Prioritising IT Projects: Combination of Fuzzy QFD and ARAS to Address Criteria Multiplicity Challenge

Completed Research Paper

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Abstract

In a world of limited resources, there is a constant and continuous challenge for the managers to decide which projects should be given priority among others. As such, project selection and prioritisation has become a popular topic among researchers. Most of prior research, however, is focused around proposing techniques for prioritising the projects based on a given set of selection criteria, and less attention has been devoted towards identifying how such criteria themselves should be identified and prioritised in the first place. This paper narrows this gap by combining Quality Function Development (QFD), fuzzy logic, and Additive Ratio Assessment (ARAS) to systematically establish and prioritise a large number of selection criteria and rank the projects accordingly, in nondeterministic conditions. The proposed method is then applied in a numerical example from real word to illustrate the applicability of the proposed methodology, and also to demonstrate its advantage over an alternative approach.

Keywords: Project selection criteria, project portfolio selection, project portfolio management, Fuzzy Quality Function Development (QFD), FQFD, project selection criteria prioritization, Additive Ratio Assessment (ARAS), Multi Criteria Decision Making (MCDM)

Introduction

Resources of the organisations are never endless, thus the project have to fiercely compete to get a place on top of the priority list to obtain the valuable resources of the company (staff, time, budget, equipment, etc). This challenging task of prioritising the projects has attracted the attention of researchers for many years resulting in accumulation of numerous theoretical and practical methods for project prioritisation, ranging from simple weighed scoring to sophisticated mathematical computing (Bardhan et al., 2004, Huang et al., 2008, Amiri, 2010, Tavana et al., 2015, Altuntas and Dereli, 2015, Kucukbay and Araz, 2016, Saborido et al., 2016, Jiménez et al., 2017, Barak and Dahooei 2018). Most of these studies however have predominantly devoted their efforts towards developing models for project prioritisation based on a given set of selection criteria, with no focus on how such selection criteria themselves should be identified and prioritized in the first place. For example, Ghapanchi et al. (2012) develops a model based on Fuzzy Data Envelopment Analysis (DEA) for prioritising the projects and determining the best project portfolio, but, as acknowledged in the paper itself (p.798), they specify the selection criteria (i.e., the feed to the DEA model) arbitrarily without any rigorous and systematic analysis and prioritisation of the criteria. Another example is Tavana et al. (2015) in which the authors introduce a hybrid model combining DEA, TOPSIS and integer programing for prioritising IT projects. While their hybrid model develops a quite sophisticated and comprehensive algorithm for project prioritisation based on any set of given selection criteria, they do not consider providing any guideline for determining the criteria. They totally leave it to the organisation to tell which selection criteria are critical for them. This is the case in a great majority of the papers in the area of project selection/prioritisation.

Table 1 summarizes a list of prior publications with an indication on how the topic of criteria identification is dealt with in those papers. While this table in not comprehensive, it implies that many studies simply pick an arbitrary set of selection criteria without proposing a solution for filtering or prioritising the many criteria that usually exist during the process of project selection. Some others consider prioritisation of the criteria but only as part of the project selection algorithm (i.e, AHP) (which makes it very limited to that particular algorithm). The only exception is a recent work by Jafarzadeh et al. (2018) in which the authors tackled the challenge of criteria prioritisation and project selection by combining Quality Function Development (QFD) with DEA. However, as acknowledged in the paper itself (p. 243), due to the intrinsic limitations of DEA (Belton and Vickers, 1993), they method is only applicable when a small set of criteria is involved in the decision making. This limits the applicability of their approach given that in the real world situation, usually a large number of competing selection criteria exist in the process of decision making.

Table 1. A summary of project prioritisation publication and how criteria selection is addressed

Publication and brief description	Any method for criteria selection/prioritisation offered?
• Bardhan et al. (2004), nested real options and traditional discounted cash flow for IT investments	No (arbitrary selection of criteria)
• Lin and Chen (2004), a fuzzy weighted average; Fuzzy integer linear programming for projects in food industry	Yes (prioritised criteria using Fuzzy weighted method)
• Eilat et al. (2006), a methodology based on DEA and balanced scorecard for R&D projects	No (arbitrary selection of criteria)
• Huang et al. (2008), a fuzzy AHP for R&D projects	Yes (however just prioritised criteria as part of AHP method)
• Tiryaki and Ahlatcioglu (2009), a fuzzy AHP for stock selection	Yes (however just prioritised criteria as part of AHP method)
• Tiryaki and Ahlatcioglu (2005), a fuzzy MCDM for stock selection	No (not applicable)
• Chen and Cheng (2009), a fuzzy MCDM for IS projects	No (arbitrary selection of criteria)
• Conka et al. (2008), DEA and AHP for R&D portfolio selection	Yes (prioritised criteria as AHP method)
• Tavana et al. (2015), a fuzzy DEA and TOPSIS and linear programming for project selection	No (arbitrary selection of criteria)
• Ghapanchi et al. (2012), a fuzzy DEA approach for selecting projects to built maximal portfolio in the context of IT/IS projects	No (arbitrary selection of criteria)
• Jiménez et al. (2017) a model for solving incompatible fuzzy Goal programming : an application to portfolio selection	No (arbitrary selection of criteria)
• Jafarzadeh et al. (2018), combination of QFD and DEA to select effective portfolio of IT projects	Yes (when number of criteria is small)

