Fuzzy Quality Systems

EDSON PACHECO PALADINI
Production and Systems Engineering Department
Federal University of Santa Catarina
CP 476 – Campus Universitário da Trindade - 88040-900 - Florianópolis - SC
BRAZIL

Abstract: This paper describes an application of fuzzy set theory to real problems. These problems refer to concepts, policies, strategies and techniques of quality systems of industrial and services organizations. The paper focuses on the quality evaluation process used to verify if the quality level of productive processes, products, services and general resources (mainly human resources) are reaching better values. The parameters and criteria from the National Brazilian Quality Award are used as a reference. Basic concepts of fuzzy set theory were applied to these concepts and criteria. So it was possible to define a more adequate way to evaluate almost 40,000 organizations, which are submitted, annually, to the evaluation process to conquer the Award. The obtained results show the theoretical and practical adjustment of fuzzy sets to quality systems and quality evaluation processes.

Key-Words: Fuzzy set applications; Quality management; Quality Systems.

1. Introduction

Evaluation is a process only applicable to functions, structures, mechanisms or situations which are dynamic, since it determines if there is progress in their actions. And also because it exactly tries to detect if progresses have occurred (improvements according to a certain parameter or a given referential) the evaluation makes sense if it is applied to accompany the evolution of these elements. All these characteristics are applicable to the quality systems management. If considering quality concepts, it is evident the need of executing the quality evaluation not only because it emphasizes the continuous improvement, but also because it highlights how to reach these improvements: through a quality planning, whose development and application is analyzed in an evaluation process.

It has been easy to list reasons that justify the need and opportunity to develop, in a permanent way, the quality evaluation [1]. But, sometimes, it is difficult to select quality evaluation strategies. In fact, Quality Management has characteristics that often make complex the evaluation activity in the best way. For instance, Quality Management evaluation is not fixed in its actions, or decisions, but in the results they determine. It means: Quality Management has compromises with the results.

These elements give a methodology outline to Quality Management evaluation. In this paper, the following elements compose this methodology: (1) Quality Management evaluation is a process having wide objectives (the organization and its action in the environment); (2) Evaluation starts from some parameters applied to the parts that compose the organization; after, aggregation methods are used and a global parameter is defined, which evaluates the whole organization; (3) Evaluation parameters have critical importance in the whole evaluation process. The basic parameter utilized will be the one from the relationship stimulus-answer: to each Quality Management action corresponds a result, as a consequence of the stimulus that the action has produced in a group of organization resources; (4) Evaluation models proposed here consider that actions generate stimulus that does not always follow the same rules and does not always produce results in the same intensity. There is not always clear proportionality between the inputs and the consequences derived from them. Therefore, Quality Management results originate from individuals processes of stimulus-answer. These processes are evaluated by indicators, aggregated later according to well defined parameters. The final aggregation determines the global result.

2. Quality Evaluation Process

Quality Management has specific characteristics. From these characteristics it was defined some points that identify a methodology to evaluate the Quality Management. Based on the characteristics and methodological proceedings, it was proposed several models, that integrate the global evaluation system, centered in the analysis of Quality Management reflexes in the organization. Here, it will be presented just one model. Basing on the evaluation system we are proposing, the global parameters and criteria of the National Brazilian Quality Award and the methods proposed from the Award indicators are used. These methods try to measure Quality Management evolution in Brazilian companies.

The National Brazilian Quality Award has seven categories. Each one of them is composed by a variable quantity of items, totaling twenty eight items receiving punctuation. These categories are: (1) **Leadership:** it involves (1.1) high direction leadership; (1.2) management for the quality and (1.3) public responsibility and the relations of the enterprise with the social community; (2) **Information and analysis:** it involves (2.1) range and data and information management about quality and performance; (2.2) comparisons with the concurrence and also with excellence references; (2.3) analysis and use of data; (3) **Strategic planning and Quality**: it involves (3.1) strategic planning process of quality and performance of the enterprise and (3.2) plans for Quality and performance improvement; (4) **Development and management of human resources**: it involves (4.1) planning and management of human resources; (4.2) employees involvement; (4.3) employees education and training; (4.4) performance of the employees and recognizing them and (4.5) employees welfare and satisfaction; (5) **Quality Management processes:** it involves (5.1) project and introduction of products and services in the market; (5.2) processes management - production and provision of products and services processes; (5.3) processes management -business and support (to clients) services; (5.4) suppliers quality and (5.5) quality evaluation process; (6) **Results obtained related to the quality and operations:** it involves obtained results (6.1) related to the quality of the products and services; (6.2) related to the enterprise operations; (6.3) related to the business and the support (to clients) services and (6.4) related to the quality of the suppliers' products and services and (7) **Focus on the client and the satisfaction:** it involves (7.1) clients' expectation: present and future; (7.2) clients relationship management; (7.3) compromise with clients; (7.4) determination of the clients' satisfaction; (7.5) results related to the clients' satisfaction and (7.6) comparison of the clients' satisfaction.

