Advances in Intelligent Systems and Computing 360

Hoai An Le Thi
Tao Pham Dinh
Ngoc Thanh Nguyen *Editors*

Modelling, Computation and Optimization in Information Systems and Management Sciences

Proceedings of the 3rd International Conference on Modelling, Computation and Optimization in Information Systems and Management Sciences - MCO 2015 - Part II

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Preface

This volume contains 86 selected full papers (from 181 submitted ones) presented at the MCO 2015 conference, held on May 11–13, 2015 at University of Lorraine, France.

MCO 2015 is the third event in the series of conferences on Modelling, Computation and Optimization in Information Systems and Management Sciences organized by LITA, the Laboratory of Theoretical and Applied Computer Science, University of Lorraine.

The first conference, MCO 2004, brought together 100 scientists from 21 countries and was a great success. It included 8 invited plenary speakers, 70 papers presented and published in the proceedings, "Modelling, Computation and Optimization in Information Systems and Management Sciences", edited by Thi Hoai An and Pham Dinh Tao, Hermes Sciences Publishing, June 2004, 668 pages, and 22 papers published in the European Journal of Operational Research and in the Journal of Global Optimization. The second conference, MCO 2008 was jointly organized by LITA and the Computer Science and Communications Research Unit, University of Luxembourg. MCO 2008 gathered 66 invited plenary speakers and more than 120 scientists from 27 countries. The scientific program consisted of 6 plenary lectures and of the oral presentation of 68 selected full papers as well as 34 selected abstracts covering all main topic areas. Its proceedings were edited by Le Thi Hoai An, Pascal Bouvry and Pham Dinh Tao in Communications in Computer and Information Science 14, Springer. Two special issues were published in Journal of Computational, Optimization & Application (editors: Le Thi Hoai An, Joaquim Judice) and Advance on Data Analysis and Classification (editors: Le Thi Hoai An, Pham Dinh Tao and Ritter Guntter).

MCO 2015 covered, traditionally, several fields of Management Science and Information Systems: Computer Sciences, Information Technology, Mathematical Programming, Optimization and Operations Research and related areas. It will allow researchers and practitioners to clarify the recent developments in models and solutions for decision making in Engineering and Information Systems and to interact and discuss how to reinforce the role of these fields in potential applications of great impact. It would be a timely occasion to celebrate the 30th birthday of DC programming and DCA, an efficient approach in Nonconvex programming framework.

Continuing the success of the first two conferences, MCO 2004 and MCO 2008, MCO 2015 will be attended by more than 130 scientists from 35 countries. The International

Scientific Committee consists of more than 80 members from about 30 countries all the world over. The scientific program includes 5 plenary lectures and the oral presentation of 86 selected full papers as well as several selected abstracts covering all main topic areas. MCO 2015's proceedings are edited by Le Thi Hoai An, Pham Dinh Tao and Nguyen Ngoc Thanh in Advances in Intelligent Systems and Computing (AISC), Springer. All submissions have been peer-reviewed and we have selected only those with highest quality to include in this book.

We would like to thank all those who contributed to the success of the conference and to this book of proceedings. In particular we would like to express our gratitude to the authors as well as the members of the International Scientific Committee and the referees for their efforts and cooperation. Finally, the interest of the sponsors in the meeting and their assistance are gratefully acknowledged, and we cordially thank Prof. Janusz Kacprzyk and Dr. Thomas Ditzinger from Springer for their supports.

We hope that MCO 2015 significantly contributes to the fulfilment of the academic excellence and leads to greater success of MCO events in the future.

March 2015

Hoai An Le Thi
Tao Pham Dinh
Ngoc Thanh Nguyen

DC Programming and DCA: Thirty Years of Developments

The year 2015 marks the 30th birthday of DC (Difference of Convex functions) programming and DCA (DC Algorithm) which were introduced by Pham Dinh Tao in 1985 as a natural and logical extension of his previous works on convex maximization since 1974. They have been widely developed since 1994 by extensive joint works of Le Thi Hoai An and Pham Dinh Tao to become now classic and increasingly popular.

