Multi-objective team formation optimization for new product development

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ABSTRACT

The formation of effective new product development (NPD) teams has played a crucial role in successful NPD projects. We propose a multi-objective team formation optimization model for NPD projects that considers the comprehensive capabilities and interpersonal relationships of all members. To address the member capabilities, an improved fuzzy Analytic Hierarchy Process based on fuzzy linguistic preference relations is applied to ensure the precision and consistency of the evaluation and overcome the drawbacks of the use of crisp values. Moreover, the Myers-Briggs Type Indicator (MBTI) is employed to model interpersonal relationships based on the personality groupings in the MBTI and to facilitate a numerical description of these relationships in the proposed model. Finally, a real world example is provided to illustrate application of the model, and the Multi-objective Particle Swarm Optimization (MOPSO) algorithm is implemented to search for Pareto solutions that represent the alternatives for optimal team composition. The results suggest that the proposed optimization model is both effective and practical.

1. Introduction

The use of project teams in the performance of daily activities is increasingly gaining popularity among many new product development (NPD) projects (Bourgeon, 2007; Carbonell & Rodriguez, 2006; Dayan & Di Benedetto, 2010; Kim & Kim, 2009). Project teams are highly advantageous because the team members share common project goals and handle technical complexity and change with the assistance of their collective cross-functional knowledge. Additionally, these cross-functional teams are often temporary organizations that are able to respond quickly to changing environmental conditions by adjusting the composition of the team members. However, a significant challenge remains for project managers or other decision-makers to assemble teams that are able to effectively carry out plans and produce successful NPD projects (Bourgeon, 2007).

The primary challenge in forming an effective NPD team is that the comprehensive capabilities of the team members must meet the requirements of the project. These comprehensive capabilities include:

1. Expertise and experience: In NPD teams, expertise is cross-functional by nature and often consists of the job-specific competencies required for projects and other functional knowledge needed to improve the understanding of other team members (Chowdhury, 2001). For example, it is highly favorable for the design engineers to have a certain level of knowledge of finance and marketing such that they are able to view their design works from different perspectives. The team members’ experience refers to certain knowledge and skills that are gained in the process of performing the project activities, including how to cope with conflicts, how to ease stress and how to encourage teamwork (Barczak & Wilemon, 2003).

2. Learning and knowledge sharing: Learning ability reflects an individual’s skill in acquiring useful information from others, and knowledge sharing ability refers to the skill of exchanging useful information among team members. Learning is the process of detecting and storing knowledge, and knowledge sharing is the process of knowledge interchange among different functionalities. The two processes interact and determine the creation of new ideas and knowledge in NPD projects (Bourgeon, 2003).

3. Communication: Communication is essential for NPD team members because the functionalities of the team members are diverse. Therefore, it is important for the team members to exchange ideas clearly and to reduce potential conflicts. Good communication among the team members facilitates cooperation and teamwork (Hoegl & Proserpio, 2004).

4. Problem solving: With the ever-changing external environment during the project period, the team members are required to adapt to changes and address problems in a...
flexible manner. The members must possess problem solving abilities that include reasoning, defining problems, assessing causation, and developing and analyzing alternatives (Akgün, Byrne, Lynn, & Keskin, 2007; Akgün & Lynn, 2002). To assemble an effective NPD team and to select competent members, the available team must be evaluated candidates according to the above four criteria of comprehensive capabilities. However, the expression of the evaluation used to describe how well a person performance according to a certain criterion is natural language rather than crisp numerical values. For example, we say that a person is “quite good” at communication with others, rather than saying that the value of communication ability of the person is 7. Moreover, the evaluation of a person’s comprehensive capabilities must consider the combination of the four criteria, yet their importance weights may differ according to different types of NPD projects. Therefore, quantitative decision-making approaches are needed to support the evaluation process for the team candidates such that the candidates with a high level of comprehensive capabilities can be identified.