Each category has several evaluation items. Each item has specific punctuation. The method application includes the evaluators and instrument definition; the selection of the facilities to evaluate; the evaluation instrument filling from the collect of evidences and mechanisms of results summary and presentation. Every item is described in details in the Award rules and discussed in [2].

3. Fuzzy Approach to Quality

There several general applications of Fuzzy Sets to quality area (see, for instance, [3], [4}, [5} and [6]). There are also specific applications like Statistical Quality Control ([7], [8] and [9]). In this paper, a different approach is used. First, we note that the described evaluation uses tests. This proceeding can suffer restrictions. In fact, the results can not always be determined in terms of "attended parameter" or "unattended parameter". Frequently, it is necessary to use a continuous scale, expressing positions that are not extremes, but intermediate, revealing, for example, if managers or organizations present evolution in their basic activities or if they are stabilized or even if they seem to recede. Undoubtedly, the Quality Management evaluation would be strongly impoverished if it would be fixed just extreme values. And besides, it can be inadequate to confer just subjective and arbitrary grades to the positions that are not identified with the extremes. Evaluation would become "fragile" if it depends on such grades. At the same time, Quality Management evaluation includes several parameters. And these parameters must be aggregated. There is no organization that can attend in a uniform way every fixed parameter. Besides that, deficiencies in some parameters can be compensated by the complete attending to other parameters; not well attended parameters can not be considered since other elements and other parameters are attended in a satisfactory way. Such analysis requires, at the same time, the evaluation of individual parameters and the evaluation of some general parameters, in an accurate way.

In order to minimize these restrictions, it is proposed to use, in this evaluation system, the fuzzy set theory, whose basic concepts are used according to situations in which there are parameters that are not completely attended; parameters aggregation; comparison among different grades of how people or organizations attend some parameters. The basic fuzzy set theory concepts used here are those also established by Zadeh and also by the basic technical literature about this theory ([10], [11]; [12]). In the analyzing organizations, for example, we have: X: set of the organizations under study; x: particular organization under study; A: subset of the organizations under study which attend a certain parameter A (for example: specific investments in Quality); U/A(x): membership grade of the subset A (organizations satisfying the parameter A).

The parameters aggregation is necessary to provide the organization evaluation as a whole and even compare it to other organizations. In fuzzy set environment, this aggregation can be represented by intersection and union operators to fuzzy sets defined by parameters which compose the evaluation. It can (or not) exist compensation for them. The aggregation models used in this paper are the Zadeh's non-compensatory aggregation (intersection and union – see [10]) and Zimmermann's compensatory aggregation models (also intersection and union - see [12]). Minimal attending conditions are fixed for any parameter in the evaluation process: it is determined a limit L in a way that, if $U/A(x) < L$, it will be characterized the organization or manager deficiency related to this parameter. It can be observed that $0 < L < 1$, and if L is near to zero, the parameter is taken as not so important; if it is near to 1, it is an important parameter. If this restriction is not attended, it does not invalidate the parameter - just exposes it as basic organization lack in a given situation.

4. Evaluation model

In this model the described 28 items are utilized. Each item includes four references to be considered, for which it is attributed values from 0 to 100 (percentage). Therefore, the evaluation provides to the organization a posture according many specific situations. Once defined the percentage to each item, this percentage is multiplied by the fixed weight. It must be noted two evaluation activities: At first the alternative is selected and it is given a grade to it. After that, considering its weight, it is obtained the "weighted grade". The maximum evaluation value just can be obtained if the maximum weights to the 7 areas are attributed. It just occurs if it is selected, in every item of each question, the alternatives "d". As example of formulated question, it is considered the first question (1.1.) of the area 1:

AREA 1: *Leadership* - *1.1. High direction Leadership: (a) t*he direction does not take part in the quality leadership; the team tries to adopt the quality practicing by itself; (b) the direction requires that the team adopt the quality practicing because other companies has been adopting; (c) the direction does recognize Quality importance for the enterprise's success and, systematically, gives the example in its actions and targets, such as participating in training, interacting and advising other employees; (d) quality practices centered in the client are normally divulged and reinforced by the direction. It does not just deal with the Quality in its environment: it extends for the whole society. Hence, it is noted that a well defined set of questions composes this model. For instance, for the area 1, data are showed in the Table 1.