DC programming and DCA can be viewed as an elegant extension of Convex analysis/Convex programming, sufficiently broad to cover most real-world nonconvex programs, but no too in order to be able to use the powerful arsenal of modern Convex analysis/Convex programming. This philosophy leads to the nice and elegant concept of approximating a nonconvex (DC) program by a sequence of convex ones for the construction of DCA: each iteration of DCA requires solution of a convex program. It turns out that, with appropriate DC decompositions and suitably equivalent DC reformulations, DCA permits to recover most of standard methods in convex and nonconvex programming. These theoretical and algorithmic tools, constituting the backbone of Nonconvex programming and Global optimization, have been enriched from both a theoretical and an algorithmic point of view, thanks to a lot of their applications, by researchers and practitioners in the world, to model and solve nonconvex programs from many fields of Applied Sciences, including Data Mining-Machine Learning, Communication Systems, Finance, Information Security, Transport Logistics & Production Management, Network Optimization, Computational Biology, Image Processing, Robotics, Computer Vision, Petrochemicals, Optimal Control and Automatic, Energy Optimization, Mechanics, etc. As a continuous approach, DC programming and DCA were successfully applied to Combinatorial Optimization as well as many classes of hard nonconvex programs such as Variational Inequalities Problems, Mathematical Programming with Equilibrium Constraints, Multilevel/Multiobjective Programming.

DC programming and DCA were extensively developed during the last two decades. They were the subject of several hundred articles in the high ranked scientific journals and the high-level international conferences, as well as various international research projects, and were the methodological basis of more than 50 PhD theses. More than 90 invited symposia/sessions dedicated to DC programming & DCA were presented in numerous international conferences. The ever-growing number of works using DC programming and DCA proves their power and their key role in Nonconvex programming/Global optimization and many areas of applications.

In celebrating the 30th birthday of DC programming and DCA, we would like to thank the founder, Professor Pham Dinh Tao, for creating these valuable theoretical and algorithmic tools, which have such a wonderful scientific impact on many fields of Applied Sciences.

Le Thi Hoai An

General Chair of MCO 2015

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Part I

Data Analysis and Data Mining

A Multi-criteria Assessment for R&D Innovation with Fuzzy Computing with Words

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Abstract. The assessment of research and development (R&D) innovation is inherently a multiple criteria decision making (MCDM) problem and has become a fundamental concern for R&D managers in the last decades. Research in identifying the relative importance of criteria used to select a favorable project has relied on subjective lists of criteria being presented to R&D managers. The conventional methods for evaluating corresponding R&D merits are inadequate for dealing with suchlike imprecise, heterogeneity or uncertainty of linguistic assessment. Whereas most attributes and their weights are linguistic variables and not easily quantifiable, 2-tuple fuzzy linguistic representation and multigranular linguistic computing manner are applied to transform the heterogeneous information assessed by multiple experts into a common domain and style. It is advantageous to retain consistency of evaluations. The proposed linguistic computing approach integrates the heterogeneity and determines the overall quality level and the performance with respect to specific quality attributes of an R&D innovation.

Keywords: R&D innovation, Heterogeneity, 2-tuple fuzzy linguistic, Group decision-making, Fuzzy linguistic computing.

1 Introduction

Technology has been extensively recognized as one of the major factors determining the competitiveness of an industry. The key to continued competitiveness for many enterprises lies in their ability to develop and implement new products and processes. In the current business environment of increased global competition and rapid change, research and development (R&D) is an investment companies make in their future. Firms need tools that can help determine the optimum allocation of resources. R&D managers and senior executives are becoming increasingly aware of challenges and opportunities in order to be more efficient and effective in delivering products and

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services to customers. At the same time, without effective performance evaluation, R&D organizations will find it hard to motivate their R&D scientists and engineers. Achieving the desired outcomes of R&D innovation remains the most critical but yet elusive agenda for all firms [1-4].

While the changing nature of competition has placed firms under heavy pressure to rapidly develop and commercialize new innovations to ensure their survival, the successful release of new products undoubtedly brings firms plenty of profits and revenue growth. Doubts often arise about what and who actually determine project success. The nature of the project may differ from project to project depending on its subject, but the success of a project is the common goal for any organization that performs the project. Performance measurement therefore plays an important role in ensuring the project success and its subsequent usefulness to the sponsoring organization [5-7].

