfully to the various divisions involved is not to be achieved without difficulty, as it commonly runs up against numerous obstacles, whether arising from the firm's structure, from its operational procedures or from the very nature of the development process. In its turn, the conversion of consumer requirements into fully detailed technical design specifications may be a hard task, since client needs are often fuzzy or vague, and in many cases contradictory. Indeed, as technical specifications for a product are expressed in a sort of language quite different from that used in stating consumer necessities, the voice of the client is frequently not heard fully clearly and the end result is a product that does not completely satisfy consumer requirements.

Thus, with the object of building a model that will permit determination of what combination of characteristics should be incorporated into new

products, the analysis to be carried out must first of all consider the variables affecting both potential technical features and requirements stated by clients. This will allow any possible relationships between these two types of information to be noted. In this way, a list of the various requirements (requirements of consumers) put forward for the new product can be taken into consideration, such as: RC_i with $i = 1, 2, \dots, n$, together with characteristics (characteristic aspects) that might be built into it CA_j with $j = 1, 2, \dots, m$. This initial information may then be reflected in a double-entry matrix in which any relationships (r_{ij}) between the variables can be specified as:

$$\begin{bmatrix} RC_1 \\ K \\ RC_i \\ K \\ RC_n \end{bmatrix} \begin{bmatrix} CA_1 & K & CA_j & K & CA_m \\ r_{11} & K & r_{1j} & K & r_{1m} \\ K & K & K & K & K \\ r_{i1} & K & r_{ij} & K & r_{im} \\ K & K & K & K & K \\ r_{n1} & K & r_{nj} & K & r_{nm} \end{bmatrix}$$

In accordance with the above, the point of interest would lie in working out the combination of characteristics that would maximize the relationships shown, while optimizing the remainder of the information available, both on requirements (exogenous information) and on the product's own characteristics (endogenous information).

Handling exogenous information: Consumer voice

Details of requirements serve as a starting point in establishing what clients expect from the new product. However, in the decision model it is necessary to consider all information that allows the data available to be differentiated and aids in decisions relative to what "best" characteristics are to be incorporated into the product from this perspective. For the purposes of the model put forward in this paper, information coming from outside the business is summed up in the following three variables:

(1) The importance of the requirements or in other words "requirements of consumers, ponderated" (RCP_i). Not all requirements have the same impact or ponderation, that is, they do not meet equally the views on the new product that potential consumers

have. Hence, it is essential to look first at the degree of importance of each requirement (g_i), this denoting the weight assigned by the clients to each of the needs or wants that they express. Similarly, in measuring this importance it is necessary to incorporate information relating to the characteristics linked to each of the requirements. This is because a requirement is not solely important in itself, but will depend upon the characteristics that affect it and the degree of relationship it has with these features. Such a joint evaluation permits a value to be established for the requirements which are weighted as a function of the importance allocated to each by the consumers (g_i) and of the characteristics with which any given requirement is related and the strength or degree of this relationship (r_{ij}):

$$RCP_i = \sum_{j=1}^m r_{ij} \times g_i$$

(2) Competitive evaluation or external benchmarking (t_i). An external competitive analysis tries to establish from the viewpoint of present or potential consumers a measurement of the extent to which each requirement is fulfilled, as compared with competing products. This evaluation yields as a result the rate of improvement or distance between the current state of affairs and the situation considered to be the objective to be: $t_i = m_i - b_i$, where m_i is a goal for requirement RC_i and b_i is the current value of requirement RC_i for the firm's product. Although in the model proposed information about the weightings of requirements and about comparative evaluation are incorporated separately, there is the possibility of establishing a joint valuation for the two together to act as a measurement of the impact or weighting (w_i) each requirement has from an external perspective. For this purpose the following operation would yield a value: $w_i = RCP_i \times t_i$

(3) Correlation between requirements (γ_{ij}). This correlation permits the highlighting of possible incompatibilities or effects of reinforcement among the requirements put forwards by clients:

$$\begin{bmatrix} \gamma_{11} & K & \gamma_{1j} & K & \gamma_{1n} \\ K & K & K & K & K \\ \gamma_{i1} & K & \gamma_{ij} & K & \gamma_{in} \\ K & K & K & K & K \\ \gamma_{n1} & K & \gamma_{nj} & K & \gamma_{nn} \end{bmatrix}$$

