The Feasibility of Fuzzy Sets Utilization in Quantifying the Results of Company Self-evaluation in Accordance With the EFQM Excellence Model

Chodúr Miroslav, Svoboda Jiří, Pálka Přemysl

Abstract

This paper elaborates on the possibility of utilizing fuzzy set methods in order to quantify the results of company self-evaluation in accordance with the EFQM model criteria. The general aim is to modify the self-evaluation method from the EFQM model with statistical utilization of fuzzy set methods in order to improve the aggregation of the indicators (criteria) and evaluate the self-evaluation results.

Key words: fuzzy set, EFQM model, self-evaluation, IF-THEN rules

1 THE INTRODUCTION

The elaboration of this work stems from the general EFQM Excellence Model. This model is currently the most objective and appropriate method for estimation of companies. Combination of questionnaire survey with logic frame of RADAR elements is used. The self-evaluation questionnaire aim is to adjust to the particular company in the maximum possible way. The answers on individual questions (criteria) are designed in order to characterize possible scenarios that can occur. The company chooses the scenario, which most closely reflects the real situation.

Fuzzy set methods are used for mathematical quantification of self-evaluation results into a statically form. Fuzzy IF-THEN rules are utilized to allow evaluation and aggregation of model criteria in appropriate and simple fashion. This approach also allows us to quantify the model criteria according to language evaluation expressions (e.c. "small" or "roughly big"). These expressions can be used for verbal (language description) evaluation of the criteria fulfillment level. For example, the expression "null" stands for zero fulfillments of the criteria. In other words the criterion isn't fulfilled (realized) at all. On the other hand, "significantly big" stands for maximal rate of fulfillment of the particular criterion.

2 BASIC KONCEPTS

In the following the text we firstly define the basic concepts involving the fuzzy sets and EFQM Excellence model.

2.1 Fuzzy sets

According to Novák (1990) the fundamental concept in fuzzy logic is the fuzzy set. It is a generalization of a classic set. Fuzzy set is from mathematical point of view a function:

$$A : U \rightarrow [0,1]$$

Function A is called the *classification function* of fuzzy set A. There is an element $a \in [0,1]$called the *classification level of x to fuzzy set A* assigned to every element $x \in U$. $x \in U$. Novák (1990 and 2004) defines classification level $x \in U$ into fuzzy set A is written as a function value $A(x)$. If $A(x)=0$, then x doesn't belong to A. If $A(x)=1$, then x belongs to A. If $A(x) \neq 0,1$, then x partly belongs to fuzzy set A.

2.2 Operation with fuzzy sets

We can implement the operation of *conjunction, disjunction and supplement* set for $\forall x \in U$ gradually. This set operation corresponds to the whole class of operations with fuzzy sets. L. Novák (2004) establishes the operations *conjunction*, *disjunction and supplement* for $\forall x \in U$ in the following order:

$$(A \cup B)(x) = A(x) \vee B(x),$$
$$(A \cap B)(x) = A(x) \wedge B(x),$$
$$\overline{A}(x) = 1 - A(x).$$

The operation disjunction means, the element $x \in U$ belongs to conjunction of sets $A, B \subset U$ with a classification degree equal to the greater of the degrees A(x) and B(x). On the contrary, the operation conjunction means, the element $x \in U$ belongs to the conjunction of sets $A, B \subset U$ with the classification degree equal to the lesser degrees of the A(x) a B(x).

Operation supplement $\overline{A}$ of fuzzy set A is a fuzzy set of all elements, that don't have the attribute characterizing A:

$$A \cap \overline{A} \neq \emptyset$$

2.3 Evaluation language expression

The basic evaluation language expression is

〈 language operator 〉 〈 atomic language expression 〉.

The basic components of evaluation language expressions are the *atomic expressions*. These involve the adjectives such as "small", "medium", "big". It is important to bear in mind, these adjectives are viewed as canonic and in specific case, you can substitute them form another proper word, such as "good", "average", "cheap" and so on. Among the atomic expressions stand the fuzzy numbers, expressions like "approximately ten", that characterize some number and its neighborhood. Evaluation language expression could be also connected through logical connectives ("AND", "OR"). Then we get the evaluation language expression form

〈 language operator 〉 AND, OR 〈 atomic language expression 〉.