In general, the concept of performance measurement implies identification of certain performance metrics and criteria for their computation [3, 8]. A number of qualitative and quantitative metrics have been conducted to measure the performance of R&D innovation at various levels during the selection phase. However, the explicit consideration of multiple, conflicting objectives in a decision model has made the area of multiple criteria decision-making (MCDM) very challenging. The goal of this paper therefore makes a point of developing an evaluation approach to assessing R&D innovation for achieving business strategies; and further , the business decision mechanism is usually composed of multiple experts who implement alternatives evaluation and decision analysis in the light of association rules and criteria. Experts devote to judge by their experiential cognition and subjective perception in decision-making process. However, there exist considerable extent of uncertainty, fuzziness and heterogeneity [9-11]. Consequently, the heterogeneous information that includes crisp values, interval values and linguistic expression is likely to happen under different criterion.

In addition, it is prone to information loss happen during the integration processes, and gives rise to the evaluation result of performance level may not be consistent with the expectation of evaluators. Hence, developing an intimate method to calculate the performance ratings while the processes of evaluation integration and appropriately to manipulate the operation of qualitative factors and evaluator judgment in the evaluation process could brook no delay. The purpose of this paper is to propose a 2-tuple fuzzy linguistic computing approach to evaluate the suppliers' performance. The proposed approach not only inherits the existing characters of fuzzy linguistic assessment but also overcomes the problems of information loss of other fuzzy linguistic approaches.

2 Literature Review

For many firms, especially those that depend on innovation to stay in business, the key to continued competitiveness lies in their ability to develop and implement new products and processes. For these organizations, R&D is an integral function within the strategic management framework. Even firms with excellent technical skills must work within the limits of available funding and resources. R&D project selection decisions, then, are critical if the organization is to stay in business. There are many mathematical decision-making approaches proposed for suchlike decisions. Accordingly, project performance is a crucial issue for the success of a project, which has attracted much attention. Most studies have attempted to analyze the factors that determine the project success; quality, time, and budget [5, 8, 12].

A number of R&D selection models and methods have been proposed in practitioner and academic literature [1-4, 13].Included in the articles reviewed in their papers is those that utilize criteria and methods such as NPV, scoring models, mathematical programming models, and multi attribute approaches. Even with the number of proposed models, the R&D selection problem remains problematic and few models have gained wide acceptance. Mathematical programming techniques such as linear and integer programming are not commonly used in industry, primarily because of the diversity of project types, resources, and criteria used. They also found that many managers do not believe that the available methods for project selection improve the quality of their decisions. Baker and Freeland [14] identified the weaknesses by are:

1. inadequate treatment of multiple, often interrelated, criteria;
2. inadequate treatment of project interrelationships with respect to both value contribution and resource usage;
3. inadequate treatment of risk and uncertainty;
4. inability to recognize and treat nonmonetary aspects;
5. perceptions held by the R&D managers that the models are unnecessarily difficult to understand and use.

The R&D project selection problem plays a critical function in many organizations. A review of literature reveals three major themes relating to R&D project selection: (1) the need to relate selection criteria to corporate strategies; (2) the need to consider qualitative benefits and risks of candidate projects; and (3) the need to reconcile and integrate the needs and desires of different stakeholders [13]. Kim and Oh [3] showed most of the R&D personnel prefer their compensation based on their performance, and indicate that lack of fair performance evaluation system could be the biggest obstacle towards implementing such a compensation scheme.

Mohanty et al. [4] indicated that R&D project selection is indeed a complex decision- making process. It involves a search of the environment of opportunities, the generation of project options, and the evaluation by different stakeholders of multiple attributes, both qualitative and quantitative. Qualitative attributes are often accompanied by certain ambiguities and vagueness because of the dissimilar perceptions of organizational goals among pluralistic stakeholders, bureaucracy and the functional specialization of organizational members.

Other factors complicate the decision process. Often, especially in portfolio selection situations, different projects with different impacts must be compared. There may also be overlaps, synergies, and other interactions of the projects that must be considered. R&D projects are often initiated and championed in a bottom-up manner, where engineers or scientists may advocate projects that have great technical merit. However, financial or strategic benefits of the technology should be considered simultaneously.

