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Designing and explaining the teamwork assignment model for new product development with a focus on improving the level of productivity

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Abstract

Companies are desperately seeking a competitive advantage in today's fast-paced business world to outperform their rivals. Competition with the rate of rapid change in technology has made the issue of new product development in a competitive market important. One of the factors that effectively play a role in the new product development process, especially when competition, flexibility and product diversity are important, is the employment of work teams. Considering the importance of the subject, this study aims to present a new model of team assignment for new product development with a focus on improving the level of productivity. In this research, mathematical modeling logic has been used. Furthermore, the research model is a Multi-Objective Integer Linear Programming (MOILP) model and because discrete variables exist, the solution space is not continuous and convex but discrete and thus non-convex. Thus, the problem is NP-hard in terms of complexity. In the end, according to various factors for the assignment of human resources in new product development processes, a multi-objective mathematical model was designed to reduce costs, control wage rates, reduce work process time, and maximize productivity in the production system.

Keywords: New product development, Teamwork assignment, Productivity, Meta-heuristic algorithm
2020 MSC: 68T20, 78A97, 78M32

1 Introduction

Companies today face fierce competition in both domestic and international markets. With the rate of rapid technological change, the issue of New Product Development (NPD) in a competitive market has become crucial. The primary motivation for introducing a new product is to address various aspects of customer demands and needs. The amount of money spent on new product development to catch up to competitors is a function of the company's current and strategic position in the demand market [11]. Companies stop producing and supplying some products or make necessary changes to respond to environmental changes as effectively as possible. They also undertake new product development in response to identify the needs and wants of consumers in various markets to meet needs, maintain long-term business, and increase the company's economic prosperity. Thus, new product development is an essential component of any company's operations [2].

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Human resources are found to be crucial in the development of new products, according to research. Thus, today's project managers for new product development are thinking about how to use human resources effectively to achieve their business goals [5]. Most new manufacturing systems necessitate a high level of participation, and management concepts are more likely to succeed in structured work teams [1]. The activity of new product development processes has shifted from exclusive management with win-loss relationships to participatory management with win-win relationships, according to the business history of businesses. One of the most significant reasons for this shift is a shift in the management approach used in the new product development process [19, 21]. Many organizations have taken steps to properly allocate the workforce in projects because of these experiences [20]. According to research, proper teamwork assignment boosts process productivity, boosts labor morale, and streamlines management efforts [12]. The main approach investigated in this study is an appropriate teamwork assignment in the new product development process. From a process standpoint, it attempts to study how to properly allocate the workforce by providing a suitable mechanism to minimize work process time and cost and maximize productivity of a production system. Much attention has been paid to the growth, development, and domestic empowerment of the national pharmaceutical industry due to the growing role and impact of new pharmaceutical products on public health and barriers to drug production, such as high drug costs, unavailability, and new requirements for international trade, investment, and intellectual property laws. Thus, both a theoretical and practical perspective is discussed on how to manage new product development teams to achieve high productivity due to the high cost of drug production, resource constraints, and time constraints in new product development management. This study has attempted to provide a teamwork assignment model in new product development that is efficient and effective. There is no comprehensive model that considers the various dimensions of teamwork assignment to date. In this regard, it aims to answer the question: "What are the target functions of the teamwork assignment model for new product development with the focus on improving productivity?".

2 Theoretical foundations and research background

2.1 New product development:

It is a process in which a new product or service is introduced to the market. The term new product development is used for products that are generally new in the world and apply minimal improvements and changes to existing products [7]. Types of new product development are classified into six groups based on the degree of novelty. According to Ringen, Holtskog and Martinsen (2012), the typology of new product development types can be displayed based on Table 1 [16].

Table 1: Typology of new product development types

	Low	New to the company	High
High	New to the company		Being new to the world
New to the company	Product improvement	Adding to production lines	
Low	Reduce costs	Repositioning	

2.2 Productivity:

Productivity is used in the word to mean the power of production and being fertile and productive. Productivity is the result of the fraction obtained by dividing the amount or value of the product by the amount or value of one of the factors of production.