Another challenge for effective NPD team formation, a subject of recent focus, is to select members who work cooperatively (Fernández, Luisa Del Río, Varela, & Bande, 2010; Hoegl & Proserpio, 2004; Millson & Wilemon, 2006; Ozer, 2003), because numerous activities are heavily dependent on human flexibility in the practice of modern project management. Additionally, one of the distinctive characteristic of an NPD team is good interpersonal relationships among the members that lead to better decisions (Badrinarayanan & Arnett, 2008). Because the NPD team members come from different departments and have different background knowledge, skills and experience, as well as personality characteristics, it is difficult for these members to coordinate with each other (Chen, 2007). However, it has been observed that personality characteristics will directly affect the team performance through individual behavior and indirectly improve performance through the good cooperation of suitable members (LePine, Buckman, Crawford, & Methot, 2011). Using a Big Five Factor model, the research of Reilly, Lynn, and Aronson (2002) focused on the relationships between the team members’ personality and cooperation performance in NPD projects, and found that heterogeneity of personalities will boost cooperative relationships and lead to better decisions and more creative ideas (Reilly et al., 2002). Chen and Lin (2004) suggest that the differences in the team members’ personality types reflect their differences in behavior in the workplace, which could lead to good or bad cooperation among them. Consequently, the personality types of the members must be taken into account to assemble a cooperative team (Chen & Lin, 2004). Therefore, an effective approach is needed to model interpersonal relationships for the purpose of evaluating cooperation between team members.

In the related literature on team formation, we found that fuzzy methods and the Analytic Hierarchy Process (AHP) are generally used in assessing the capabilities candidates (Hlaoittinun, Bonjour, & Dulmer, 2008; Tseng, Huang, Chu, & Gung, 2004; Zakarian & Kusiak, 1999). However, in using fuzzy methods, it is difficult at times to determine the fuzzy membership functions because the lower and upper bounds of the functions are uncertain. Moreover, in the traditional AHP method, crisp numerical scales of 1–9 are used to describe the preference and judgments of experts (Zakarian & Kusiak, 1999). In practice, however, natural language is more often applied in those decision processes because crisp values fail to reflect the expert judgments and can cause imprecision. Furthermore, in the traditional AHP method, substantial time is required to consider \( n(n - 1)/2 \) pairwise comparisons in a hierarchy structure with \( n \) criteria, and it is often difficult to maintain the consistency of the evaluations. Therefore, we implement a fuzzy Analytic Hierarchy Process (AHP) method based on fuzzy linguistic preference relations (Fuzzy LinPreRa) for assessment of the comprehensive capabilities of candidates (Wang & Chen, 2008). Only \( n - 1 \) pairwise comparisons are needed in a structure with \( n \) criteria, and the judgment matrix is constructed by adding the missing values according to the additive reciprocity and additive consistency. This method will be fully described in Section 2.1.

In addition, as mentioned above, cooperation between the team members is an indispensable factor that must be considered in the process of NPD team formation, and the members’ personalities have a major impact on the team cooperation. However, the members’ personalities are normally difficult describe numerically. Therefore, we employ the approach of modeling the members’ personalities based on the Myers-Briggs Type Indicator (MBTI), as proposed by Chen and Lin (2004) (Chen & Lin, 2004). The MBTI is used to profile the members’ personalities, and quantitatively predict their cooperative abilities (or interpersonal relationships) based on the personality relationships described in the MBTI. We will present this approach in Section 2.2.