Language operators are specific adverbs modifying the meaning of adjectives in front of which they stand. Typical language operators are "very" "considerably" "roughly" etc. Language operators are divided into following groups:

- with narrowing effect (very, considerably,...)
- with widening effect (roughly, quite roughly, more or less,...)
- with specifying effect (rather,...)
- empty operator (no operator)

2.4 Fuzzy IF-THEN rules

Fuzzy rules of IF-THEN type play the main role in the everyday human judgment. These are conditional language expressions in the shape of:

$$P: = \text{IF } X_1 \text{ is } A_1 \text{ AND } \ldots \text{ AND } X_n \text{ is } A_n \text{ THEN } Y \text{ is } B, \qquad (1)$$

where the expressions X_n is A_n , i = 1, … ,n, stand for evaluation predictions. Symbols X_1, …, X_n, Y are nouns and as we mentioned before, are called language variables and can gain fuzzy values representing the language expressions [5], [6]. According to Novák (2000 and 2004) the part of the rule following IF, i.e. in (1) the expression

$$X_1 \text{ is } A_1 \text{ AND } \ldots \text{ AND } X_n ,$$

is called antecedent. The part of the rule following THEN, i.e. in (1) the expression

$$Y \text{ is } B,$$

is called succedent. If we assume n = 1, then the rules P will be in form:

$$\text{P:= IF } X \text{ is } A \text{ THEN } Y \text{ is } B,$$

where A, B are evaluation language expressions. One fuzzy rule of IF-THEN type expresses our local knowledge about existence of effects relationship. For complicated knowledge characteristics, one rule doesn't suffice. Novák (2000 and 2004) claims it is necessary to assume, that we have more shape (1) rules at our disposal. The decision situation is characterized by the P language rules sets (conditional expressions).

$$P_1\text{:= IF } X_1 \text{ is } A_1 \text{ THEN } Y_1 \text{ is } B_1$$

$$\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

$$P_m\text{:= IF } X_m \text{ is } A_m \text{ THEN } Y_m \text{ is } B_m$$

The fuzzy set rules of IF-THEN $P=\{P_1,...,P_m\}$ are called the language description.

2.5 EFQM Excellence model

EFQM Excellence forms a complex concept dealing with organization performance. Important criterion for choosing this concept stands in process focus in particular organization. Petrášová and Huňát (2004) and Nenadál (2007) characterize successful management of processes according to EFQM logic leads to achieving excellent. European quality foundation[1] characterizes EFQM Excellence model as *„evaluation tool for gaining complex view on organizational performace regardless of its size, business focus or market lifespan."* Thus EFQM Excellence model can be applied in every type of organization regardless of its size and nature of product portfolio.

EFQM model comprises of 9 main criteria (see Fig. 1). First five criterions (i. e. pre-requisites) are used to recommend procedures the organization should employ, in order to maximize its results. Moreover the criteria show which concepts, methods and tools are utilized. Dror (2008) states the resulting criteria point out achievements in significant areas of company activities.

1 http://www.efqm.org

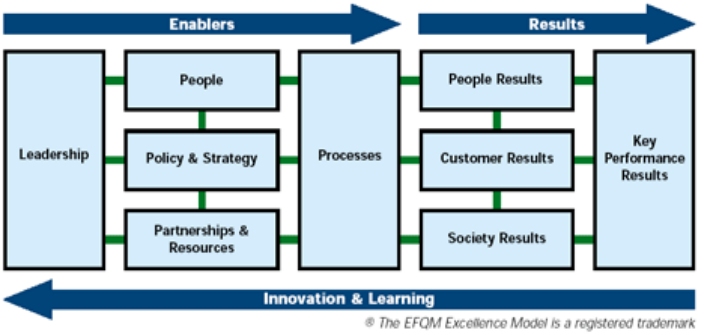

Fig. 1 - EFQM Model Excellence . Source: Author's processing [2]

Lamotte and Carter (2000) and Rusjan (2008) claim the logic of EFQM Excellence stems from assumption, that excellent results can be achieved only through satisfied external customers and employees and through complying with company surroundings. Rusjan (2008) adds: *„Achievement in these areas is conditioned by precise mastering and managing of processes, that require not only appropriatelly defined and cultivated company policy and strategy, but also well worked-out management of resources (involving human resources) as well as partnership building. EFQM model allowes all aspects by adequate approach to company culture on all levels of management."*

2.6 Problem definition and basic solution scheme

We want to create a static mathematic model for scenarios evaluation (companies) according to the general aim that is set (self-evaluation). This aim is expressed by a set of criteria.