2.3 Work team:

A work team consists of a small group of people who are responsible for performing a series of complementary tasks and are all committed and responsible for achieving a common goal. In another definition, a team is a group of people who have different characteristics and work together to achieve organizational goals independently of each other. In another definition, a team is a set of at least two colleagues, with different tasks [10].

2.4 Background Research

One of the most important issues in the field of new product development and manufacturing is the labor allocation approach, which has been investigated in this study. Thus, a summary of the most important research conducted in this field, with an emphasis on productivity, is presented in this section for a review of the problem and to analyze different strategies. The labor allocation approach is reviewed first in this section, followed by examining various labor allocation strategies. After that, different criteria are used to examine labor allocation in new product development processes.

As part of their research on workforce allocation in work teams, Askin and Fitzpatrick [9] proposed an integer linear programming model for forming effective human teams in cell production design. Team members are chosen to cover the necessary technical skills in this model. Mohaghar and Mostafavi [14] presented a model for workforce allocation in another study. Human interactions are not considered in this model, but the proportion between project objectives and the skills of individuals in teams, as well as the appropriate allocation to meet project goals, are. The required activities and skills, the duration of activities, the costs of each person, and the program of allocating people to the project were all performed in this study. The mathematical model used in the study sped up delivery and cut costs.

In new product development projects, Chang et al. [4] focused on labor knowledge and used this perspective to transform the work process faster and more smoothly. Patanakul et al. [15] emphasized the importance of independent teams in new product development projects in another study. Carbonell and Rodriguez [3] investigated the formal and informal management of new product development teams, finding that management style influenced team job satisfaction. A multi-objective programming model with integers zero and one has been used. Feng Bo et al. [8] is another study that did a good job of allocating the workforce to work teams. The method for selecting members of mid-functional teams is presented in this study, which takes into account both individual performance and collaboration performance between members (both inside and outside the organization). A multi-objective programming model with integers zero and one has been used. Baysan et al. [2] proposed a new, all-encompassing approach to labor allocation in the new product development process. The findings showed that the formation of work teams and labor allocation leads to a reduction in delivery time when compared to traditional contract methods. Yilmaz et al. [22] conducted a study in a high-tech company. This study examines a lean fuzzy methodology for new product development to deal with project uncertainty, with a focus on multi-skill labor and its impact on delivery time and costs. The results show that using the concept of employing a skilled workforce, the proposed method reduces delivery time and operating costs simultaneously.

3 Research method and presentation of the proposed model

In this research, a mathematical model for the design problem of new product development is presented. Meta-heuristic methods are also used to find a solution close to the optimal solution according to the optimization criteria for the given problem. We also introduce the parameters of the problem, including the input parameters of the presented model and the decision variables, and finally we present the objective function of the problem along with the defined constraints.

3.1 Assumptions

- There are number of human resources I are available to carry out the new product development process.
- In the new product development process, a set of expertise is needed.
- Each workforce can have more than one specialization.
- Every workforce has a skill level.
- The duration of task depends on the skill level of human resources.
- The total time allocated to the workforce should be less than the time available to him.
- A profile has been defined for each task, which indicates the skill level of human resources.
- The skill level of each workforce is known.
- Five skill levels are defined for each specialty. 1 is the lowest skill level and 5 is the highest skill level.
- The wage rate of each workforce is proportional to the skill level of the person in that task.

3.2 Mathematical Modeling

3.2.1 Indexes and Sets

I	Set of workforce members available	$i \in \{1, 2, \ldots, n_I\}$
J	Set of expertise required for project	$j \in \{1, 2, \ldots, n_J\}$
P	Set of products	$p \in \{1, 2, \ldots, n_P\}$
K	Set of skill levels in expertise	$k \in \{1, 2, 3, 4, 5\}$
D	Set of departments	$d \in \{1, 2, \ldots, n_D\}$
Q	Set of the number of members required to form a team	$q \in \{1, 2, \ldots, n_Q\}$
M	Set of the number of members needed to form a team	$m \in \{1, 2, \ldots, n_M\}$