In this paper, we propose a multi-objective optimization model for NPD team formation that addresses the comprehensive capabilities and interpersonal relationships of the candidates in the early stage of the project. The candidates come from different functional departments in an organization, and the process of team formation involves the selection of members that best satisfy the requirements of the NPD team. In a review of the current literature on team formation and related team allocation problems, we found that many models have been proposed, and a variety of algorithms have been used to solve these models, including Linear Programming (LP) (Chen, 2007; Chen & Lin, 2004; Zakarian & Kusiak, 1999), Heuristic (Fitzpatrick & Askin, 2005), Simulated Annealing (SA) (Baykasoglu, Dereli, & Das, 2007), the Multi-objective Genetic Algorithm (MOGA) (Fan, Feng, Jiang, & Fu, 2009; Feng, Jiang, Fan, & Fu, 2010) and the Multi-objective Particle Swarm Optimization (MOPSO) algorithm (Abdelsalam, 2009; Yang & Chou, 2011). These examples indicate that intelligent algorithms are applicable for dealing with team formation problems. However, the strategy of most of the proposed algorithms is to convert a multi-objective into single objective problem by assigning a utility function or giving weights to every objective, which causes the multi-objective optimization to lose much of its significance (Baykasoglu et al., 2007; Chen, 2007; Chen & Lin, 2004). In many circumstances, project managers or other decision-makers prefer to have different team composition alternatives so that the team can be flexible in dealing with situations in which the team members are unexpectedly unavailable for the projects. In this paper, we use the MOPSO algorithm to search for the Pareto optimal solutions of the multi-objective model (Coello Coello & Lechuga, 2002). This method runs faster and uses fewer parameters than the MOGA is thus suitable for solving problems with discrete decision variables (Kennedy & Eberhart, 1997).

The reminder of the paper is organized as follows. Section 2 presents the theoretical background of the team formation model, and the fuzzy AHP method based on Fuzzy LinPreRa and the interpersonal relationship evaluation based on the MBTI are also fully explained in this section. The problem statement and a multi-objective model for project team formation are presented in Section 3. Section 4 demonstrates the application of the model and the MOPSO algorithm in a real world example of an NPD project. Finally, the main conclusions are summarized in Section 5.
2. Theoretical background of new product development team formation

2.1. The fuzzy AHP method based on Fuzzy LinPreRa

The selected team members’ capabilities must meet the requirements of the NPD teams. For this goal G, we assume that there are m candidates (alternatives) available for selection, and the evaluation criteria of the candidates’ capabilities are C1 to Cn. A fuzzy AHP method based on Fuzzy LinPreRa is used to relate the candidates to the goal, and to decide on each candidate’s fuzzy weight in comparison with that of the others. The application procedure is as follows:

Step 1: Establishment of a Hierarchy Structure

If we position the goal G at the top layer of the hierarchy structure, and the evaluation criteria in the middle layer, then the alternatives will be located on the bottom layer (Fig. 1).

Step 2: Construction of the fuzzy judgment matrix Ď

The fuzzy judgment matrix consists of the pairwise comparisons of each evaluation criterion or alternative. The evaluation experts use natural language to express their preferences for each criterion and alternatives over others. The linguistic variables in the linguistic set S = {VP, P, MP, M, MG, G, VC} are used to describe the preferences. For example, constructing the fuzzy judgment matrix using the following equations (propositions can be referred to (Wang & Chen, 2008)):

\[
\begin{align*}
D^{ij} &= \frac{x_{ij}^L + x_{ij}^C + x_{ij}^U}{3}, & x_{ij}^L < x_{ij}^C < x_{ij}^U, \\
&= \frac{0 + x_{ij}^C + x_{ij}^U}{2}, & x_{ij}^L = x_{ij}^C = x_{ij}^U.
\end{align*}
\]

where the linguistic variable \(x_{ij}\) denotes the experts’ preference for the jth criterion over the jth alternative, \(\tilde{D}\) is represented by a triangular fuzzy number (TFN) \((x_{ij}^L, x_{ij}^C, x_{ij}^U)\). If the values of \(x_{ij}\) are not in the interval \([-c, 1 + c][c > 0]\), then the transformation functions (Eq. (5)) are needed to transform the obtained fuzzy numbers to maintain consistency:

\[
f(x_{ij}) = \frac{x_{ij}^L + c}{1 + 2c}, \quad f(x_{ij}^C) = \frac{x_{ij}^C + c}{1 + 2c}, \quad f(x_{ij}^U) = \frac{x_{ij}^U + c}{1 + 2c}
\]

where \(c = \frac{1}{1 + \frac{1}{2} - \min x_{ij}}\).