This research therefore is an attempt to address the above-mentioned gap, that is, lack of thoughtful, rigorous and systematic identification of selection criteria for project prioritisation when the number of selection criteria is high. We propose combining Quality Function Development (QFD), in fuzzy form, with Multi Criteria Decision Making, in form of Additive Ratio Assessment (ARAS), to achieve our goal. We then apply the proposed model in a real anonymous IT organisation with 30 projects to illustrate the applicability of the approach, and also to show that it overcome the deficiencies of the DEA approach.

Research background

Fuzzy Set theory

Fuzzy Set Theory, introduced by Zadeh (1965), has been widely used to support decision making progress in the situations where the decision is made under uncertainty and with imprecise data. In fuzzy logic, linguistic terms are used to qualitatively express the value of the variables which are then converted to quantitative valued using fuzzy sets membership functions (Lima-Junior and Carpinetti, 2016, Zadeh, 1978).

Any fuzzy set has a membership function and the members of this set have a different membership grade. $f_A(X)$ as membership function of fuzzy set maps each element of this set to real number in the interval $[0,1]$. For example, when the grade of membership is 0, it means that the element does not belong to that set. When the grade of membership for x is 1, it means that the element belongs completely to the fuzzy set. Ambiguous cases are assigned values between 0 and 1. As shown in Figure 1, a triangular fuzzy number can be determine by a triplet $(a_1.a_2.a_3)$. The parameters that describe a fuzzy event is a_1, a_2, and a_3 respectively, indicating the minimum possible value, the most probable value, and the maximum possible value. In the following, we briefly discuss some definitions and properties on fuzzy set theory (Zadeh, 1978, Zimmermann, 2010).

Figure 1. Membership function of triangular fuzzy number

The membership function of the fuzzy number $f_{\tilde{A}}(X)$ is defined as:

$$f_{\tilde{A}(x)} \begin{cases} 0 & x < a_1 \\ \frac{x-a_1}{a_2-a_1} & a_1 \le x \le a_2 \\ \frac{a_3-x}{a_3-a_2} & a_2 \le x \le a_3 \\ 0 & x > a_3 \end{cases} \qquad (1)$$

Let $\tilde{A} = (a_1.a_2.a_3)$ and $\tilde{B} = (b_1.b_2.b_3)$ be two triangular fuzzy numbers. Then the algebraic operational of these two triangular fuzzy numbers are defined as follows:

- Addition/subtraction of two triangular fuzzy numbers: $\widetilde{A} \pm \tilde{B} = (a_1 \pm b_1.a_2 \pm b_2.a_3 \pm b_3)$ (2)
- Multiplication of two triangular fuzzy numbers: $\tilde{A} \times \tilde{B} = (a_1 \times b_1.a_2 \times b_2.a_3 \times b_3)$ (3)
- Division of two triangular fuzzy numbers: $\tilde{A} \div \tilde{B} = (a_1 \div b_3.a_2 \div b_2.a_3 \div b_1)$ (4)
- Multiplication of two triangular fuzzy number by a constant *r*: $r \times \tilde{A} = (ra_1.ra_2.ra_3)$ (5)

Fuzzy QFD

Quality Function Deployment (QFD) is a comprehensive and well-accepted quality management method which was developed in 1960s and 70s to translate customer requirements into the characteristics of new services need products (Akao and Mazur, 2003). In QFD approach, the customer needs (usually called the voice of the customer) are converted into a set of detailed qualitative and quantitative requirements through which the features and characteristics of the product or service can be engineered. QFD has been widely used in different areas such as project portfolio selection or supplier selection to determine the criteria for decision-making (Lima-Junior and Carpinetti, 2016, Chen et al., 2017). In general, QFD is applicable when the intention is to prioritize a list of objectives (HOWs) based on a list of requirements (WHATs).

QFD approach is based on a semantic visualization called “House of Quality (HOQ)” (see Figure 2) which facilitates transforming customer needs (WHATs) to design specification (HOWs). HOQ consists of several blocks as explained below (refer to Figure 2) (Brown, 1991, Chen et al., 2017).

The QFD process begins with the QFD team (i.e., the experts) identifying the customer requirements (CR) (voice of customer, or WHATs) *(block A)* and determining the relevant importance score of each requirement *(block B)*, via listening to the customers. Drawing on their judgment and experience, the QFD team translate the customer requirements into a number of design specification (DS) (or HOWs) *(block C)*. In the next step, the QFD team judges which DS (WHAT) impacts which CR (HOW) and to what extent *(block D)*. Also, the correlation between design specifications (HOWs) is identified by the team *(block E)*. Using the data seated in block A to E, the importance score of the design specifications is calculated *(block F)*, which is the aim of HOQ process. These scores will then be used in the process of developing the new product or service by informing which DSs should receive more resources to ensure that the relevant high importance customer requirement(s) are best satisfied.