It is however difficult and laborious to measure R&D projects' performance using traditional crisp value directly as the process of R&D project performance measurement is possessed of many intangible or qualitative factors and items [2, 4, 15]. Linguistic variable representation is therefore favorable for experts to express and evaluate the ratings of R&D projects under such situation. The fundamentals of 2-tuple fuzzy linguistic approach are to apply linguistic variables to stand for the difference of degree and to carry out processes of computing with words easier and without information loss during the integration procedure [16]. That is to say, decision participators or experts can use linguistic variables to estimate measure items and obtain the final evaluation result with proper linguistic variable. It is an operative method to reduce the decision time and mistakes of information translation and avoid information loss through computing with words.

3 Preliminary Concepts

Many aspects of different activities in the real world cannot be assessed in a quantitative form, but rather in a qualitative one, i.e., with vague or imprecise knowledge. Whereas characteristics of the fuzziness and vagueness are inherent in various decision-making problems, a proper decision-making approach should be capable of dealing with vagueness or ambiguity.

A fuzzy set $\tilde{A}$ in a universe of discourse X is characterized by a membership function $\mu_{\tilde{A}}(x)$, which associates with each element x in X a real number in the interval [0,1]. The function value $\mu_{\tilde{A}}(x)$ is termed the grade of membership of x in $\tilde{A}$. A fuzzy number is a fuzzy subset in the universe of discourse X that is both convex and normal. (See Fig. 1)

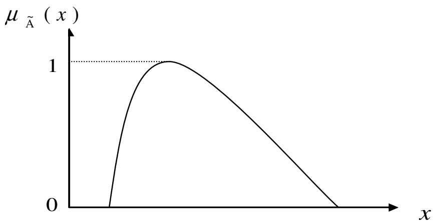

Fig. 1. Fuzzy number $\tilde{A}$

The fuzzy linguistic approach represents qualitative aspects as linguistic values by means of linguistic variables [17]. The concept of linguistic variable is very useful in dealing with situations which are too complex or too ill-defined to be reasonably described in conventional quantitative expressions. For easing the computation and identifying the diversity of each evaluation item, linguistic terms are often possessed of some characteristics like finite set, odd cardinality, semantic symmetric, ordinal level and compensative operation. At present, many aggregation operators have been developed to aggregate information. Herrera and Martinez [18] proposed a 2-tuple fuzzy linguistic representation model. The linguistic information with a pair of values is called 2-tuple that composed by a linguistic term and a number. This representation benefits to be continuous in its domain. It can express any counting of information in the universe of the discourse, and can be denoted by a symbol $L=(s_i,\ \alpha_i)$ where s_i denotes the central value of the i^{th} linguistic term, and α_i indicates the distance to the central value of the i^{th} linguistic term. (See Fig. 2)

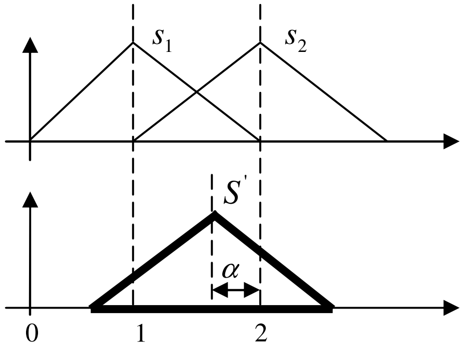

Fig. 2. Representation of 2-tuple linguistic

Suppose $L_1=(s_1,\ \alpha_1)$ and $L_2=(s_2,\ \alpha_2)$ are two linguistic variables represented by 2-tuples. The main algebraic operations are shown as follows:

$$L_1 \oplus L_2 = (s_1\ ,\ \alpha_1) \oplus (s_2\ ,\ \alpha_2) = (s_1 + s_2\ ,\ \alpha_1 + \alpha_2)$$
$$L_1 \otimes L_2 = (s_1\ ,\ \alpha_1) \otimes (s_2\ ,\ \alpha_2) = (s_1\, s_2\ ,\ \alpha_1\, \alpha_2)$$

where $\oplus$ and $\otimes$ symbolize the addition and multiplication operations of parameters, respectively.