Step 3: Calculation of the fuzzy weights of each criterion

The fuzzy weights of each criterion are calculated as follows (with \(c_1 = \frac{1}{1 + \frac{1}{2} - \min x_{ij}}\)):

\[
\bar{w}_i = \frac{\sum_{j=1}^{n} \tilde{D}_{ij} \cdot \tilde{r}_{ij}}{n}, \quad \bar{A}_i = \frac{\sum_{i=1}^{n} \bar{w}_i}{n}
\]

Step 4: Alternative ranking

The fuzzy weight of each alternative on the goal G is determined by Eq. (7):

\[
\bar{U}_l = \frac{\sum_{j=1}^{n} \bar{w}_j \cdot \tilde{r}_{lj}}{n}
\]

where \(\bar{U}_l\) is the fuzzy weight of the jth alternative on the jth criterion. Notably, \(\bar{U}_l\) is also a TFN \((\bar{U}_l^L, \bar{U}_l^M, \bar{U}_l^U)\), and is defuzzied using Eq. (8):

\[
\mu(U_l) = \frac{(l + m + u)}{3}
\]

where \(\mu(U_l)\) is the fuzzy mean of \(U_l\). Next, we rank the fuzzy numbers \(\bar{U}_1, \bar{U}_2, \ldots, \bar{U}_m\) according to the fuzzy mean \(\mu(U_l)\) to decide on the optimal alternatives.

2.2. Interpersonal relationship evaluation based on the MBTI

The MBTI is a personality assessment instrument based on psychological type theory, which was proposed by Swiss psychologist Carl Gustav Jung. Myers and Briggs extended Jung’s theory and put it into practice. After 50 years of development and improvement, the MBTI has become one of the most famous personality assessment instruments in the world and it has a wide range of applications in the areas of career planning, senior management training, team building, and group dynamics research.

The MBTI consists of four personality scales, each with a pair of opposite preferences. The four pairs of preferences are: (1) Extroverts or Introverts, according to where an individual confines his/ her attention and gains strength; (2) Sensors or iNtuitives, according to how an individual prefers to acquire information; (3) Thinking or Feeling, according to how an individual prefers to arrive at information; (4) Judging or Perceiving, according to how a person

![Fig. 1. Analytic hierarchy structure.](Image)
interacts with the outside world. It is assumed that all of these preferences exist in every person’s personality, but an individual prefers one over the other in each of the four pairs. Therefore, a person’s personality type is specified by combining the four preferences in each pair. For example, a person with an ENFP personality type refers to the combination of Extroverts, iNtuitives, Feeling and Perceiving. The personality types are tested using the MBTI form M, which consists of 93 questions, and the preferences of the respondents are identified by analyzing their answers (Myers, 2003).

The best teams share one thing in common: their members have complementary preferences on the Sensors/iNtuitives (S/N) and Thinking/Feeling (T/F) scales and similar preferences on the Judging/Perceiving scale. People who differ in Sensors/iNtuitives alignment as well as Thinking/Feeling complement each other in making decisions and managing problems, which leads to more favorable results. People similar in their Judging/Perceiving preferences will facilitate understanding and communication, and tend to share common interests (Chen, 2005; Chen & Lin, 2004). According to the theory, the relationships among different personality types can be positive, neutral, and negative and are shown in Table 1.

The positive, neutral, and negative relationships are modeled by assigning numeral representations of +9, +3, and −3, respectively. For example, the interpersonal relationship value between an ENFP and an INTP is 24 (3 + 3 + 9 + 9). Moreover, the maximum value among of all the relationships is 36 (e.g., ESTJ and ENFJ), and the minimum is 0 (e.g., ISTJ and ISTP). Therefore, each value of these relationships is normalized into the interval [0,1] by dividing by 36. The normalized interpersonal relationship scaling matrix is presented in Table 2.