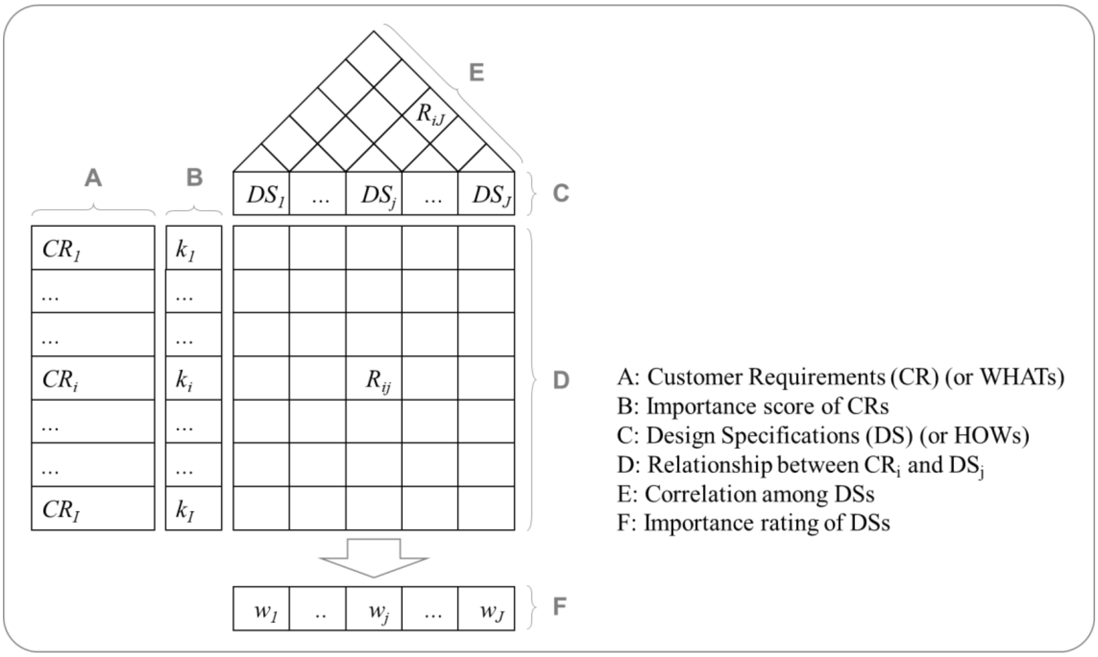

Figure 2. House of Quality

Traditionally, all importance scores and weights in HOQ matrix are set as crisp values (Cohen, 1995, Chan and Wu, 2005, Terninko, 1997), but decision-making in the real word is always tied to vagueness and imprecision. Therefore, considering the inherent fuzziness in decision-making, applying fuzzy methods to QFD is very suitable and useful for practical applications (Chen et al., 2017). Prior researchers have introduced different fuzzy QFD approaches (Temponi et al., 1999, Fung et al., 1999, Karsak, 2004, Juan et al., 2009, Dursun and Karsak, 2013, Lu et al., 2017) among which triangular fuzzy numbers and algebraic operations is a very popular and widely used approach. In this approach, fuzzy numbers are applied to model the linguistic judgments of the decision makers. For instance, the linguistic terms such as “very low, low, medium, high and very high” can be used to evaluate the degree of importance of a requirement and also the relationship between a requirement and a criterion (Lima-Junior and Carpinetti, 2016, Bevilacqua et al., 2006). We use this approach (fuzzy numbers and algebraic operations) in our study, which will be explained later in the proposed method section.

Additive Ratio Assessment (ARAS)

ARAS is a relatively new tool for Multiple Attribute Decision making (MADM). The underlying theory for the model is that decision-making for a complex real world phenomenon can be made through simple relative comparisons of the alternatives (Zavadskas and Turskis, 2010; Zavadskas et al., 2010; Heidary Dahooie et al., 2018). The ARAS method uses the concept of optimality degree to achieve rankings. The optimality degree is equal to the sum of the weighted normalized values of the criteria according to each alternative divided by the sum of the weighted normalized values of the best alternative.

Proposed Method

The model proposed in this study integrates fuzzy QFD and ARAS methods. The model consists of three main phases from which the first two follow the baseline work by Jafarzadeh et al. (2018)[1]: 1) modelling the problem, 2) HOQ construction to prioritize the criteria that affect IT project selection (WHATs) as well as the benefits of project portfolio selection (HOWs), and 3) prioritising and ranking the projects using ARAS. Each step is composed of several steps, which are visualised in Figure 3.