3.2.2 Parameters

N_{ij}	The number of workforces i with expertise j
Q_d	The number of workforces required to form a team from each unit
M_d	The number of workforces available to form a team in each unit
T_{jkpd}	Average time required (man-hours) to perform specialization j with skill level k for product development pr
AT_i	Workforce available time i
K_{ij}	Skill level of workforce i with expertise j
NS_{ij}	Skill level required of workforce i to perform expertise j
R_{ijkpd}	Efficiency rate of workforce i to perform expertise j with skill level k for product development process p in d
FC_i	The fixed cost of workforce i selected for the product development process
RPH_{ijk}	Wages of workforce i per hour of task performance to perform expertise j with skill level k
C_{ijk}	Cost of training workforce i to acquire skill level k to perform expertise j
B_{ijk}	The time required to train (to have the desired skill level) workforce i to obtain the skill level k to perform t
T_{total}	Total training time available for all available workforces to form the team
T^{Max}	Maximum training time for all workforces
T^{Min}	Minimum training time for all workforces
C_{labor}	Maximum cost of workforce
C_{Budget}	Maximum cost of workforce training
CIT_i	Cost of idle time per hour for selected workforce i
IT_i	Idle time of workforce i
M	Large positive number
α_k	The ratio of completing a task at skill level k to completing that work in standard skill level
h_{ijkpd}	The cost of hiring i with expertise j with technical skill level k for product development process p in depart
f_{ijkpd}	Cost of firing manpower i with expertise j with technical skill level k for product development process p in c

3.2.3 Decision variables

X_{ijkpd}	If workforce i with expertise j with technical skill level k is assigned to product development process p from d
t_{ijkpd}	The amount of time allocated (person-hours) to workforce i with expertise j with skill level k for the product

3.2.4 Objective Functions

$$\begin{aligned} Min\, F_1 = & \sum_i \sum_j \sum_k \sum_p \sum_d FC_i . X_{ijkpd} \\ & + \sum_i \sum_j \sum_k \sum_p \sum_d RPH_{ijk} . t_{ijkpd} \\ & + \sum_i \sum_j \sum_k \sum_p \sum_d CIT_i . IT_i , X_{ijkpd} \\ & + \sum_i \sum_j \sum_k \sum_p \sum_d C_{ijk} . X_{ijkpd} \\ & + \sum_i \sum_j \sum_k \sum_p \sum_d h_{ijkpd} . X_{ijkpd} \\ & + \sum_i \sum_j \sum_k \sum_p \sum_d f_{ijkpd} . X_{ijkpd} \end{aligned} \tag{3.1}$$

$$Max\,F_2 = \sum_i \sum_j \sum_k \sum_p \sum_d K_{ij}, \frac{\alpha_k.t_{ijkpd}}{T_{jkpd}} \tag{3.2}$$

$$Max\,F_3 = \sum_i \sum_j \sum_k \sum_p \sum_d N_{ij}, K_{ij}.R_{ijkpd}.X_{ijkpd} \tag{3.3}$$

The objective function 3.1 aims to reduce the costs of human resources, the meaning of costs is fixed, variable and other costs. The first part is related to the fixed costs for the new product development process. Fixed costs are fixed regardless of the company's activities. The second part of the function includes costs that are related to the cost of wages. The salary cost includes all the salaries and benefits that the specialist receives for performing his tasks. Reduction of personnel costs, according to the assumptions of the problem and the level of difficulty of the activities in the projects and the different rate of the wage cost of each person. In this research, skill level-based payment system is used to calculate wages as variable cost. Variable costs change as activities change during the process. Due to the recent changes in technology, most companies are increasingly focusing on the productivity and quality of human resources. In the third part, the cost of idle time of the selected workforce is calculated, which is considered as a variable cost at the end of the process. The fourth part shows the minimization of training cost. The cost of training includes in-service training of employees. In the above optimization model, the fifth and sixth parts show the cost of recruiting and adjusting human resources.

The objective function 3.2 aims to maximize the skill level for the specialties used in all departments. This function selects the workforce that has the highest skill level to perform the specialization based on the time allocated to the candidate.

In the objective function 3.3 the maximization of efficiency is obtained based on the allocation of workforces according to the level of technical and specialized skills and the efficiency rate of the desired human resources to perform task.