Handling endogenous information: Design engineer voice

This section attempts to analyze information relating to those aspects which may affect the selection of possible characteristics for inclusion in the new product on the basis of information supplied from within the firm, which in the model being proposed would be captured by the following four variables:

(1) Importance of features or "characteristic aspects, ponderated" (CAP_j). The attributes of the new product translated into characteristics that can be measured in it should be quantified from a twofold perspective: the weight that each has as a function of its relationship with the requirements noted by clients and the importance assigned to these requirements from the viewpoint of future potential consumers. Thus, and similarly to what was done for requirements, the first step to be taken is to quantify each characteristic on the basis of the two aspects mentioned. This quantification is to be carried out as follows:

$$CAP_j = \sum_{i=1}^n r_{ij} \times g_i$$

(2) Competitive evaluation or internal benchmarking (B_j). This attempts to evaluate product characteristics by comparing each of the design requirements with those of competitors, except that this time it is the business itself that does the evaluation and determines its positioning in accordance with studies of the competition undertaken. The measurement for this variable is then established as follows: $B_j = m_j - b_j$

where m_j is a goal for characteristic CA_j and b_j is the current value for characteristic CA_j to be incorporated into the firm's product.

(3) Technical difficulty (C_j), which measures the level of difficulty in technical terms of fulfilling the objectives, defined for each of the design characteristics of the product. This difficulty may be established from the point of view of putting the feature into practice or alternatively in terms of the cash cost associated with including each of the characteristics.

Likewise, as a function of the weighting of the characteristics and of an evaluation of the technical difficulty each presents, it is feasible to calculate an intermediate variable showing up the "impact of the technology of characteristic aspects" ($ITCA_j$):

$$ITCA_j = CAP_j \times C_j$$

(4) The correlation between characteristics (δ_{ij}). The possible characteristics to be developed in the new

product that are noted within the business are not always independent one from another, but may have synergies or negative relationships among themselves that it is necessary to take into consideration when the time comes to favour certain of them over others. This may be represented by means of the following matrix:

$$\begin{bmatrix} \delta_{11} & K & \delta_{1j} & K & \delta_{1m} \\ K & K & K & K & K \\ \delta_{i1} & K & \delta_{ij} & K & \delta_{im} \\ K & K & K & K & K \\ \delta_{m1} & K & \delta_{mj} & K & \delta_{mm} \end{bmatrix}$$

The considerations above make it appropriate to propose a flow chart as in figure 1, in which it is possible to visualize in an integrated and overall fashion the first phase of new product development. This is based in [8] which establishes the order in which different tasks and sections are performed so as to complete the production of a decision model.

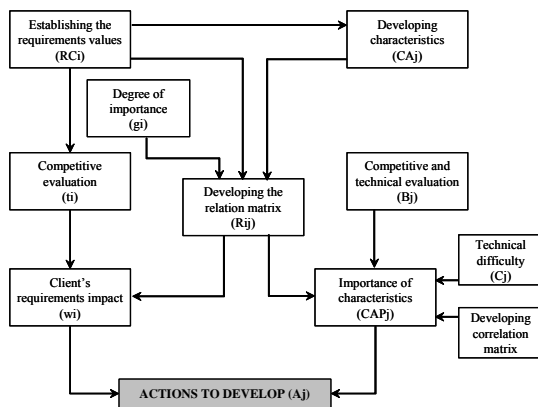


Fig. 1. The first phase of new product development

2 Design of a Genetic Algorithm for New Product

Genetic algorithms (GAs) are methods based on the genetic processes of living organisms and are used in resolving search and optimization problems [3] [7] [9]. GAs use a direct analogy with natural behaviour in which the individuals involved in a population compete among themselves so that those individuals with more success in surviving have a greater probability of generating a large number of descendants while the less well-adapted yield a smaller number of descendants.

This section will attempt to describe the components of the sort of GA implemented as a mechanism for optimizing the information available to the decision

process about the characteristics that should be emphasized in developing a new product.

Implementation of the GA was done with a view to operating with language information and to facilitating the adoption of decisions independently of the number of characteristics and requisites involved.

Further, the starting point was the assumption that to develop its new product, the firm has to hand a volume of resources established a priori, so that the optimum combination of characteristics will have to fit into such a budgetary restriction.