It is used, here, a variable t, associated to 8 basic membership functions according to the classification described by a variable y. The table 2 describes these functions. In the table 3, for the example above, it is described the intervals of t, whose selection is made as the original model, and the respective membership functions, selected by the evaluation process consultants, in the terms of the National

Brazilian Quality Award. The variable y represents the several model situations, in terms of the relationship stimulus-answer. It can be observed that: (1) **y > 1** and **y** $\notin$ **Z** (f_1 *to* f_4): The incentive overcomes the answer in the interval beginning. After that, the tendency is reverted; low reaction capacity to the action taken; return higher in the beginning; (2) **y < -1** and **y** $\notin$ **Z** (f_5 *e* f_6): The incentive is lower than the answer in the interval beginning. After that, the tendency is reverted; high reaction capacity to the action taken; return higher in the final; (3) **-1< y < 1** and **y ≠ 0** (f_7 *e* f_8) : It occurs a tendency alteration in the interval; (4) **y = 1** (f_0): The actual model reproduces the original model; the incentive is equal to the answer in every application moments; the action capacity tends to be equal to the reaction capacity; the same return during the interval and **(5) y ≠ 1, y ≠ 0, y** $\in$ **Z**: The model turns as linear. Here, Z represents the integer number set.

A team of consultants, hired to analyze the matter, decided and affirmed that there were compensatory and non-compensatory parameters among the 28 items. The paper's author does not agree, necessarily, with these compensations. However, here they are accurately transcript, according to the list of item 2. Hence, according to item 2, it is considered: (a) Non-compensatory parameters: 1.2.; 2.2.; 3.1.; 3.2.; 4.5.; 5.3.; 5.4.; 5.5.; 6.3.; 6.4.; 7.3.; 7.4; (b) Compensatory parameters are 1.1. - 1.3; 2.1. - 2.3; 4.1. - 4.4; 4.2. – 4.3; 5.1. – 5.2; 6.1. – 6.2; 7.1. – 7.2; 7.5. – 7.6. All these compensatory parameters are justified. For instance, the parameter 1.1 is compensated by 1.3 because the social sense stresses the organization toward the Quality adopting.

The same thinking was used in the global parameters elaboration. So, the items 1, 4 and 7 were considered non-compensatory. The item 2 was compensated by the item 3, and the item 5, was compensated by the item 6. We can consider these arguments as discussible. The model, nevertheless, aggregated them, by reasons concerning the fidelity to the "hired" consultants for the evaluation of the enterprises. Resulting from these positions, the model aggregation functions are the following:

(a) Function to each item: U1/A(t) = min { U1.2./A(t); U1.1./A(t) + U1.3./A(t) - (U1.1./A(t)*U1.3./A(t))}; U2/A(t) = min { U2.2./A(t); U2.1./A(t) + U2.3./A(t) - (U2.1./A(t)*U2.3./A(t))}; U3/A(t) = min { U3.1./A(t); U3.2/A(t)}; U4/A(t) = min {U4.5/A(t); U4.2./A(t)+U4.3./A(t)-(U4.2./A(t) *U4.3./A(t));U4.1./A(t)+ U4.4/A(t) - (U4.1./ A(t) * U4.4./A(t))}; U5/A(t) = min { U5.3./ A(t); U5.4/A(t); U5.5/A(t); U5.1./A(t) + U5.2./ A(t) - (U5.1./A(t)*U5.2./A(t))}; U6/A(t) = min { U6.3./A(t); U6.4./A(t); U6.1./A(t) + U6.2./ A(t) - (U6.1./A(t) *U6.2./A(t))}; U7/A(t) = min{ U7.3./A(t); U7.4./A(t); U7.1./A(t) + U7.2./A(t) - (U7.1./A(t)* U7.2./A(t)); U7.5./ A(t) + U7.6./A(t) - (U7.5./A(t) *U7.6./A(t))}

(b) General Aggregation Function: U/A(t) = min { U1./A(t); U2./A(t) + U3./A(t) - (U2./ A(t) *U3./A(t)); U4./A(t); U5./A(t) + U6./A(t) - (U5./A(t)*U6./A(t)); U7./A(t)}