3.2.5 Constraints

$$\sum_{i=1}^{M_d} X_{ijkpd} = Q_d, \qquad \forall d \tag{3.4}$$

$$q = \sum_{d=1}^{n_D} Q_d \tag{3.5}$$

$$\sum_j X_{ijkpd} \geq 1, \qquad \forall i, k, p, d \tag{3.6}$$

$$\sum_k \sum_j \sum_k X_{ijkpd} = 1, \qquad \forall i, p, d \tag{3.7}$$

$$NS_{ij} \leq \sum_j X_{ijkpd}.K_{ij}, \qquad \forall j, p, d \tag{3.8}$$

$$\sum_j \sum_k \sum_p \sum_d C_{ijk}.X_{ijkpd} \leq C_{Budget}, \qquad \forall i \tag{3.9}$$

$$\sum_j \sum_k \sum_p \sum_d B_{ijk}.X_{ijkpd} \leq T_{total}, \qquad \forall i \tag{3.10}$$

$$\sum_j \sum_k \sum_p \sum_d N_{ijk}.RPH_{ijk}.X_{ijkpd} \leq C_{Labor}, \qquad \forall i \tag{3.11}$$

$$T^{Min} \leq \sum_j \sum_k \sum_p \sum_d T_{jkpd}.X_{ijkpd} \leq T^{Max}, \qquad \forall i \tag{3.12}$$

$$\sum_i t_{ijkpd}.\alpha_k = T_{jkpd}, \qquad \forall j,k,p,d \tag{3.13}$$

$$t_{ijkpd} \le M, X_{ijkpd}, \qquad \forall i,j,k,p,d \tag{3.14}$$

$$\sum_j t_{ijkpd}.\alpha_k \le AT_i, X_{jkpd}, \qquad \forall i,k,p,d \tag{3.15}$$

$$AT_i \le IT_i, \qquad \forall i \tag{3.16}$$

$$\sum_k \sum_j \sum_k R_{ijkpd} \le 1, \qquad \forall i,p,d \tag{3.17}$$

$$t_{ijkpd} \in \{0,1\}, \qquad t_{ijkpd}, AT_i, T^{Min}, T^{Max} \ge 0. \tag{3.18}$$

Constraint 3.4 shows that the number of selected workforces should be equal to the number of personnel required from each department. Constraint 3.5 indicates that the number of people selected from each department should be equal to the number of new product development team requirements. Constraint 3.6 shows that each selected workforce is assigned to at least one expertise. Constraint 3.7 shows that every workforce has a skill level to perform each of the specializations. Constraint 3.8 guarantees that the selected workforce has the minimum required skill level k to perform the specialty j. Constraint 3.9 ensures that the total amount spent on training does not exceed the budget allocated for training. Constraint 3.10 states that the total time spent on labor training should not exceed the total training time allowed. In the constraint 3.11, the maximum cost for each labor is specified. Constraint 3.12 shows the minimum and maximum training time for allocation.

Constraint 3.13 determines the average time required to perform specialization j based on the skill level of the selected human resources. This limitation shows that the skill level of workforce is effective on the time of doing the activity until the end of the new product development process. Constraint 3.14 guarantees that the time allocated to each expertise in each department is limited. Constraint 3.15 indicates that the total time of each labor to perform the desired specialization in each department should be less than the available time of workforce. Constraint 3.16 guarantees that the idle time of labor does not exceed the available time of workforce. Constraint 3.17 expresses the maximum efficiency of workforce in the product development process in each department, which is equal to one. Having a picture of the state of efficiency can help decision makers in the direction of development goals and to eliminate inefficiency. Constraint 3.18 expresses the decision variables.

4 Problem solving approaches

In this section, the main concepts of optimization methods for problems with multiple objective functions, as well as the ϵ-constraint method, which is related to solving the proposed model, are presented. Also, the method of solving the proposed model in large dimensions will be explained through the NSGA-II algorithm.