Let $(s_i,\ \alpha_i)$ and $(s_j,\ \alpha_j)$ be two 2-tuples, with each one representing a counting of information as follows:

1. If $i > j$ then $(s_i,\ \alpha_i)$ is better than $(s_j,\ \alpha_j)$;
2. If $i = j$ and $\alpha_i > \alpha_j$ then $(s_i,\ \alpha_i)$ is better than $(s_j,\ \alpha_j)$;
3. If $i = j$ and $\alpha_i < \alpha_j$ then $(s_i,\ \alpha_i)$ is worse than $(s_j,\ \alpha_j)$;
4. If $i = j$ and $\alpha_i = \alpha_j$ then $(s_i,\ \alpha_i)$ is equal to $(s_j,\ \alpha_j)$, i.e. the same information.

The symbolic translation function Δ is presented to translate β into a 2-tuple linguistic variable [19]. Then, the symbolic translation process is applied to translate β ($\beta \in [0, 1]$) into a 2-tuple linguistic variable. The generalized translation function can be represented as [20]:

$$\Delta : [0,1] \rightarrow S \times [-\frac{1}{2g}, \frac{1}{2g}) \tag{1}$$

$$\Delta(\beta) = (s_i, \alpha_i) \tag{2}$$

where $i = round(\beta \times g)$, $\alpha_i = \beta - \frac{i}{g}$ and $\alpha_i \in [-\frac{1}{2g}, \frac{1}{2g})$.

A reverse function Δ^{-1} is defined to return an equivalent numerical value β from 2-tuple linguistic information (s_i, α_i). According to the symbolic translation, an equivalent numerical value β is obtained as follow [20].

$$\Delta^{-1}(s_i,\alpha_i)=\frac{i}{g}+\alpha_i=\beta \tag{3}$$

Let $S=\{(s_1,\ \alpha_1),\ldots,(s_n,\ \alpha_n)\}$ be a 2-tuple linguistic variable set and $W=\{w_1,\ \ldots,\ w_n\}$ be the weight set of linguistic terms, their arithmetic mean $\overline{S}$ is calculated as [16]

$$\overline{S}=\Delta[\frac{1}{n}\sum_{i=1}^{n}\Delta^{-1}(s_i,\alpha_i)]=\Delta(\frac{1}{n}\sum_{i=1}^{n}\beta_i)=(s_m,\alpha_m) \tag{4}$$

The 2-tuple linguistic weighted average $\overline{S}^W$ is computed as

$$\overline{S}^w=\Delta\left(\frac{\sum_{i=1}^{n}\Delta^{-1}(s_i,\alpha_i)\cdot w_i}{\sum_{i=1}^{n}w_i}\right)=\Delta\left(\frac{\sum_{i=1}^{n}\beta_i\cdot w_i}{\sum_{i=1}^{n}w_i}\right)=(s^w,\alpha^w) \tag{5}$$

Moreover, let $W=\{(w_1,\ \alpha_{w1}),\ \ldots,\ (w_n,\ \alpha_{wn}\}$ be the linguistic weight set of linguistic terms. The linguistic weighted average $\overline{S}^{LW}$ can be computed as

$$\overline{S}^{LW}=\Delta\left(\frac{\sum_{i=1}^{n}\beta_i\times\beta_{w_i}}{\sum_{i=1}^{n}\beta_{w_i}}\right)=(s^{LW},\alpha^{LW}) \tag{6}$$

with $\beta_i=\Delta^{-1}(s_i,\alpha_i)$ and $\beta_{w_i}=\Delta^{-1}(w_i,\alpha_{w_i})$

Table 1. Different types of linguistic variables

Type	No. of linguistic	Linguistic variable
A	3	Poor(s_0^3), average(s_1^3), good(s_2^3)
B	5	Very poor(s_0^5), poor(s_1^5), average(s_2^5), good(s_3^5), very good(s_4^5)
C	7	Extremely Poor(s_0^7), Poor(s_1^7), Medium Poor(s_2^7), Fair(s_3^7), Medium Good(s_4^7), Good(s_5^7), Extremely Good(s_6^7)
D	9	Extremely poor(s_0^9), very poor(s_1^9), poor(s_2^9), fair(s_3^9), average(s_4^9), good(s_5^9), very good(s_6^9), extremely good(s_7^9), excellent(s_8^9)