5. Practical Applications

Two industrial companies were invited, and kindly accepted, to make possible the experimental implantation of the proposed models. The companies have been actuating in the metal-mechanic sector. Their importance is similar and they are installed in the same region. Three consultants integrate the evaluation commission. The consultants analyzed the 28 items suggested by the National Brazilian Quality Award to give values to the variable t, basic parameter of the fuzzy model. The analysis process was an agreement reunion, according to the patterns defined by the Award evaluation process. This process, also called "American jury", given the similarity with the USA justice decision model, has determined the values of t, listed below. Applying the respective membership functions, it was obtained the complete table data. Taking the specified aggregations suggested by the consultants into account, it is obtained the following results (see table 4) by item and by company. From the last line of the table it can be observed that the final result for the company A is ***0.4858*** and the company B is ***0.2182***. Therefore, the result for the company A is better. It also can be noted that the critical items are: for the company A the item 7 (focus on the client); for the company B, the item 4 (human resources). It also occurs that the company B has other items below the minimum value of A (0.4858) which are

0.3963 (resulting from the item 7 - focus on the client) and 0.4135 (resulting from the parameters 5 - Process Management and 6 - Results, which were analyzed together by compensation). Thus, it can be considered that four items put the company B in an inferior position comparing it with the company A. Considering a level set, it can be observed that most attended parameters are, for the company A, by order, the item 1 (administration) and the union of the items 2 (information) and 3 (strategic planning) and for the company B, the single value for a level set 0.7 is the item 1 (administration). It is concluded that the company A is superior to B and the strong and weak points of each one are identified.

6. Model Application Results

After the model application, each company we have analyzed will have a value between zero and one (in the case of the example, they got 0.4858 and 0.2182). Results close to one indicate good situations; results close to zero indicate poor systems and deficient in terms of quality. Knowing these results, it can be done what follows: (1) classify the companies in an objective form; (2) create groups of companies (for instance, the ones that are between 0.6 and 0.8 - intermediate ones); (3) define individual situations (for example: between 0.1 and 0.3, we have enterprises whose quality system is in an initial phase of the systemic focus, coming from the reaction process toward the prevention process; the system application is restrict to some important areas of the company and the results present some positive tendency). It is also can be defined operation minimum levels of the enterprises (in order to accept as suppliers only those firms that had grades equal or bigger than 0.6 for example).

7. Conclusions

From the model applications in at least 140 real situations, we have obtained several interesting practical conclusions. Initially, it must be denoted that the idea of applying fuzzy sets to Quality Management proceedings came from the practical observation. Thus, it is a proposal of strong empirical content. The model operational structure assumed the global parameters of National Brazilian Quality Award and the evaluation methods proposed from the Award indicators. We concluded that the option by this referential has been adequate by some reasons: firstly by being a methodology accepted at national level, considered as referential for Quality Management in Brazil; secondly by being an implantation methodology relatively simple; and besides, it is considered an adequate method to Quality Management objectives. Analyzing from the practical point of view, the fuzzy approach seemed to be, in its use, easier than its theoretical outline suggests. It can be assumed that, in the implantation process, these theoretical elements become transparent to the users, and do not compromise its utilization. And besides, the fuzzy logic has easy acceptation, it is not oppose users' intuitive actions. It can be concluded that the fuzzy set theory is an adequate, useful and relevant tool to structure quality evaluation models.

It is possible to diverge from the consultant opinions concerning the proposed questions and the evaluations, but this is not fundamental, because it is just showed how the models operate. We could not observe contradictions and that there was relative easiness in the questionnaires filling and in the information processing by the consultants.

An additional protection given by the fuzzy approach to the models is the fact that, in several cases, the variable t results from calculations, and not from the value selection for this variable. It is possible that these performance indicators, added to the aggregation operations, are great fuzzy approach advantages.

References

[1] Paladini, E. P. Gestão da Qualidade. São Paulo, Atlas, 2004.

[2] Matos, J.; Reis, D..; Meira, R.; Schedegger, J. Auto-avaliação: um caminho para a excelência. São Paulo, QualityMark, 2005.

[3] Masud, Abu S M; Dean, Edwin B. Using fuzzy sets in quality function deployment. Proceedings of Industrial Engineering Research Conference, IIE, NORCROSS, GA, (USA), 1993, pp. 270-274.