As appropriate solution appear to be the utilization of evaluation language expressions theory and IN-THEN fuzzy rules. With the help of these concepts we can comprehensively characterize the criteria fulfillment method, so the overall scenario evaluation is optimal. This practicaly mean, that the decision situation is described by the language characterization created by a rule system in form:[2]

$$\begin{aligned} P_1 &: = \text{IF } K_1 \text{ is } A_{11} \text{ AND } \ldots \text{ AND } K_n \text{ is } A_{1n} \text{ THEN H is } B_1, \\ &\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \\ P_m &: = \text{IF } K_1 \text{ is } A_{p1} \text{ AND } \ldots \text{ AND } K_n \text{ is } A_{mn} \text{ THEN H is } B_p, \end{aligned} \qquad (2)$$

where $K_1,.., K_n$ are the criteria, H the overall evaluation and A_{ji}, B_{ji}, j = 1,…,m,i = 1,…, m are the evaluation expressions. $K_1,.., K_n$ a H have the roles of variables. The rules have the following meaning: If the criteria $K_1,.., K_n$ are fulfilled in the complete rate (for example the rate of fulfillment of a particular criteria is "small", "very big" etc.), then the overall evaluation is appraised by the language expression according to the our evaluation demands, so the fulfillment rate of the criteria is as big or small as possible. One of the advantages of IF-THEN fuzzy rules utilization is, that there is no need to use the criteria importance weighting (9 basic EFQM model criteria are an exception). The reason is, the weighting is naturally included in the way the rules are formulated. The expert doesn't have to think about different importance

2 http://www.exchange2improve.com/about/efqm-excellence-model-framework/

of criteria when he's using the language discretion. He characterizes his knowledge directly, in his own language.

Problem can appear in the moment, when the overall number of criteria n is in tens. It is beyond human powers to fabricate and understand the language description, which contains so many independent variables. The maximum amount of independent variables that a man can candle is four (exceptionally five). Therefore it is necessary to work with the hierarchy of language description. We divide the criteria K_1.., K_n into r groups H_1,…, H_r. In every group there will be at maximum five criteria aggregated. Lets denominate the criteria belonging to group H_k by symbols - K_1^k,...$K_{n(k)}^k$. Then the language description mentioned above (see formula 2) transforms the hierarchy of language descriptions as follows:

$$P_1^k := \text{IF } K_1^k \text{ is } A_{11} \text{ AND … AND } K_{n(k)}^k \text{ is } A_{1n(k)} \text{ THEN } H_k \text{ is } B_1$$

……

$$P_{p(k)}^k := \text{IF } K_1^k \text{ is } A_{p(k)1} \text{ AND … AND } K_{n(k)}^k \text{ is } A_{p(k)n(k)} \text{ THEN } H_k \text{ is } B_{p(k)}$$

$$k = 1,\ldots, r$$

$$P_1 := \text{IF } H_1 \text{ is } A_{11} \text{ AND … AND } H_r \text{ is } A_{1r} \text{ THEN } H \text{ is } B_1$$

……..

$$P_s := \text{IF } H_1 \text{ is } A_{p1} \text{ AND … AND } H_r \text{ is } A_{sr} \text{ THEN } H \text{ is } B_s$$

From the interpretation point of view, it is useful to comply with these principles:

- The criteria generating the group should be semantically related in order to allow naming of the particular group. Such group creates a new aggregated criterion. For example, the criteria „optimization of technical equipment usage", „optimization of material inventory", „maintenance management and property utilization" can create new aggregated criterion Managing the establishment of buildings, equipment and materials.
- If possible, there should be criteria in the group with same degree of requirement for fulfillment that is if we want the degree of fulfillment to be as big or small as possible. In this case the rules have unified form of "increasing" ("decreasing") of the degree in the partial language description. The fulfillment of the particular criteria leads to "increasing" ("decreasing") the degree of scenario evaluation

3 ALGORITHM FOR EVALUATION OF ADAPTED METHODOLOGY OF SELF-ASSESSMENT

In the following text is within the individual steps described the procedure of usage of the main ideas of fuzzy sets to quantify the results of self-assessment according to the criteria of the EFQM model. Created mathematical model (algorithm) is based on fuzzy sets and is considered to be static, i.e. it does not use the methods of fuzzy sets (fuzzy logic) to the full.