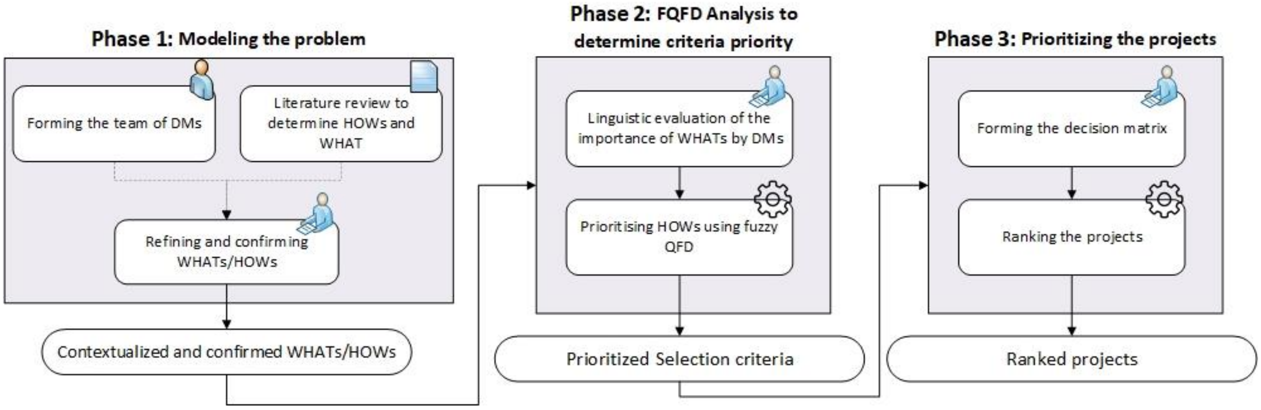

Figure 3. Proposed method

Phase 1. Modeling the problem

Step 1a. Forming the team of decision makers (DMs):

Step one starts with choosing the decision makers (DMs), or the experts, participating in the process of selecting the best project portfolio for the organization. In our proposed method, these DMs are responsible for first, refining and confirming the project selection criterion and project portfolio benefits for their organization (in phase 1), second, determining the required importance factors to build the HOQ matrix (in phase 2), and third, evaluating the benefits of the projects for ARAS analysis (in phase 3).

Step 1b. Identifying initial list of WHATs and HOWs from literature:

In the context of project selection, the QFD *HOWs* refer to the criteria influencing the selection of the projects, and the *WHATs* refer the benefits expected from implementing those projects. There is no lack of research in the literature elaborating on both the selection criteria and the benefits, with a great deal of overlap and consensus among them. For this paper, we use a set of criteria and benefits proposed by Jafarzadeh et al. (2018) (which was based on an aggregation of several prior studies) (Table 2).

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[1] These two phases are (briefly) explained here as needed for understanding this paper. For more details, refer to Jafarzadeh et al (2018).

Table 2. Criteria affecting the selection of IT projects (HOWs), and the expected benefits (WHATs) (from Jafarzadeh et al, 2018)

	HOWs		*WHATs*
B1	Alignment with strategic objectives	C1	Contribution to corporate strategic goals
B2	Risk of project	C2	Maximize the value of the portfolio
B3	Acceptance and support of senior management	C3	Acceptance by users
B4	Technology requirements	C4	Minimize the risk
B5	Complexity of the project	C5	Balance in the portfolio of projects
B6	Dependency to other projects	C6	Organizational performance
B7	Alignment between team skills and project needs	C7	Proper stakeholders management
B8	ROI of project		
B9	Project transparency requirements		
B10	Innovation required		
B11	Flexibility in time and project activities		
B12	Implementation cost		
B13	Alignment of project manager skills to the project		
B14	Net present value of earnings		

Step 1c. Refining and confirming WHATs and HOWs

While an initial list of WHATs and HOWS were identified in the two previous steps, some of them may not be applicable in the specific situations of a particular company (Tavana et al., 2015). At the same time, there might be some additional factors that are of interest to a specific organization due to its unique internal or environmental conditions. Thus, in our proposed method, the factors listed in Table 2 and 3 are presented to the DMs to make sure that a valid and reliable list of WHATs and HOWs is used in the portfolio selection. The DMs may cross out some factors or add others considering the characteristics of their organization.

The output of phase 1 is a screened and validated list of WHATs and HOWs tailored to the needs of the organization, ready to be fed into the next phase to generate the house of quality (HOQ) matrix.

Phase 2. Fuzzy QFD analysis to determine criteria priority

In phase 2, the house of quality structure is built to calculate the relevant importance of the selection criteria and the benefits, and prioritize them based on the judgment of the DMs and the fuzzy QFD algorithm.

Step 2a. Linguistic evaluation of the importance of WHATs by the DMs:

When the benefits (WHATs) and the selection criteria (HOWs) have been determined (in phase 1), then the decision makers judge the important of the benefits using fuzzy logic. In our proposed method, we use the linguistic terms *very high*, *high*, *medium*, *low* and *very low* (Lima-Junior and Carpinetti, 2016, Bevilacqua et al., 2006).

Step2b. Prioritizing HOWs as per Fuzzy QFD algorithm:

Once the linguistic importance of the WHATs are judged by the DMs, we use fuzzy set logic, as explained below, to translate the linguistic terms into quantified fuzzy values. Then fuzzy QFD procedure is applied to prioritize the benefits of project portfolio (HOWs). This is one of the key contributions of our proposed method in which, unlike other studies (e.g., Ghapanchi et al., 2012, Tavana et al., 2015) , the criteria are prioritized before feeding into the MCDM step to determine the optimum portfolio. Table 3 and Figure 4 shows the triangular fuzzy membership function used in this paper.