[4]Kim, K.; Moskowitz H.; Dhingra A.; Evans G. Fuzzy multi criteria models for quality

function deployment. European Journal of Operational Research, 121, 3, , 504-518.

[5] Glushkovsky E. A. ; Florescu R. A.; Fuzzy sets approach to quality improvement Quality and reliability engineering international. 1996, vol. 12, n°1, pp. 27-37.

[6]Melin, P.; Castillo, O. An intelligent hybrid approach for industrial quality control combining neural networks, fuzzy logic and fractal theory. Inf. Sciences: an International Journal. Volume 177 , Issue 7 (April 2007)

[7] Wang, R.-C. and Chen, C.-H. (1995) Economic statistical np-control chart designs based on fuzzy optimization, Int. J. of Quality and Reliability Manag. 12(1), 82-92.

[8] Zhang, H.-C. and Huang, S. H. (1994) A fuzzy approach to process plan selection, International Journal of Production Research, 32(6), 1265-1279.

[9] Yongting, C. (1996) Fuzzy quality and analysis on fuzzy probability, Fuzzy Sets and Systems, 83(2), 283-290.

[10] Zadeh, L. Fuzzy Sets. Inform. and Control. Vol. 8, N. 3, 1965

[11] Dubois, D. & Prade, H. Fuzzy Sets and Systems. New York, Academic Press, 1980.

[12] Zimmermann, H. J. Fuzzy Set Theory. Boston, Kluwer-Nijhoff Publishing. 1985.

Question	Item Percentages					Total
	A	B	C	D	Weight (%)	(Area 1)
1.1	0	30	80	100	4,8	
1.2	0	30	80	100	2,4	
1.3	0	20	60	100	2,4	9,6

Table 1 – Percentages

Variation of t	Y	Basic Function	Membership function
$0 \leq t \leq 1$	$y = 1$	f_0	$f(t) = t$
$0 \leq t \leq 1$	$y > 1$ and $y \notin Z$	f_1 f_2 f_3	$f(t) = (t^3)/(2 - t^2)$ $f(t) = t^3$ $f(t) = t^2$
$0 \leq t \leq 1$	$y < -1$ and $y \notin Z$	f_4 f_5 f_6	$f(t) = t^{3/2}$ $f(t) = t^{1/2}$ $f(t) = t^{1/3}$
$0 \leq t \leq ½$	$-1 < y < 0$	f_{7A}	$f(t) = 2t^2$
$½ \leq t \leq 1$	$-1 < y < 0$	f_{7B}	$f(t) = -2t^2 + 4t - 1$
$0 \leq t \leq ½$	$0 < y < 1$	f_{8A}	$f(t) = -t^2 + (3/2)t$
$½ \leq t \leq 1$	$0 < y < 1$	f_{8B}	$f(t) = 8/3t^2 - 3t + 4/3$

Table 2 - Functions

Ranges to t					Membership function
Item	Answer A	Answer B	Answer C	Answer D	
1.1	0	0 - 0,3	0,3 - 0,8	0,8 - 1	f_6
1.2	0	0 - 0,3	0,3 - 0,8	0,8 - 1	f_5
1.3	0	0 - 0,2	0,2 - 0,6	0,6 - 1	f_3

Table 3 - t intervals and respective membership functions.

Item	Company A	Company B
1	0.8062; 0.9144	0.7616; 0.8511
2	0.6403; 0.4729	0.5657; 0.3886
3	0.8963; 0.5362	0.8434; 0.4079
4	0.8367; 0.8217; 0.6820	0.7071; 0.4527; 0.2182
5	0.7022; 0.8124; 0.3583; 0.9372	0.3536; 0.7810; 0.2519; 0.7545
6	0.5314; 0.9434; 0.9045	0.2160; 0.9055; 0.8842
7	0.8707; 0.8832; 0.4858; 0.7859	0.7663; 0.8367; 0.3963; 0.6875
General	**MINIMUM**: 0.8062; 0.4729; 0.5362; 0.6820; 0.3583; 0.5314; 0.4858 ***COMPENSATORY AGGREGATION:*** 0.8062; 0.6820; 0.4858; 0.7555; 0.6993	**MINIMUM**: 0.7616; 0.3886; 0.4079; 0.2182; 0.2519; 0.2160; 0.3963 ***COMPENSATORY AGGREGATION:*** 0.7616; 0.2182; 0.3963; 0.6380; 0.4135

Table 4 – Final results