In general, decision makers will use the different types of 2-tuple linguistic variables based on their knowledge or experiences to express their opinions [21]. For example, the different types of linguistic variables are shown as Table 1. Each 2-tuple linguistic variable can be represented as a triangle fuzzy number. In order to aggregate the evaluation ratings of all decision-makers, a transformation function is needed to transfer these 2-tuple linguistic variables from different linguistic sets to a standard linguistic set at unique domain. According to the method of Herrera and Martinez [19], the domain of the linguistic variables will increase as the number of linguistic variable is increased. To overcome this drawback, a new translation function is applied to transfer a crisp number or 2-tuple linguistic variable to a standard linguistic term at the unique domain [20]. Suppose that the interval [0, 1] is the unique domain. The linguistic variable sets with different semantics (or types) will be defined by partitioning the interval [0, 1].

Furthermore, transforming a crisp number β ($\beta \in [0, 1]$) into i^{th} linguistic term (s_i, α_i) $(s_i^{n(t)}, \alpha_i^{n(t)})$ of type t as

$$\Delta_t(\beta) = (s_i^{n(t)}, \alpha_i^{n(t)}) \tag{7}$$

where $i = round(\beta \times g_t)$, $\alpha_i^{n(t)} = \beta - \frac{i}{g_t}$, $g_t = n(t)\text{-}1$ and $n(t)$ is the number of linguistic variable of type t.

Transforming i^{th} linguistic term of type t into a crisp number β ($\beta \in [0, 1]$) as

$$\Delta_t^{-1}(s_i^{n(t)}, \alpha_i^{n(t)}) = \frac{i}{g_t} + \alpha_i^{n(t)} = \beta \tag{8}$$

where $g_t = n(t)\text{-}1$ and $\alpha_i^{n(t)} \in [-\frac{1}{2g_t}, \frac{1}{2g_t})$.

Therefore, the transformation from i^{th} linguistic term $(s_i^{n(t)}, \alpha_i^{n(t)})$ of type t to k^{th} linguistic term $(s_k^{n(t+1)}, \alpha_k^{n(t+1)})$ of type t+1 at interval [0, 1] can be expressed as

$$\Delta_{t+1}(\Delta_t^{-1}(s_i^{n(t)}, \alpha_i^{n(t)})) = (s_k^{n(t+1)}, \alpha_k^{n(t+1)}) \tag{9}$$

where $g_{t+1}=n(t+1)\text{-}1$ and $\alpha_k^{n(t+1)} \in [-\frac{1}{2g_{t+1}}, \frac{1}{2g_{t+1}})$.

4 Procedure for Fuzzy Linguistic Evaluation

R&D innovation evaluation/selection is full of uncertainty and can be viewed as a multiple-criteria decision that is normally made by a review committee. Afterward the following questions are expected to be answered via the proposed approach:

- Which innovation ideas should be selected ultimately? (It means perfect ideas).
- Which innovation ideas must be supported via evaluation programs? (It means favorable ideas).
- Which innovation ideas no longer should be considered in any level? (It means bad or unsuitable ideas).

Based on the profound discussions with decision-makers (DMs) the most prevalent and meaningful concerns and sub-criteria for this exemplification can be concluded as follows.

C1. ***Technical*****:** factors related to the project itself and the technology being investigated. Specific measures include:

C_{11}: Existence of project champion (EPC);
C_{12}: Probability of technical success (PTS);
C_{13}: Existence of required competence (ERC);

C_{14}: Availability of available resources (AAR);
C_{15}: Time to market (TM).