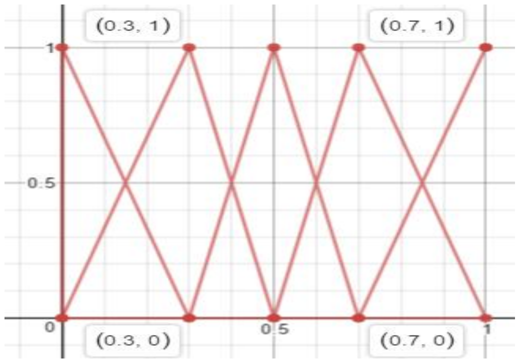

Figure 4. Linguistic scale used in this paper

Table 3. Linguistic terms used in this paper

Very High	(	0.7	,	1	,	1	)
High	(	0.5	,	0.7	,	1	)
Medium	(	0.3	,	0.5	,	0.7	)
Low	(	.	,	0.3	,	0.5	)
Very Low	(	.	,	.	,	0.3	)

Assume A_i be the fuzzy number of WHATs (benefits of project portfolio selection) that shows the experts opinion about the i^{th} requirement (i=1,2, . . .,n).

$$(a_{i,1}, a_{i,2}, a_{i,3}) \tag{6}$$

$$\tilde{A}_i = \frac{1}{k}\left(\sum_{x=1}^{k} a_{i,x}\right) \qquad i=1, \ldots, n \qquad x=1, \ldots, k \tag{7}$$

Let $\widetilde{r_{ij}}$ be the linguistic expert judgment of the relationship between the i^{th} benefit (i=1,2,…,n) and j^{th} criterion (j=1,2…,n), made by the i^{th} decision maker (k = 1, 2, . . ., k). The aggregated judgments of the decision makers regarding the relationship between the i^{th} benefits and the j^{th} criterion, represented by $\widetilde{r_{ij}}$, is calculated by:

$$\widetilde{R_{ij}} = \frac{1}{k}\left(\sum_{x=1}^{k} \widetilde{r_{ij}}\right) \tag{8}$$

in which $\widetilde{R_{ij}}$ is the aggregated judgment of the decision maker.

$\widetilde{W}_j^*$ is a fuzzy number that called. The weighted mean of the j^{th} criterion is calculated as:

$$\widetilde{W}_j^* = \tilde{R}_{ij} \times \tilde{A}_i \tag{9}$$

After that the absolute weight of the j^{th} criterion, W_j^*, is calculated as:

$$W_j^* = \frac{\left(a_{1\widetilde{W}_j^*} + 2 \times a_{2\widetilde{W}_j^*} + a_{3\widetilde{W}_j^*}\right)}{4} \tag{10}$$

After defuzzification, the absolute weight of the j^{th} criterion is converted to the relative weight wc_j according to:

$$WC_j = \frac{W_j^*}{\sum_{j=1}^{m} W_j^*} \tag{11}$$

Phase 3. Prioritising the projects

In this paper, we propose to use ARAS instead of DEA used by Jafarzadeh et al. (2018). The reason is that DEA is too sensitive to the number of decision making criteria. Too many variables will reduce the usefulness of the ranking in practice as the calculated numbers become too close (Belton and Vickers, 1993, Yousefi and Hadi-Vencheh, 2016). It is commonly known that the number of DEA variables should be smaller than the number of decision making units divided by 3 (Bowlin, 1998) (e.g., if we have 30 projects to rank, the number of criteria should be smaller than 30/3=10). This is a daunting limitation as in real world situation, usually a *large* number of competing factors do exist when selecting projects over each other. This limitation can be rectified by employing ARAS.

Step3a. Forming the decision matrix

The first step in ARAS is generating a decision matrix $m \times n$, where m and n denote alternatives and criteria, respectively.

$$X = \begin{bmatrix} x_{01} & \cdots & x_{0j} & \cdots & x_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{i1} & \cdots & x_{ij} & \cdots & x_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mj} & \cdots & x_{mn} \end{bmatrix}; \; i = \overline{0,m}; \; j = \overline{1,n} \tag{12}$$

x_{ij} denotes the performance value of the i-th alternative with respect to the j-th criterion. Also, x_{0j} represents the optimum value for the j-th criterion. The unknown optimum value for the variable j can be obtained using Eq. (13):

$$\begin{aligned} &\text{when } \max_i x_{ij} \text{ is optimal, } x_{0j} = \max_i x_{ij} \\ &\text{when } \min_i x_{ij}^* \text{ is optimal, } x_{0j} = \min_i x_{ij}^* \end{aligned} \tag{13}$$

In general, the alternative evaluation values form the decision matrix entries, with respect to criteria (x_{ij}) and each criterion weight (w_j). Since each criterion have its certain dimension, to carry out a comparative analysis and to avoid potential consequences of different dimensions, dimensionless quantities should be obtained. For this purpose, weighted values are divided by optimal value obtained from Eq. (13). Then the primary entries for all criteria should be normalized $(\bar{x}_{ij})$ requlting in a normalized matrix.