4.1 Epsilon constraint method (ϵ-constraint)

The epsilon constraint method is one of the well-known approaches for dealing with multi-objective problems, which solves this type of problems by transferring all the objective functions except one of them to the constraint at each stage. The model of the upgraded epsilon constraint method to solve the minimization problem is as follows, where δ is a small number and r_i is the domain of the ith objective function:

$$\begin{aligned}
&Min\left(f_1(x) - \delta\left(\frac{s_2}{r_2} + \frac{s_2}{r_2} + \cdots + \frac{s_k}{r_k}\right)\right)\\
&S.T:\\
&f_2(x) + s_2 = \delta_2\\
&f_3(x) + s_3 = \delta_3\\
&\vdots\\
&f_k(x) + s_k = \delta_k\\
&x \in S, s_i \in \mathbb{R}^+
\end{aligned} \tag{4.1}$$

The proposed algorithm's steps are as follows:

1. Using the lexicography method, calculate the values of the final table.
2. Select one of the objective functions as the main objective function of the problem.
3. Extract the best and worst value of each sub-objective function in the results table (respectively, the highest and lowest value of the corresponding column in the results table in the maximization model).
4. Calculate the domain of each sub-objective function.
5. Divide the range of sub-objective functions into a predetermined number according to the number of desired Pareto solutions (each of the values resulting from this division is used as one of ϵ_i for the objective function f_i).
6. Put the original objective function as the objective function of the model and the other objective functions in the constraints as the model (20).
7. Solve the resulting model (20) for each of the values of $\epsilon_2, \ldots, \epsilon_k$ (the answers obtained for each of the values of $\epsilon_2, \ldots, \epsilon_k$ are one of the solutions of the Pareto problem).
8. Report the Pareto solutions to the problem [13].

4.2 Non-dominated Sorting Genetic Algorithm II (NSGA-II)

The NSGA-II algorithm is one of the most widely used and powerful multi-objective optimization algorithms available, and its effectiveness in solving a variety of problems has been demonstrated. Along with all the functions that NSGA-II has, it can be considered as the model for the formation of many multi-objective optimization algorithms. This algorithm and its unique way of dealing with multi-objective optimization problems have been used many times by different people to create newer multi-objective optimization algorithms. This algorithm is one of the most basic members of the collection of evolutionary multi-objective optimization algorithms, which can be called the second generation of such methods [6, 18].

4.2.1 Steps of NSGA-II algorithm

Step 1: Generate the initial population in this method as usual based on the scale and constraint of the problem.

Step 2: Assess the generated population in terms of defined objective functions, a schematic of which is shown in Figure 1.

Step 3: Apply the non-dominated sorting method.

Members of the population are divided into groups in such a way that those in the first category are completely non-dominated by the rest of the population. Thus, only the members of the first category dominate the members of the second category. This process is repeated in other categories to the point where all members of each category are assigned a rank based on their category number. Figure 2 shows a schematic of this step.

Step 4: Calculate a control parameter called crowding distance.

This parameter is calculated for each member in each group and represents a measure of the sample's proximity to the rest of the population. A large value for this parameter will result in divergence and a wider range of members in the population. Equation (21) is used to calculate a control parameter called crowding distance, as shown in Figure 3.

$$d_j\left(k\right) = \sum_{i=1}^{n} \frac{f_i\left(k-1\right) - f_i\left(k+1\right)}{f_i^{max} - f_i^{min}} \tag{4.2}$$