3.1 Defining linguistic evaluation expressions

Firstly, we define the context of individual variables (criteria). For all criteria we consider context <0, 0.4, 1>. If the fulfilment of criteria is minimal, then evaluate as 0, conversely if the criterion is met up, we assess it as 1.

Linguistic evaluation terms are designed to cover the entire interval [0,1]. For the purpose of design of evaluation expressions is used LFLC software 2000, which allows us to choose the different parameters of evaluation expression and then draws us its shape in a chart.

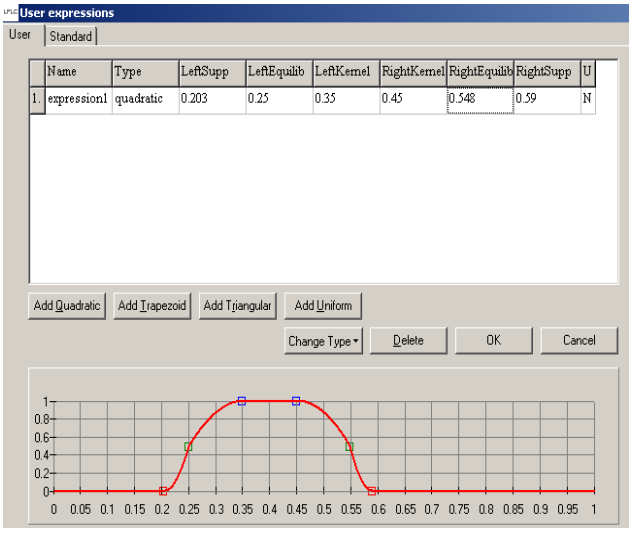

Fig. 2 - Defining evaluation expression "medium". Source: Author's processing in LFLC software 2000

Evaluation terms are defined by six parameters (see Table 1.), that indicate values of an evaluation expression from the interval [0,1] in degrees of classification 1, 0.5, and 0 in the left and right side of expression. Parameters of evaluation expressions are chosen to cover the whole interval [0,1] and should characterized the level of fulfilment of individual criteria.

Tab. 1 - List of defined linguistic evaluation expression and their ranges. Source: Author´s processing

Evaluation expression	Abbreviation	Left side of expression			Right side of expression		
		0	0,5	1	1	0,5	0
Extremely small	Ex Sm	0	0	0	0,03	0,077	0,09
Significantly small	Si Sm	0	0	0	0,05	0,096	0,144
Very small	Ve Sm	0	0	0	0,09	0,174	0,216
Rather small	Ra Sm	0	0	0	0,12	0,232	0,3
Small	Sm	0	0	0	0,16	0,255	0,36
More or less small	Ml Sm	0	0	0	0,21	0,291	0,4
Roughly small	Ro Sm	0	0	0	0,26	0,318	0,4
Quite roughly small	QR Sm	0	0	0	0,31	0,345	0,4
Very roughly small	VR Sm	0	0	0	0,36	0,371	0,4
Evaluation expression	**Abbreviation**	**Left side of expression**			**Right side of expression**		
		0	**0,5**	**1**	**1**	**0,5**	**0**
Medium	Be	0,203	0,25	0,35	0,45	0,548	0,59
More or less medium	Ml Be	0,145	0,257	0,35	0,487	0,603	0,77
Roughly medium	Ro Be	0,145	0,245	0,32	0,54	0,674	0,77
Quite roughly medium	QR Be	0,145	0,234	0,295	0,62	0,721	0,77
Very roughly medium	VR Be	0,145	0,222	0,28	0,676	0,749	0,77
Evaluation expression	**Abbreviation**	**Left side of expression**			**Right side of expression**		
		0	**0,5**	**1**	**1**	**0,5**	**0**
Very roughly big	VR Bi	0,4	0,44	0,52	1	1	1
Quite roughly big	QR Bi	0,4	0,46	0,58	1	1	1
Roughly big	Ro Bi	0,4	0,51	0,64	1	1	1
More or less big	Ml Bi	0,4	0,54	0,7	1	1	1
Big	Bi	0,44	0,6	0,76	1	1	1
Rather big	Ra Bi	0,53	0,67	0,82	1	1	1
Very big	Ve Bi	0,64	0,76	0,88	1	1	1
Significantly big	Si Bi	0,77	0,84	0,94	1	1	1
Extremely big	Ex Bi	0,88	0,92	1	1	1	1
Zero	Ze	0	0	0	0	0	0

3.2 Linking Evaluation expressions to the particular variants

The entire model is using linguistic evaluation criteria for assessing the degree of criteria fulfilment and for quantification of results. In the questionnaire we use for evaluation our own answers (variants). Therefore, the next step is to link our evaluation expressions (see in table 1) to the particular variants (linguistic evaluation).