Therefore, in the process of NPD team formation, the MBTI personality types of all team candidates are tested by the MBTI form M, and their interpersonal relationships are estimated using the normalized interpersonal relationship scaling matrix.

### 3. Multi-Objective NPD team formation model formulation

#### 3.1. Problem statement

This paper focuses on the formation of an NPD team that works effectively and cooperatively in the early stages of projects. Given a set of team candidates, a requirement exists to select the members with high levels of comprehensive capabilities, as well as good interpersonal relationships. In this case, we must produce a quantitative evaluation of the team candidates. This problem scenario makes several assumptions. First, the evaluation experts are assumed to be familiar with all of the candidates, and therefore they are able to give objective and accurate evaluations of all candidates. Additionally, it is assumed that the candidates’ personality types can be measured by the MBTI Form M. It is also assumed that the selection pertains to equal team members, which means that there are no subgroups or hierarchies among the team members. Moreover, we assume that direct communications occur among the team members during the project period. In certain cases, the NPD team size is large, and it is possible that certain members are not required to have face-to-face contact with other members or will have contact through other people instead. However, in other cases, the team size is relatively small, and the project period is often more than 6 months. Therefore, team members may interact dyadically during the project period. Furthermore, it should be noted that the building of an effective NPD team is a dynamic process and requires continuous efforts in training the team and establishing business rules and team procedures. However, in this paper, we focus on the selection of the desired team members in the early stage of project. In other words, we focus on how to identify the most competent and cooperative team members to assemble a team that is potentially effective for the NPD project, and thus the process of team building or development is not considered in this work.

#### 3.2. Multi-objective NPD team formation model

The NPD team formation model is formulated based on the characteristics of effective NPD teams. The objectives are: (1) to select the team members that best meet the requirements of the NPD project, i.e., the members with the highest fuzzy weights relative to this goal; (2) to select the team members that have the best interpersonal relationships with others within and between departments. The objectives are denoted by $f_1$, $f_2$, and $f_3$ consists of interpersonal relationships within departments and relationships between departments. Eq. (11) states that the number of person selected should be equal to the number of persons required in each department, and Eq. (12) denotes the constraint that the number of persons selected in the departments must meet the requirements of the NPD team.

### Table 1

Relationships among different personality types.

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The fuzzy AHP method based on Fuzzy LinPreRa is used to calculate personal relationships with other team members at the same time. fulfilling the product development tasks and maintaining good interdepartmental relationships. In each department, and the team requirements from each department and person according to the activities of the new construction machinery design, engineering, finance, and marketing departments be implemented using a NPD team whose members come from the design, engineering, finance, and marketing departments.

The proposed model includes the following notations:

- \( n \): Number of departments;
- \( p_i \): Number of members required for the team from the \( i \)th department;
- \( m_i \): Number of persons available for selection from the \( i \)th department;
- \( w_{iq} \): Fuzzy weight of the candidates’ capabilities relative to the \( i \)th department;
- \( r_{iqj} \): Interpersonal relationship between person \( q \) from the \( i \)th department and person \( t \) from the \( j \)th department;
- \( y_{iqj} \): 1 if person \( q \) from the \( i \)th department is selected for the team and 0 otherwise; these are the decision variables in the model.

4. Illustrative case

A manufacturer of construction machinery intends to upgrade the current products to meet an increased market demand and enhance the competitiveness of the company. The company plans to integrate newly introduced technologies into its existing construction machinery and develop a new series of products. One of the company’s senior managers is designated as the manager of this new product development project. An executive meeting is held to specify the development process as follows: (1) product demand analysis and product development goals definition; (2) preliminary scheme design and review; (3) implementation of preliminary scheme design and verification; (4) final detailed design specification; (5) production of technical documentation. The project will be implemented using a NPD team whose members come from the design, engineering, finance, and marketing departments according to the activities of the new construction machinery development process. Table 3 shows the number of available people in each department, and the team requirements from each department.