C2. ***Market*:** factors related to the success of the technology and its associated products as related to commercial and marketing. Specific measures include:
C_{21}: Probability of market success of product (PMS);
C_{22}: Number and strength of competitors (NSC);
C_{23}: Potential size of market (PSM);
C_{24}: Net present value (NPV);

C3. ***Organizational*:** includes internal and external cultural and political factors that might influence the decision.
C_{31}: Strategic fit (SF);
C_{32}: External regulations (ER);
C_{33}: Workplace safety (WS);

The algorithm procedure of the proposed evaluation approach is organized sequentially into six steps (see Fig. 3), and explained as follows:

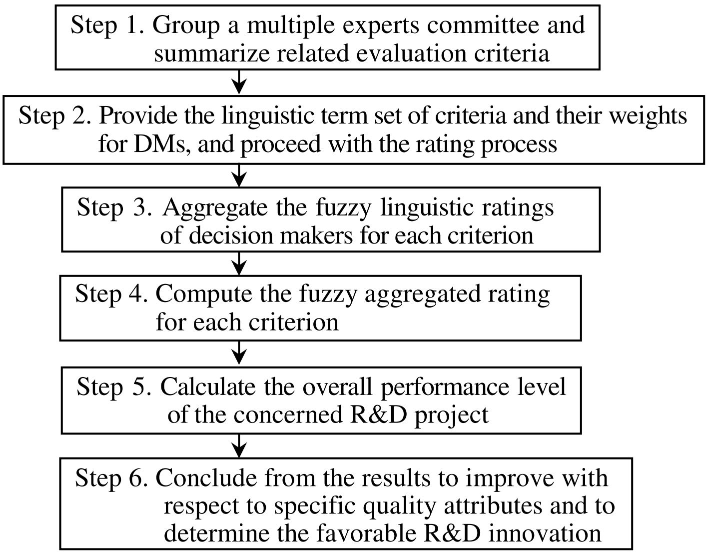

Fig. 3. Procedure of algorithm on proposing approach

Step 1. Group the committee who are familiar with marketing, business strategies, selling and the relationship of supply and demand. Identify and divide the evaluation criteria into positive criteria (the higher the rating, the greater the preference) and negative criteria (the lower the rating, the greater the preference). For example, DMs choose one kind of linguistic variables respectively to determine the importance of each criterion and the performance of each factor with respect to each criterion. Afterward the rating outcome is shown in Tables 2 and 3.

Table 2. Linguistic evaluations of each decision maker for each criterion and elements

Criteria	Decision-makers			
C1. Technical:	D_1	D_2	D_3	D_4
C_{11}: Existence of project champion (EPC)	G	VG	A	VG
C_{12}: Probability of technical success (PTS)	VG	A	VG	G
C_{13}: Existence of required competence (ERC)	G	VG	G	G
C_{14}: Availability of available resources (AAR)	VG	G	A	VG
C_{15}: Time to market (TM)	A	A	VG	VG
C2. Market:				
C_{21}: Probability of market success of product (PMS)	VG	A	VG	A
C_{22}: Number and strength of competitors (NSC)	VG	G	A	G
C_{23}: Potential size of market (PSM)	A	G	VG	G
C_{24}: Net present value (NPV)	G	VG	VG	A
C3. Organizational:				
C_{31}: Strategic fit (SF)	VG	G	G	VG
C_{32}: External regulations (ER)	A	VG	A	VG
C_{33}: Workplace safety (WS)	G	VG	VG	G

Table 3. Linguistic evaluations of importance of each criterion and corresponding elements

Criteria	Decision-makers			
C1. Technical:	D_1	D_2	D_3	D_4
C_{11}: Existence of project champion (EPC)	VI	VI	VI	I
C_{12}: Probability of technical success (PTS)	VI	VI	VI	I
C_{13}: Existence of required competence (ERC)	A	VI	A	A
C_{14}: Availability of available resources (AAR)	I	I	A	A
C_{15}: Time to market (TM)	I	I	VI	I
C2. Market:	VI	VI	VI	VI
C_{21}: Probability of market success of product (PMS)	I	I	VI	I
C_{22}: Number and strength of competitors (NSC)	I	VI	VI	VI
C_{23}: Potential size of market (PSM)	I	A	VI	VI
C_{24}: Net present value (NPV)	A	I	A	I
C3. Organizational:				
C_{31}: Strategic fit (SF)	I	VI	VI	I
C_{32}: External regulations (ER)	I	I	I	I
C_{33}: Workplace safety (WS)	A	VI	A	I

Step 2. Selectable categories of linguistic terms in Table 1 for experts are prepared when they apply the linguistic importance variables to express the weight of each criterion and employ the linguistic rating variables to evaluate the performance of sub-criteria with respect to each criterion.