Codification of the solutions

The solution sought should establish a given number of characteristics implying a "good" combination, without their order being of any importance. For this reason a representation by means of vectors of whole numbers was chosen. The vector's length is equal to the number of characteristics possible (m) and each whole number thus represents the number of the characteristic that should be considered in reaching a decision.

As for the selection of the initial population, the option taken was for random initialization such that the same number of vectors of random whole numbers would be generated as there were individuals in the initial population. An example of the representation of a solution for the case of 10 possible characteristics might be: $S = (10, 8, 1, 6, 5, 7, 9, 4, 3, 2)$

However, as mentioned above, the combination of characteristics that can be achieved is limited by the costs to which they are subject, since it is a requisite that the characteristic should fall within the budgetary constraints. In consequence, the randomly generated solutions must be submitted to a procedure to eliminate individuals or solutions that are not feasible. The mechanism used for this consists of reducing the initial combination of characteristics to one whose cost does not exceed the established budget.

For this purpose, the cost of each solution, starting with the first number in the vector representing them, is added to a running total, so that once a point is reached at which there would be a budget over-run, all further positions are taken as being zero.

In this way, if the cost of each characteristic is as follows:

$$\begin{array}{cccccc} CA_1 = 10 & CA_2 = 8 & CA_3 = 5 & CA_4 = 2 & CA_5 = 12 & \\ CA_6 = 7 & CA_7 = 12 & CA_8 = 3 & CA_9 = 10 & CA_{10} = 4 & \end{array}$$

the conversion of the initial solution S into a feasible outcome for a budget fixed at 35 monetary units would yield a representation like the following:

$$S = (10, 8, 1, 6, 0, 0, 0, 0, 0, 0)$$

This procedure must be repeated for each generation, since the action of the genetic operators can lead to changes in the position that a given characteristic occupies in the vector of whole numbers simulating the solution. This would alter the cost accumulated in vector order.

Fitness Function

As a measurement of the adequacy of each solution generated would be to utilize:

$$\tilde{F}_S = \begin{cases} \sum_{j=1}^m \left(\tilde{C}A_j^P + \tilde{B}_j + \tilde{C}_j + \sum_{s=1}^n \tilde{\delta}_{sj} + \tilde{C}A_j^i \right) & \text{if } CA_j \subset S \\ 0 & \text{if } CA_j \not\subset S \end{cases}$$

Comparison of the goodness of the various solutions obtained was done on the basis of the fuzzy distance, defined as follows:

$$d(\tilde{A}, \tilde{B}) = \int_{\alpha=0}^1 \left(|A_\alpha^1 - B_\alpha^1| + |A_\alpha^2 - B_\alpha^2| \right) d\alpha$$

where $[A_\alpha^1, A_\alpha^2]$ is the interval of confidence of \tilde{A} for a level of presumption α .

Selection operator

The selection operator permits determination of which chromosomes in the initial population go on to have an active part in the reproductive process. In the model proposed a method of selection proportional to adequacy or roulette method [3] was used, setting down that those individuals with higher adequacy will have a greater likelihood of being selected as parents.

Crossover operator

In the GA proposed, the choice was made to utilize a variant of the classic crossing operator, which is the double point cross or crossing at two points. This process consists of choosing two points at random and dividing the chains representing the individuals selected as parents into three segments, a head, a central section and a tail, interchanging the central sections of the parent chains and obtaining two offspring that will have characteristics from both initial chains.

Nonetheless, in view of the coding mechanism used, this operator's action can lead to the repetition of certain characteristics in the descendents, because the parts of the parents exchanged may contain identical characteristics. Consequently, it is necessary to subject the individuals resulting from this operator to a procedure allowing the elimination of such repeats. An example of the functioning of this operator might be as follows:

Given parents $S_1 = (2, 3, 4, 1, 9, 10, 8, 7, 6, 4)$ and $S_2 = (1, 2, 6, 5, 10, 9, 4, 8, 3, 7)$, if the randomly selected points for crossing are points 2 and 6, the interchanging of the central chain of the two parents will yield the following descendents:

$$S_1 = (2, 3, 6, 5, 10, 9, 8, 7, 6, 4) \quad S_2 = (1, 2, 4, 1, 9, 10, 4, 8, 3, 7)$$

It can be seen that the first offspring has a repeated characteristic 6 and missing characteristic 1, while the second offspring is lacking characteristic 6 and has a superfluous 1.