This process belongs among the most difficult stage of quantification. It is important to assess the particular variants with the appropriate linguistic expressions. As an example of such an assessment can be illustrated in specific sections of the questionnaire dealing with the responses to the degree of implementation of existing approaches and methods:

Question II.: What is the degree of implementation of existing approaches and methods?

Answer:

- Existing approaches **are not** use at all.

Linked evaluation expression = Zero – Ze

- Existing approaches are used **very rarely**, i.e. are implemented only in few very important areas and processes.

Linked evaluation expression = Small – Sm

- Existing approaches **are largely** used in important areas and processes, while this extension in not done systematically (i.e., the method used for the application of these approaches are systematically planned and properly implemented).

Linked evaluation expression = Medium – Be

- Existing approaches **are used systematically and largely** implemented in important areas and processes.

Linked evaluation expression = Roughly Big – Ro Bi

- Existing approaches **are adequately used** and implemented almost in all important areas and processes; extension of these approaches and methods **is not done systematically.**

Linked evaluation expression = Very Roughly Big – VR Bi

- Existing approaches **are sufficiently used** and implemented almost in all important areas and processes; extension of these approaches and methods **is done systematically** (i.e. used methods for application of these approaches are systematically planned and properly performed)

Linked evaluation expression = Significantly Big – Si Bi

- Existing approaches **are appropriately used** and implemented in all important areas and processes; extension of these approaches and methods **is done systematically** (i.e. used methods for application of these approaches are systematically planned and properly performed)

Linked evaluation expression = Extremely Big – Ex Bi

3.3 Quantification of the results of self-assessment by fuzzy IF-THEN rules

The evaluation results are quantified using fuzzy IF-THEN rules, which allow us to adapt to the natural language during the situation of decision-making, and thus to take advantage of linguistic evaluation expressions. The task will be treated as a decision-making situation, where we want to find a suitable conclusion, ie. we look for expressions that occur in the antecedent of some rules in a language description. Because of great complexity and difficulty of conventional methods (algorithms) of logical deduction we decided to use simplified static approach for calculation of particular criteria. That facilitates the overall quantification process of quantifying evaluation criteria.

Tab. 2 - Linguistic description for evaluation of individual criteria of EFQM model. Source: Author´s processing

Pravidlo	K_1	K_2	K_3	H_1
1.	Ve sm	Sm	Sm	Ra Sm
2.	Ve sm	Sm	QR Sm	Ml Sm
3.	Ve sm	Sm	Ro Bi	QR Sm
4.	Ve sm	Be	Sm	Ml Sm
5.	Ve sm	Be	QR Sm	Ro Sm
6.	Ve sm	Be	Ro Bi	VR Sm
7.	Ve sm	VR Bi	Sm	Ro Sm
8.	Ve sm	VR Bi	QR Sm	QR Sm
9.	Ve sm	VR Bi	Ro Bi	Ml Be
10.	Be	Sm	Sm	Ro Sm
11.	Be	Sm	QR Sm	QR Sm
12.	Be	Sm	VR Bi	VR Sm
13.	Be	Be	Sm	QR Sm
14.	Be	Be	QR Sm	VR Sm
15.	VR Be	Be	Ro Bi	VR Bi
16.	VR Be	VR Bi	Sm	Be
17.	VR Be	Ro Bi	QR Sm	VR Be
18.	VR Be	Ve Bi	Ro Bi	Ro Bi
19.	VR bi	Sm	Sm	Ro Sm
20.	VR Bi	Sm	QR Sm	VR Sm
21.	QR Bi	Sm	VR Bi	Ml Be
22.	QR Bi	Be	Sm	VR Sm
23.	QR Bi	Be	VR Bi	VR Be
24.	QR Bi	Be	Ve Bi	Ro bi
25.	Ve Bi	VR Bi	Sm	VR Bi
26.	**Ve Bi**	**Ro Bi**	**VR bi**	**Ml Bi**
27.	Ve Bi	Si Bi	Ve Bi	Ve Bi
28.	Ve Bi	Ve Bi	Ro Bi	Ra Bi
29.	QR Bi	VR Bi	Ro Bi	QR Bi
30.	QR Bi	Si Bi	Ve Bi	Ra Bi