$$\bar{X} = \begin{bmatrix} \bar{x}_{01} & \cdots & \bar{x}_{0j} & \cdots & \bar{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{i1} & \cdots & \bar{x}_{ij} & \cdots & \bar{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \bar{x}_{m1} & \cdots & \bar{x}_{mj} & \cdots & \bar{x}_{mn} \end{bmatrix}; \; i = \overline{0,m}; \; j = \overline{1,n} \tag{14}$$

Since there are two generic types of criteria commonly known as benefit type and cost type, the entries can be normalized positively or negatively according to Eq. (15) and (16), respectively.

$$\bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{15}$$

$$x_{ij} = \frac{1}{x_{ij}^*} \bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}} \tag{16}$$

The framework resulting from the use of dimensionless quantities makes it possible to compare each criterion with all others.

Step3b. Ranking the projects:

Then we need to calculate the weighted normalized decision matrix $(\hat{X})$. In our proposed model, the weight values are those resulted from the FQFD analysis (i.e., Eq. 11). These weights should satisfy the following equations:

$$0 < w_j < 1, \quad \sum_{j=1}^{n} w_j = 1$$

$$\hat{X} = \begin{bmatrix} \hat{x}_{01} & \cdots & \hat{x}_{0j} & \cdots & \hat{x}_{0n} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{i1} & \cdots & \hat{x}_{ij} & \cdots & \hat{x}_{in} \\ \vdots & \ddots & \vdots & \ddots & \vdots \\ \hat{x}_{m1} & \cdots & \hat{x}_{mj} & \cdots & \hat{x}_{mn} \end{bmatrix}; \; i = \overline{0,m}; \; j = \overline{1,n} \tag{17}$$

$$\hat{x}_{ij} = \bar{x}_{ij} \times w_j; \quad i = \overline{0,m} \tag{18}$$

Where, $\bar{x}_{ij}$ represents the normalized value for i-th alternative and w_j denotes the weight value for the j-th criterion. Then, the optimality function value, S_i, can be calculated using Eq. (19):

$$S_i = \sum_{j=1}^{n} \hat{x}_{ij}; \quad i = \overline{0, m} \tag{19}$$

ARAS logic states that the highest optimality function value indicates the best and the lowest optimality function value indicates the worst alternative. Accordingly, alternatives can be ranked based on the value of S_i. The degree of utility K_i for the alternative A_i can be determined by comparing each alternative with the best/optimal alternative S_0, as follows:

$$K_i = \frac{S_i}{S_0}; \quad i = \overline{0, m} \tag{20}$$

Where S_0 and S_i are calculated by Eq. (20). K_i is applied in order to rank all the alternatives, which is placed on [0,1].

Numerical example

Similar to the majority of the cutting-edge studies on project portfolio selection methods, this paper uses a numerical example to demonstrate an application of the proposed method in a real word anonymous scenario. This example relates to a large scale Tele-Communication Company (called TCC hereafter) with more than 60 million active users. The Project Management Office (PMO) of the company constantly faces the challenge of choosing the most efficient portfolio of the projects subject to the monitory limitations of the company. In the following, we illustrate how the proposed method can systematically assist with such decision-making. It is important to note that Phase 1 and Phase 2 of the numerical example are as the same as the research reported in Jafarzadeh et al. (2018). Therefore, to save space and avoid replication, in this conference paper we only review the logic of Phase 1 and 2 very briefly, and tend our focus on Phase 3 (ARAS calculation) which is the main contribution of this paper. Readers interested in the full details of Phase 1 and 2 should refer to Jafarzadeh et al. (2018).

Phase 1. Modelling the problem

Step 1a, 1b, 1c. Forming the team of decision makers, identifying WHATs and HOWs, and refining them

In consultation with the Project Management Office of the organisation, four expert decision makers (DMs) were chosen, who were fully aware of the digital strategy of the organization and understood the 30 projects well (all at managerial position with minimum of 5 years work experience in TCC). Each DM was given the list of project selection criteria (HOWs) and the project portfolio benefits (WHATs) extracted from the literature (Table 2). The DMs confirmed that the list is OK to the situation of their organisation and did not suggest adding or removing any factors.

Phase 2. Fuzzy QFD analysis to determine criteria priority

Step 2a. Linguistic evaluation of the importance of WHATs by the DMs:

Each DM was provided with a questionnaire and was asked to estimate the importance of each factor using the linguistic terms (*very high*, *high*, *medium*, *low* and *very low).* Then, using the triangular fuzzy numbers function outlined in Table 3, the decision-makers' judgments were aggregated with the average operator.