In consequence, by simply interchanging these characteristics in the two resultant individuals, both would fall into conformity with the coding utilized, as shown below:

$$S_1 = (2, 3, 1, 5, 10, 9, 8, 7, 6, 4) \quad S_2 = (1, 2, 5, 6, 9, 10, 4, 8, 3, 7)$$

In this way, after the crossing operator has been applied two new individuals representing solutions to the problem are obtained, although there is a need to run them once more through comparison with the budgetary restriction fixed a priori in order to ensure their feasibility.

Mutation operator

The purpose of this operator is to increase diversity in the set of solutions. In the model proposed mutation is performed on a random basis, combined with an interchange of characteristics. This means that a position in the chain is selected at random and a characteristic is likewise randomly chosen to move to occupying the given position in the chain.

After this operation the characteristic is present in duplicate and the initial characteristic is missing, so that to avoid this flaw the place where the repeated characteristic is set in the chain is located and it is then changed for the missing one.

After this movement, the resulting individual must be subjected to the process for handling individuals that are not viable on the basis of the budget established.

Criteria for terminating or halting the search for the best solution

In choosing the criterion for bringing to a halt execution of the algorithm the route taken was to set a number of generations defined by the end user of the model as one of its operational parameters.

Further, with the aim of not losing any good solutions arising in each generation, the mechanism called "elitism" [3] was introduced. This consists of holding on to the best individual in a generation during following iterations until another individual betters it in adequacy for the problem. In this way, through elitism, it is possible to avoid loss of the best solution from a given generation until it is improved upon by another individual which will take its place as the elite, and keep this until an even better solution emerges.

Example of a practical application

With a view to facilitating detailed analysis of the functioning of the model put forward, the following example is considered: In order to develop a new product a list of the requirements mentioned by clients ($n = 15$) has been drawn up, as also the weighting that they assign to each. Likewise, an inventory is available of the possible technical characteristics ($m = 10$) that could be incorporated into the new product, seen from an internal perspective, and the relationships between these and the requirements mentioned (\tilde{r}_{ij}) worked out and set down in table 1.

Table 1: Relationships between Requirements and Characteristics

	\tilde{g}_i	CA_1	CA_2	CA_3	CA_4	CA_5	CA_6	CA_7	CA_8	CA_9	CA_{10}
RC_1	VI	VS		M							
RC_2	VI	S	QW	W							
RC_3	I	W	VS	QS	EW						
RC_4	M	E		VW							
RC_5	VI	VW	EW		VS	M	M				
RC_6	I				S	S	VW				
RC_7	LI				QW	M	M	QW			
RC_8	LI								M		
RC_9	VI							VS	W		
RC_{10}	M							QS	VW	QW	
RC_{11}	LI										VW
RC_{12}	M							W	QW	VS	E
RC_{13}	I							M		VW	QS
RC_{14}	VI							M	M	S	S
RC_{15}	VI								E		M

Here: E = Essential, VS = Very_Strong, QS = Quite_Strong, S = Strong, M = Moderate, W = Weak, QW = Quite_Weak, VW = Very_Weak and EW = Extremely_Weak. VI = Very_Important, I = Important, M = Middling, LI = Of_Little_Importance and N = Nil.

The values listed above permit an awareness both of the importance or weighting of requirements (\tilde{RC}_i) and of the importance or weighting of characteristics (\tilde{CA}_j). Evaluation in comparison with competing products fixes a measurement for the firm's situation with regard to fulfilment of consumer requirements in the light of competition. The values utilized in the example are shown in table 2.

Table 2: Values for the valuation in comparison

	RC_1	RC_2	RC_3	RC_4	RC_5	RC_6	RC_7	RC_8	RC_9	RC_{10}	RC_{11}	RC_{12}	RC_{13}	RC_{14}	RC_{15}
\tilde{b}_i	G	E	E	G	A	P	A	P	B	P	A	E	G	P	B
\tilde{m}_i	E	P	A	E	A	E	A	G	E	E	E	E	B	B	E

Here: E = Excellent, G = Good, A = Acceptable, P = Poor and B = Bad.