For the purpose of assembling an effective NPD team, the team members must be selected who possess the capabilities required to fulfill the product development tasks and maintain good interpersonal relationships with other team members at the same time. The fuzzy AHP method based on Fuzzy LinPreRa is used to calculate the fuzzy weights of the team candidates according to the following four evaluation criteria: Expertise and experience (C1); Learning and knowledge sharing (C2); Communication (C3); and Problem solving (C4). First, the evaluation experts use the linguistic variables in Table 4 to express their preferences on the team candidates.

Table 5 shows the expert preferences for each criterion relative to the project team requirements (Goal).

Tables 6–9 display the expert preferences for each candidate in the associated departments according to the four criteria. The team candidates are coded using their home departments plus numbers.

Each candidate’s fuzzy weight is calculated using the fuzzy AHP method based on Fuzzy LinPreRa, and the results are shown in Table 10. Moreover, the MBTI personality types for the team candidates are tested using the MBTI Form M; the test results are also presented in Table 10.

Once the available data for the proposed multi-objective NPD team formation model are collected, the MOPSO algorithm is implemented to solve the model.

First, we define a particle (solution) in the algorithm. For all departments, the binary value 1 or 0 is used to denote whether a candidate is chosen or not chosen for the team, respectively. For example, in the design department, assume that D3, D6, and D8 are chosen, and their values are 1; the remaining persons are not chosen, and therefore their values are 0. Therefore, [0 0 1 0 0 1 0] represents a piece of the feasible solution of the model. A particle or a feasible solution is formed by combining the results of the choices of all departments. Fig. 2 provides an example of a particle in the model.

Next, we define the fitness function in the algorithm according to Eq. (14):

\[
\text{Fitness}(x) = \text{Fitness}_1 + \text{Fitness}_2
\]

where

\[
\text{Fitness}_1 = \sum w_{iq}y_{iqj}
\]

and

\[
\text{Fitness}_2 = \sum r_{iqj}y_{iqj} + \sum y_{iqj}
\]

The objective of the algorithm is to minimize the fitness function to find the best feasible solution.
Fitness = \( w_1(-f_1)/(\lambda_{\text{max}} - \lambda_{\text{min}}) + w_2(-f_2)/(\theta_{\text{max}} - \theta_{\text{min}}) \)  

(14)

where \( \lambda_{\text{max}} \) and \( \lambda_{\text{min}} \) represent the maximum and minimum values of \( f_1 \) without considering \( f_2 \). Additionally, \( \theta_{\text{max}} \) and \( \theta_{\text{min}} \) represent the maximum and minimum values of \( f_2 \) without considering \( f_1 \). We use Dynamic Weighted Aggregation (DWA) to change the weights of the two objective functions, and the objective weights \( w_1 \) and \( w_2 \) are gradually modified according to Eq. (15):

\[
\begin{align*}
  w_1 &= n/F \\
  w_2 &= 1 - w_1
\end{align*}
\]

(15)

where \( F \) is the change frequency, and \( n \) is the frequency index.

Next, we implement the MOPSO algorithm to solve the model, and the flows are shown in Fig. 3.

The renewed velocities of the particles are calculated using Eq. (16):

\[
V = w \times V + c_1 \times R_1 \times (\text{Pbest} - X) + c_2 \times R_2 \times (\text{Gbest} - X)
\]

(16)

To ensure that the positions of renewed particles are 0 or 1, we apply a sigmoid function (Kennedy & Eberhart, 1997) (Eq. (17)):

\[
S_i^t = \frac{1}{1 + \exp(-V_i^t)}
\]

(17)

For a particle \( X_i^t \) (\( t \) is the dimension of \( X_i \)), if the velocity is \( V_i^t \), then \( S_i^t \) can be attained from Eq. (17). Next, \( S_i^t \) is compared with a random number \( S_{\text{rand}}^t \) between 0 and 1; if \( S_i^t > S_{\text{rand}}^t \), then \( X_i^t = 1 \); otherwise, \( X_i^t = 0 \).