Step 2b. Prioritizing HOWs as per Fuzzy QFD algorithm:

We then asked each decision maker to express their opinion of the impact of each HOW on each WHAT using same linguistic variables (very high to very low in five intervals). We then applied the same triangular fuzzy membership function to quantify the linguistic terms. The fuzzy numbers obtained for each decision–maker were then aggregated and the weight of each criteria was calculated and defuzzified. Finally, the relative weight , WC_j, of each item was calculated, which is reported in Table 4 (for full details of calculations and formulae, please refer to Jafarzadeh et al, 2018).

Table 4. Final weight of each HOW (i.e, the importance of each benefit of portfolio selection)

HOWs, i.e., the benefits of portfolio selection		WC_j	Rank
B1	Alignment with strategic objectives	0.1018	1
B2	Risk of project	0.0875	2
B3	Acceptance and support of senior management	0.0831	3
B13	Alignment of project manager skills to the project	0.0817	4
B12	Implementation cost	0.0805	5
B10	Innovation required	0.0741	6
B8	ROI of project	0.0729	7
B9	Project transparency requirements	0.0694	8
B11	Flexibility in time and project activities	0.0678	9
B7	Alignment between team skills and project needs	0.0631	10
B6	Dependency to other projects	0.0619	11
B14	Net present value of earning	0.0567	12
B5	Complexity of the project	0.056	13
B4	Technology requirements	0.0434	14

Phase 3. Prioritising the projects

The weighted list of benefits obtained at the end of Phase 2 (Table 4) forms a solid foundation for Phase 3 in which the ARAS method is applied to determine the optimum portfolio of the project that can create the maximum value for the organization (as per identified benefits).

Step 3a. Forming decision matrix

Using a questionnaire, the four DMs (the same experts engaged in the previous steps) were asked to score the 30 IT projects (P1 to P30) against the 14 criteria (8 positive and 6 negative). Five-point Likert scale was employed to collect experts' opinions. Table 5 shows the matrix of collected data for each of the projects.

Table 5. The decision matrix

Projects	B1 (+)	B2 (-)	B3 (+)	B4 (-)	B5 (-)	B6 (-)	B7 (+)	B8 (+)	B9 (+)	B10 (-)	B11 (+)	B1 2(-)	B13 (+)	B14 (+)
P1	2.5	3	3.25	3.5	3	3.5	3.25	4	4.25	0.225	2.5	3.75	3.75	3.25
P2	3.75	3.25	1.5	2.75	2.25	2	3.75	3.25	2.5	0.25	2	2.25	2.25	2.75
P3	3	3.5	2.5	3.75	3	4.25	2.75	3.5	3.5	0.325	3.25	1.75	1.75	2.5
P4	3.25	2.5	3.5	2.75	3.25	3	4	3	3.5	0.175	2.75	3.25	3.25	4.5
P5	1.5	4.25	4	3.75	2.75	2.5	3.75	4.5	1.75	0.25	3.25	3	3	3.75
P6	3.25	3.5	3.75	3	3.5	3.5	3.5	4.25	2	0.2	2.75	3.25	3.25	3.75
P7	2.25	3	2.25	3.75	2.5	4.25	2.5	2	3.5	0.3	3.5	3.5	3.5	3.5
P8	2.25	2.5	2.5	3	3.5	2.75	2.5	2.75	3.25	0.2	2.25	2	2	3.75
P9	3	2.25	3.75	3.5	2.5	3.5	3.25	2.5	3.75	0.225	4.25	2.75	2.75	3.25
P10	2.75	3.25	2.5	2.75	3	3.75	2.5	2.25	3.25	0.2	3	4.25	4.25	3
P11	3.5	3.25	3.25	1.75	3	4	3.25	3.75	3.75	0.25	3.5	2.5	2.5	1.75
P12	1.75	3.25	2.5	3.75	3.25	2.5	4	4.25	4	0.225	1.25	3.5	3.5	2
P13	2.25	2.5	2	3.25	3.5	3.5	2.25	3.5	2.5	0.15	2.75	4	4	2.25
P14	3.5	4	4.25	3.75	3.25	3.25	3.25	4.25	2.25	0.225	1.5	4	4	3.5
P15	3.25	3	3.5	1.75	3.5	3	2.75	3.25	2.25	0.25	3	2.75	2.75	3
P16	3.25	2.75	3.25	3	2.75	3.25	2.75	3.5	2.5	0.25	4	4.25	4.25	3.25
P17	3.5	3.25	3	3.75	4.25	1.75	1.75	2.25	3	0.25	2.25	3.5	3.5	3.75
P18	3.25	3	3.75	4	3.5	3.25	3.5	2.25	2.75	0.225	2	3.75	3.75	3.5
P19	4.25	4	4	1.5	4	3	2.5	2.5	3.5	0.4	3.5	3.75	3.75	1.75
P20	2.5	2.25	2	3	4.25	2.5	3.25	2	2.25	0.25	2.5	2.75	2.75	3