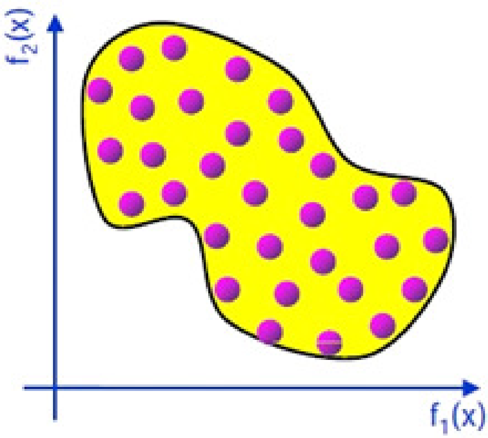

Figure 1: Schematic of the second step

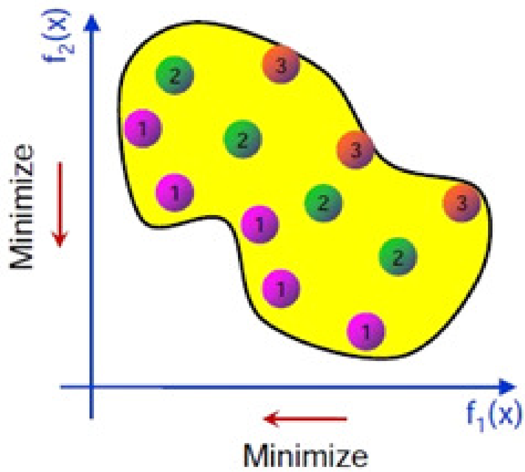

Figure 2: Schematic of the third step

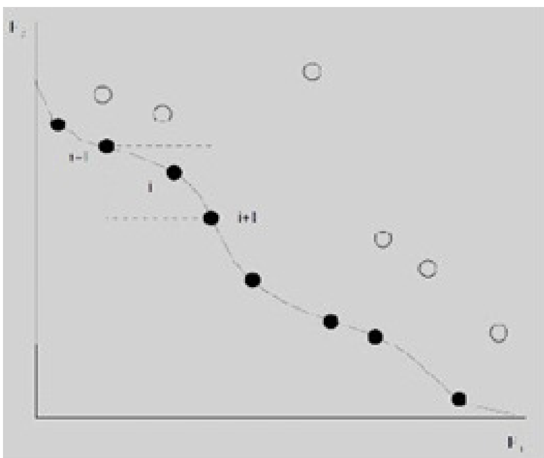

Figure 3: Calculation of a control parameter called crowding distance (Deb et al., 2000)

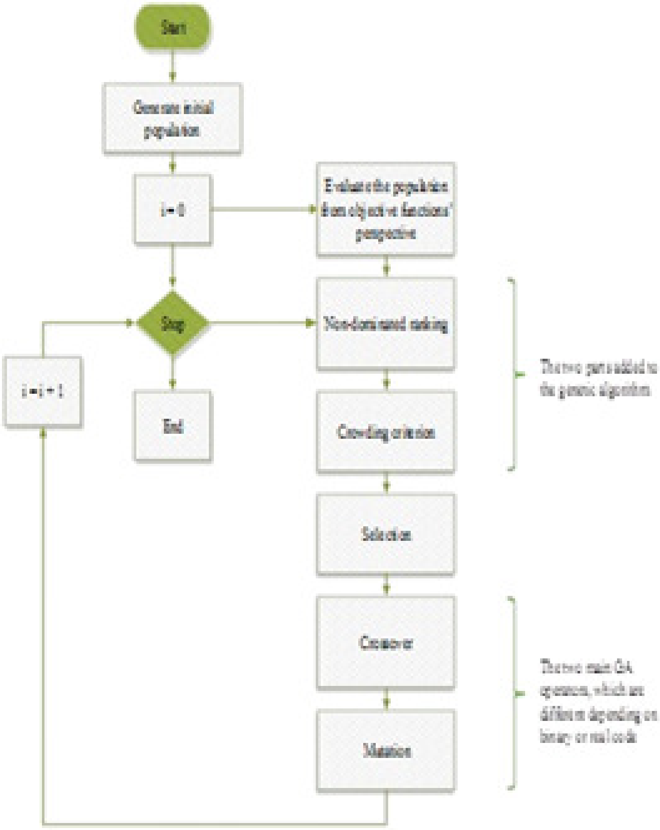

Figure 4: Performance of the NSGA-II algorithm [18]

Step 5: Select the parent population for reproduction.

One of the selection mechanisms is based on a double tournament between two members randomly selected from the population.

Step 6: Perform mutation and crossover.

Step 7: Combining the initial population and the population obtained from crossover and mutation.

Step 8: Replacing the parent population with the best members of the population combined in previous steps.

Step 9: All steps are repeated until the desired generation (or optimal condition).

Figure 4 shows the performance of the NSGA-II algorithm.

4.2.2 Comparison criteria for evaluating the quality of the solution

The proposed algorithm is evaluated using comparative criteria. In general, because convergence to Pareto optimal solutions and providing diversity among the resulting set of solutions are two distinct and somewhat contradictory objectives in multi-objective evolutionary algorithms, a criterion has yet to be developed that can decide on the performance of algorithms on its own. Because we have three objectives in this study, at least two criteria will be used to evaluate the algorithm's performance.