However, the updated particle \( X_i \) may be unfeasible because it is determined by comparison between \( S_i^t \) and a random number \( S_{\text{rand}}^t \). Therefore, we use a Judge-and-Repair strategy in the flow (see * in Fig. 3) to determine whether \( X_i \) (which is consists of four pieces) is in the search space. If it is not, we repair it using the following strategy. Assume that the number of the variable 1 in the kth piece of \( X_i \) is \( x_{ik} \), the number of the variable 1 in the kth piece of updated \( X_i' \) is \( \beta_k \), making \( n = x_{ik} - \beta_k \). If \( n = 0 \), the piece in the updated particle is feasible because it satisfies the constraint. If \( n > 0 \), we change \( n \) random positions with variable 1 into 0, and if \( n < 0 \), we change \( n \) random positions with variable 0 into 1.

We set the change frequency \( F \) to 200, and the size of the particle swarm and the maximum iteration as 50 and 1000, respectively. Fig. 4 shows that \( w_1 = w_2 = 0.5 \) represents the fitness values of the best particle in every iteration. With the use of the sigmoid function in the MOPSO, we can achieve a notably good convergence.

Table 7

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Table 8

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Table 9

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<th>M3:M4</th>
<th>M4:M5</th>
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Table 10

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<th>F1–F7</th>
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<td>Finance</td>
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Fig. 2. An example of a particle (solution).

Fig. 3. The MOPSO algorithm flow.
The challenges of carrying out a successful NPD project in changing and uncertain competitive environments have underscored the demand for the cross-functional expertise of team members. In this scenario, the primary challenge is how best to assemble a cross-functional team that works effectively and cooperatively. Therefore, it would be greatly helpful if an effective procedure existed for team formation in the early stages of a project. The proposed multi-objective team formation optimization model considers both the members’ comprehensive capabilities and their interpersonal relationships. The use of the fuzzy AHP based on Fuzzy LinPreRa in the capability ratings ensures the precision and consistency of the evaluation, and shortens the time required for decision-making. Additionally, the assessment of personality relationships based on the MBTI in the interpersonal relationships ratings facilitates the numerical descriptions of team cooperation in the proposed model. The illustrative case demonstrates that the use of the MOPSO algorithm to search for optimal team combinations aids in accelerating the process of NPD team formation, and the produced Pareto solutions correspond more exactly to the practical needs. Additionally, the NPD team formation model is easily extended to other team-based projects.

5. Conclusion

The result of the proposed MOPSO algorithm is shown in Fig. 5. A Pareto front exists such that each solution identifies an optimal candidate combination option. Several samples of these solutions are shown in Table 11, which are subsequently used to support the project manager and the panel of experts in choosing a NPD team composition that best fits their requirements. For example, if they choose \( w_1 = 0.4, w_2 = 0.6 \), and the objective function \( f_1 = 2.1982 \) and \( f_2 = 32.1300 \), then the team composition is: design department D5, D7 and D8; engineering department E2, E4 and E5; finance department F2 and F4; and marketing department M1 and M2.

### Table 11

<table>
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<tr>
<th>( w_1 )</th>
<th>( w_2 )</th>
<th>( f_1 )</th>
<th>( f_2 )</th>
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<td>0.6</td>
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<td>32.1300</td>
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<tr>
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<td>0.5</td>
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<tr>
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Fig. 4. The fitness values of the best particle in every iteration (\( w_1 = w_2 = 0.5 \)).

Fig. 5. Trade-off between members’ comprehensive capabilities and interpersonal relationships in the model.

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### Acknowledgements

### References