Step 3. Aggregate the fuzzy linguistic assessments of the N experts for each criterion by Eqs. (4), (5) and (6); In the meanwhile transform crisp numbers and linguistic terms mutually by Eqs. (7) and (8), and Transform different types of linguistic terms mutually by Eq. (9);

Step 4. Compute the fuzzy aggregated rating of $C_i(\overline{S}_i)$ through Eq. (5);

Table 4. Aggregation results

Criteria	Mean rating	Mean weighting	Weighted rating	Aggregated weighting
C1. Technical:				
C_{11}: Existence of project champion (EPC)	(S_3, 0.0625)	(S_2, 0.125)		
C_{12}: Probability of technical success (PTS)	(S_3, 0.0625)	(S_2, 0.125)		
C_{13}: Existence of required competence (ERC)	(S_3, 0.0625)	(S_3, 0.0625)	(S_3, 0.0494)	(S_4, -0.0625)
C_{14}: Availability of available resources (AAR)	(S_3, 0.0625)	(S_4, 0)		
C_{15}: Time to market (TM)	(S_3, 0)	(S_3, 0.0625)		
C2. Market:				
C_{21}: Probability of market success of product (PMS)	(S_3, 0)	(S_3, 0.0625)		
C_{22}: Number and strength of competitors (NSC)	(S_3, 0)	(S_2, 0.125)	(S_3, 0.015)	(S_4, -0.0625)
C_{23}: Potential size of market (PSM)	(S_3, 0)	(S_4, -0.0625)		
C_{24}: Net present value (NPV)	(S_3, 0.0625)	(S_3, 0)		
C3. Organizational:				
C_{31}: Strategic fit (SF)	(S_3, 0.125)	(S_3, 0)		
C_{32}: External regulations (ER)	(S_3, 0)	(S_3, -0.0625)	(S_3, 0.0846)	(S_3, 0.125)
C_{33}: Workplace safety (WS)	(S_3, 0.125)	(S_3, -0.0625)		

Step 5. Compute the overall performance level (*OPL*) of a concerned R&D project, the linguistic term s_T, can be applied to represent the control and management performance level of projects as well as being the improvement index directly.

$$OPL = \Delta\left(\frac{\sum_{i=1}^{n}\beta_i \cdot \beta_{w_i}}{\sum_{i=1}^{n}\beta_{w_i}}\right) = (s_T, \alpha_T) \quad \text{with } \beta_i = \Delta^{-1}(r_i, \alpha_i) \text{ and } \beta_{w_i} = \Delta^{-1}(w_i, \alpha_{w_i}) \tag{10}$$

According to the above-mentioned values, the *OPL* can be computed as:

$$OPL = \Delta \frac{\left(\begin{array}{l}\Delta^{-1}(s_3,0.0494)\cdot\Delta^{-1}(s_4,-0.0625)+\Delta^{-1}(s_3,0.015)\cdot\Delta^{-1}(s_4,-0.0625)\\ +\Delta^{-1}(s_3,0.0846)\cdot\Delta^{-1}(s_3,0.125)\end{array}\right)}{[\Delta^{-1}(s_4,-0.0625)+\Delta^{-1}(s_4,-0.0625)+\Delta^{-1}(s_3,0.125)]}$$

$$= \Delta\left(\frac{0.7994\cdot 0.9375 + 0.765\cdot 0.9375 + 0.8346\cdot 0.875}{0.9375 + 0.9375 + 0.875}\right)$$

$$= \Delta\,(0.7988) = (s_3, 0.0488)$$

Step 6. Conclude from the results to improve with respect to specific quality attributes and to determine the favorable R&D innovation further. For example, in contrast with linguistic term set *S*, the obtained overall performance level (*OPL*) is 2-tuple fuzzy linguistic information. The transformed value (S_3, 0.0488) represents slightly better than "Good".