The linguistic labels associated with the evaluation carried out on technical characteristics, both for the firm's current status and for products from the competition, are indicated in table 3.

Table 3: Linguistic Labels for the Evaluation

	CA_1	CA_2	CA_3	CA_4	CA_5	CA_6	CA_7	CA_8	CA_9	CA_{10}
\tilde{b}_j	E	G	G	B	A	G	G	P	E	G
\tilde{m}_j	E	P	A	E	G	E	G	A	B	P
\tilde{C}_j	VL	L	H	VH	M	H	H	L	VH	H

In the table 3 the values associated with the technical difficulty of each characteristic are also shown, with the labels used being the following: VH = Very_High, H = High, M = Medium, L = Low and VL = Very_Low.

The correlations existing both between the various requirements and between the possible characteristics, with the meanings being as follows: Extremely Positive (EP), Very Strongly Positive (VSP), Strongly Positive (SP), Weakly Positive (WP), Practically Zero (PZ), Weakly Negative (WN), Strongly Negative (SN), Very Strongly Negative (VSN) and Extremely Negative (EN).

As for the development cost for each characteristic, the values applied in the example of a practical solution are those listed below:

$CA_1 = (1000,1100,1200,1300)$ $CA_6 = (1350,1370,1380,1390)$
 $CA_2 = (1300,1340,1350,1350)$ $CA_7 = (1100,1180,1180,1200)$

$$\begin{aligned}
 CA_3 &= (600, 600, 600, 600) & CA_8 &= (90, 110, 120, 130) \\
 CA_4 &= (90, 95, 100, 104) & CA_9 &= (850, 900, 900, 950) \\
 CA_5 &= (1420, 1430, 1440, 1450) & CA_{10} &= (750, 760, 800, 850)
 \end{aligned}$$

Once the values in use for the example have been fixed it is necessary to establish the budgetary restrictions put in place by the firm in setting the maximum cost that can be afforded in the development of the new product. In this example a budgetary restriction (\tilde{B}) has been assumed such that: $\tilde{B} = (4400, 4500, 4500, 4600)$

It is likewise necessary to define the operational parameters for the genetic algorithm, which for illustrative purposes were assumed to be as follows: number of generations (50), number of individuals (100), probability of crossing (90%) and probability of mutation (10%). The screen print shown in figure 2 indicates the evolution of the best individual in each generation.

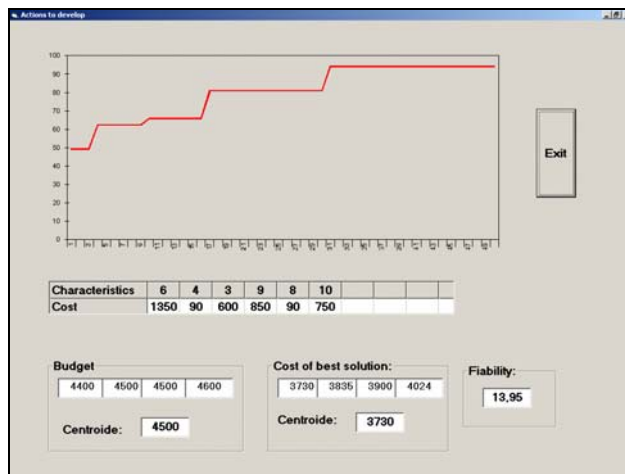


Fig. 2. Evolution best individual in each generation

3 Conclusions

The importance that the New Products Development has in the survival of the companies widely is recognized. In more and more uncertain environments, an increasing competence, mature industries, demanding markets and constant technological advances, the companies find that the satisfying the needs of the consumers is not a strategic option but a strategic necessity.

This work show a new soft-computing based decision support system to help companies to cope with challenges of globalisation: contracting life cycles, high quality product, minimum time to market and flexibility to change. For this purpose, a Fuzzy Genetic Algorithm model was built up as a

means of optimizing linguistic information so as to permit solutions to be provided in environments of high combinatorial complexity.

In this fashion, once the principal defining aspects of the considerations laid out above had been presented, a model of FGA was adumbrated whose application to design of new products, supplemented with a complete illustrative example, permits it to be demonstrated that this model overcomes the drawbacks described earlier, making it easy for the decision process to be carried out with full account taken of the conditions of uncertainty and complexity that characterize current economic reality.

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