Note:
K1, K2, K3 ... ... sub-criteria of evaluation approaches and methods, the degree of implementation of existing approaches and methods, the degree of subsequent evaluation and review of existing approaches.
H …… assessment of the individual criteria according to the sub criteria K1, K2, K3
Interpretation of the first rule:
P_1: = **IF** evaluation of approaches and methods is Be (medium)
AND level of implementation of existing approaches and methods is Sm (small)
AND level of subsequent evaluation and review of existing approaches is QR Sm (Quite Roughly Small)
THEN evaluation of criteria is QR Sm (Quite Roughly small)

3.4 Quantifying the results of company self-evaluation according to the EFQM Excellence model questionnaire

Questionnaire output:

- evaluation of existing approaches and methods = Ve Bi (very big)
- the level of implementation (application) of existing approaches and methods = Ro Bi (Roughly Big)
- the level of the subsequent evaluation and review of existing approaches = Ve Bi (Very Big)

We search for appropriate conclusion by logical deduction on the basis of linguistic description (see Table 2.) and perception of observed value, i.e. we seek the right expression that occurs in the antecedent of some rules in the language description. This process is as follows:

Perception of three variables (K1, K2, K3) in the context of < 0, 0.4, 1 > are subsequently linguistic expressions Ve Bi ("Very Big"), Ro Bi ("Roughly Big") and Ve Bi ("Very Big"). We will try to choose the most accurate expression form the rules (see Table 2.), that are available. For criteria 1.A.1, we found the appropriate rule (No. 26), that the most accurately describes the measured values (expressions) obtained from the questionnaire.

P_{26} : = **IF** evaluation of approaches and methods is Ve Bi

AND level of implementation of existing approaches and methods is Ro Bi

AND level of subsequent evaluation and review of existing approaches is VR Bi

THEN evaluation of criteria is Ml Bi

From the comparison of the selected rule (No. 26) and measured values (expressions) of the selected EFQM Excellence model criteria is evident that the expressions of the first and second variables (K1, K2) are equal, while the expression *Ve Bi* ("Very Big") of the third variable (K3) is slightly different from the expression *VR Bi* (rule No. 26), i.e. that the variables "rate of the subsequent evaluation" and "review of existing approaches" of selected sub-criteria are slightly different from the corresponding variables of found rule (No. 26).

In the next step we perform editing, i.e. that we try to find appropriate conclusion of observation, which would accurately describe the achievement level of the selected EFQM criteria. In contrast to the conventional methods (algorithms) using approximate deduction is simplified approach (methodology) utilized. We will use expert knowledge of the evaluator (expert that evaluates the level of compliance rate for each criteria of a model) and who intuitively express opinions and who can modify it in the consequent of a rule (No. 26) Ml Bi ("more or less big") expression if it is necessary and if the new expression would more accurately reflect the real level of compliance with selected criteria. In our case, the expert finds intuitively a suitable conclusion, i.e. chooses the expression Bi ("Big"), which accurately reflects the degree of compliance with selected criteria of the EFQM Excellence Model.

The above described methodology is used to quantify all other criteria. Next step is aggregation of partial results of evaluation that are subsequently linked with convenient evaluation expressions. All is done for 9 fundamental criteria of EFQM Excellence Model.

4 DISCUSSION

The designed concept of self-evaluation results quantification according to EFQM model could become an interesting alternative to other evaluation approaches. Main advantage of designed methodology stands in opportunity to mathematically quantifies natural language from which the answer options in questionnaire surveys are created. Therefore the designed concept brings in specific information for performance evaluation according to EFQM model. By „fuzzification process", the approach enhances the objectiveness of self-evaluation for companies.

5 CONCLUSION

In this article, we attempted to outline the possibility of fuzzy set methods utilization in a concrete practical application, i.e. in process of the self-evaluation results quantification of company according to EFQM model criteria. The aim was to describe such application and to bring new inspiration about alternative way of questionnaire evaluation according to EFQM model.

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Contact information
Mgr. Miroslav Chodúr, Ing. Jiří Svoboda, Ing. Přemysl Pálka
Tomas Bata University in Zlín, Faculty of Management and Economics
Mostní 5139, 76001 Zlín
Tel: +420 576 032 417
E-mail: chodur@fame.utb.cz, svobodaj@fame.utb.cz, ppalka@fame.utb.cz

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