- **Mean Ideal Distance (MID):** This criterion calculates the average distance of Pareto solutions from the origin of coordinates.

- **Maximum spread or diversity (D):** The length of the space cubic diameter used by the final values of objectives for a non-dominated solution set, as proposed by Zitzler [23], is measured by this criterion. This criterion is equal to the Euclidean distance between two boundary solutions in the objective space, for example, in the case of two objectives. The criterion should be as broad as possible.

Table 2: Schematic of the third step

Department	The number of human resources required to form a team from each department (Q_d)	The number of human resources available in each department (M_d)
1	1	1
2	2	3

Table 3: Fixed costs of workforce for new product development (monetary unit per person)

Human resource	**1**	**2**	**3**	**4**
Fixed cost	1000	800	800	800

- **Spacing (S):** The relative distance between successive solutions, as proposed by Schott, is a criterion. The minimum value of the sum of the absolute values of the difference in the values of the objective functions between the ith solution and the solution in the final non-dominated set is called the measured distance. This criterion assesses how far different criteria deviate from each other. Because the value of S is small when the solutions are evenly spaced, an algorithm with small spacing values in its final non-dominated solutions is preferable [17].

- **Number of Pareto Solutions (NPS):** The NPS criterion indicates the number of Pareto optimal solutions that can be found in each algorithm.

- **CPU Time:** The CPU time of algorithms is among the most important performance indicators of any meta-heuristic algorithm.

5 Analysis of numerical results

The input values in the problem of teamwork assignment in the new product development process in a pharmaceutical company are shown in the following tables. In this problem, the coefficient of completing expert (α_k) at skill level k=1,2,3,4,5 is 0.1, 0.3, 0.5, 0.7 and 1 respectively. The required skill level is considered NS_{ij}=2 and the maximum cost of training and the maximum cost of human resources are 4000 and 50000 respectively.

Note: The time considered in the problem is based on 8 hours of work per day and every month equal to 22 working days.

In order to verify the correctness of the proposed model, the sample problem has been solved by the GAMS software with the upgraded epsilon-constraint method, and it was found that the mathematical model works intelligently.

Table 4: Skill level of workforce for new product development

Human resource	**Product**	**Workforce expertise**				
		1	**2**	**3**	**4**	**5**
1	1	4	3	-	-	-
	2	5	4	-	-	-
2	1	-	-	2	3	2
	2	-	-	2	3	3
3	1	-	-	3	4	4
	2	-	-	3	5	4
4	1	-	-	4	4	5
	2	-	-	4	5	4

Table 5: Variable workforce costs for new product development (monetary unit per person-hour)

Human resource	**Product**	**Workforce expertise**				
		1	**2**	**3**	**4**	**5**
1	1	60	70	-	-	-
	2	70	70	-	-	-
2	1	-	-	35	25	20
	2	-	-	30	30	20
3	1	-	-	25	35	35
	2	-	-	30	40	35
4	1	-	-	30	20	35
	2	-	-	30	40	35

Table 6: Workforce training costs for new product development (monetary unit per person)

Human resource	**Product**	**Workforce expertise**				
		1	**2**	**3**	**4**	**5**
1	1	50	60	-	-	-
	2	60	70	-	-	-
2	1	-	-	35	25	20
	2	-	-	30	20	20
3	1	-	-	25	35	35
	2	-	-	30	35	40
4	1	-	-	30	20	35
	2	-	-	25	20	30

Table 7: Time required for training human resources for new product development (person-hours)

Human resource	**Product**	**Workforce expertise**				
		1	**2**	**3**	**4**	**5**
1	1	10	12	-	-	-
	2	-	10	-	-	-
2	1	-	-	15	10	15
	2	-	-	15	10	10
3	1	-	-	7	6	6
	2	-	-	7	-	6
4	1	-	-	4	4	-
	2	-	-	5	-	4

Table 8: Level of efficiency of workforce for new product development

Human resource	**Product**	**Workforce expertise**				
		1	**2**	**3**	**4**	**5**
1	1	0.85	0.75	-	-	-
	2	0.95	0.90	-	-	-
2	1	-	-	0.55	0.65	0.55
	2	-	-	0.45	0.55	0.60
3	1	-	-	0.70	0.85	0.85
	2	-	-	0.75	0.95	0.90
4	1	-	-	0.70	0.70	0.95
	2	-	-	0.85	0.85	0.75