P21	4.25	3.75	2.25	2.75	2.5	3.75	3.5	3.25	3.5	0.175	3.25	3.5	3.5	3.75
P22	3.5	3.75	2.25	3	1.75	2.5	3.75	4	1.5	0.2	2.25	2.75	2.75	2.75
P23	3.75	2.25	1.5	3.75	3.5	3.75	2	3.75	3	0.3	3.25	2	2	3.5
P24	3.5	2.5	3.75	3.5	3.5	3.5	2.75	4	2.75	0.175	2.75	2.25	2.25	3.75
P25	2.75	3.25	3.5	3	2	2.5	3.25	3.5	1	0.275	3.25	3.25	3.25	2.25
P26	3.25	2.75	4.25	4.5	3	3	3.5	4	3.25	0.225	2.5	4.75	4.75	4.25
P27	2.25	1.75	2.25	3.25	2.25	2.5	3.75	2.75	2	0.25	1.75	1.75	1.75	3.5
P28	3.25	3	3.5	2.75	4.25	4.5	4	3.5	3.75	0.275	3.25	3	3	3
P29	2.75	3	3	2	2.75	3	4.75	2	3.75	0.25	1.75	2	2	2.75
P30	2.5	3	2.75	2.5	3	3	3.5	3.25	1.75	0.275	4.5	2	2	2.75

Step 3b. Ranking the projects

According to the requirements of ARAS method, we normalised the values in the decision matrix and then, by mean of Eq. (18), applied the weights already obtained out of FQDF analysis (Table 4).

The final rank of each project was eventually computed based on Eq. (19) and (20). The result is shown in Table 6.

Table 6. The final rank of each project using ARAS (this study)

Project	Si	Ki	Rank	Project	Si	Ki	Rank	Project	Si	Ki	Rank
P0	0.049187	1.00000		P19	0.032212	0.654879	**11**	P25	0.03086	0.627394	**21**
P4	0.034939	0.71034	**1**	P15	0.031916	0.648872	**12**	P18	0.03077	0.625575	**22**
P26	0.034637	0.704198	**2**	P22	0.031908	0.648703	**13**	P8	0.030737	0.624892	**23**
P9	0.034223	0.695776	**3**	P27	0.031904	0.648622	**14**	P17	0.030639	0.622907	**24**
P21	0.033796	0.68709	**4**	P29	0.031823	0.646984	**15**	P10	0.030109	0.61214	**25**
P24	0.033788	0.686924	**5**	P14	0.031587	0.642183	**16**	P3	0.030037	0.610673	**26**
P11	0.033051	0.671945	**6**	P2	0.031547	0.641363	**17**	P13	0.029857	0.607019	**27**
P16	0.032881	0.668494	**7**	P30	0.031257	0.635472	**18**	P12	0.029761	0.605066	**28**
P6	0.03233	0.657289	**8**	P5	0.03103	0.630855	**19**	P20	0.02891	0.587765	**29**
P28	0.032278	0.656232	**9**	P23	0.030918	0.628589	**20**	P7	0.028842	0.586381	**30**
P1	0.032265	0.655961	**10**								

Conclusion

Prior research in the domain of project selection and prioritisation have developed various methodologies for portfolio selection but they have largely focused on the selection technique itself as the focal point of their method, and tended to ignore explaining how the selection criteria should be determined and prioritised in the first place. For example, in their proposed approach based on fuzzy DEA, Ghapanchi et all (2012) states that their selection model assumes that a couple of selection criteria is simply picked by the decision makers. They do acknowledge that this is an oversimplification and urge that future studies should develop seamless and integrated methodologies that not only suggest selection algorithms but also propose solutions for determining and prioritising the selection criteria in the first place. As far as our literature survey indicates, the only exception to this gap was a work by Jafarzadeh et al. (2018), however their approach is only applicable when the number of selection criteria is low (due to analytical limitation of DEA in dealing with large number of decision making factors) (Belton and Vickers, 1993, Yousefi and Hadi-Vencheh, 2016). To address this shortcoming, in this paper we suggested to replace DEA with ARAS.

Applying our proposed method in a numerical case confirmed the applicability of our approach in real world situation and attested that it rectifies the limitation of DEA in prioritising the alternatives when the number of selection criteria in relatively large. Table 7 is the result of project ranking by DEA in Jafarzadeh et al (2018) paper (the baseline paper). As it can be seen in this table, two-thirds of the projects have received efficiency factor of 1 (i.e., no differentiation between the alternatives). This is a typical outcome in many DEA analyses (Eilat et al., 2008) even though they only had eight criteria in the analysis. Whereas in our model, we had 14 criteria yet our ranking approach managed to adequately differentiate between the alternative projects (see Table 6).

Table 7. The final rank of each project using DEA (Jafarzadeh et al. 2018)

Project (DMU)	Efficiency score	Project (DMU)	Efficiency score	Project (DMU)	Efficiency score
P1	1.0	P11	1.0	P21	1.0
P2	1.0	P12	1.0	P22	0.53
P3	0.8	P13	0.93	P23	0.94
P4	0.91	P14	1.0	P24	0.88
P5	1.0	P15	1.0	P25	1.0
P6	0.95	P16	0.92	P26	1.0
P7	1.0	P17	1	P27	1.0
P8	1.0	P18	0.93	P28	1.0
P9	1.0	P19	1.0	P29	0.6
P10	1.0	P20	1.0	P30	1.0

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