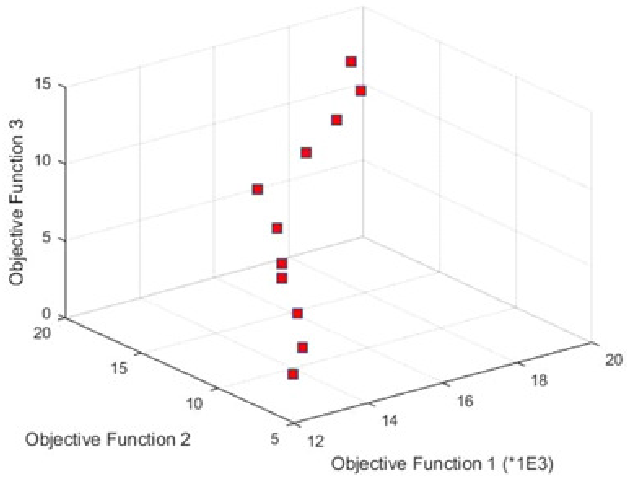

Figure 5: An example of the Pareto front obtained from the epsilon constraint method of the problem

Table 9: Idle time of human resources for the new product development process (hours in a period of one month)

Human resources	**Product**	**Workforce expertise**				
		1	**2**	**3**	**4**	**5**
1	1	6	7	-	-	-
	2	3	4	-	-	-
2	1	-	-	9	9	9
	2	-	-	10	10	10
3	1	-	-	9	7	7
	2	-	-	9	7	7
4	1	-	-	6	3	6
	2	-	-	7	4	7

Table 10: Cost of workforce idle time for new product development process (monetary unit per person)

Human resource	**Product**	**Workforce expertise**				
		1	**2**	**3**	**4**	**5**
1	1	60	70	-	-	-
	2	70	70	-	-	-
2	1	-	-	35	25	20
	2	-	-	30	30	20
3	1	-	-	25	35	35
	2	-	-	30	40	35
4	1	-	-	30	20	35
	2	-	-	30	40	35

The Pareto front in Figure 5 is related to the three objective functions of the proposed model, and since one of the objective functions is cost minimization and the other objective function is to increase the skill level, which reduces the time required for the new product development process, and the other function is to increase The level of productivity is, with the increase in the skill level of human resources, the costs increase, and at the same time, the time required for the new product development process decreases, and with the increase in costs, the level of productivity also increases. So, it confirms that the first objective function is opposite to the second and third objective function. In the following, 9 examples of test problems from small to large size have been produced in table 13:

The results for the sample problems presented in Table 13 show that the CPU time for the small size problem instances varies from 3.42 (s) to 7.15 (s). Also, the CPU time for the medium size problem instances varies from 174.59 (s) to 284.79 (s). These results indicate that the performance of our solution methodology is good for these two sets. For large size problems the CPU time for L1 and L2 are 3180.99 (s), and 5324 (s), respectively. But the CPU time for L3 exceed 2.5 (h). Therefore, with the increase in the size of the sample problems presented in Table 13, the CPU time has increased significantly, so meta-heuristic algorithms are used for problems with large dimensions. In the following, the set of Pareto solutions for problem number 4 using the genetic algorithm is presented.

Table 11: The cost of hiring and firing human resources

Instance	Number of human resources	Number of experts	Level of skills	Number of products	Number of departments
Small	4	5	5	2	2
	10	5	5	2	2
	20	5	5	4	2
Medium	30	6	6	4	3
	40	6	6	6	3
	50	6	6	6	3
Large	70	7	7	8	4
	90	7	7	8	4
	120	7	7	9	4

Table 12: List of results for the numerical example of the problem

The optimal solution for kth single-objective model ($k = 1, 2, \ldots, K$)	F_1	F_2	F_3
(x^1, t^1)	18200	16.4	14.25
(x^2, t^2)	18200	16.4	14.25
(x^3, t^3)	18200	16.4	14.25
Max	18200	16.4	14.25
Min	18200	16.4	14.25

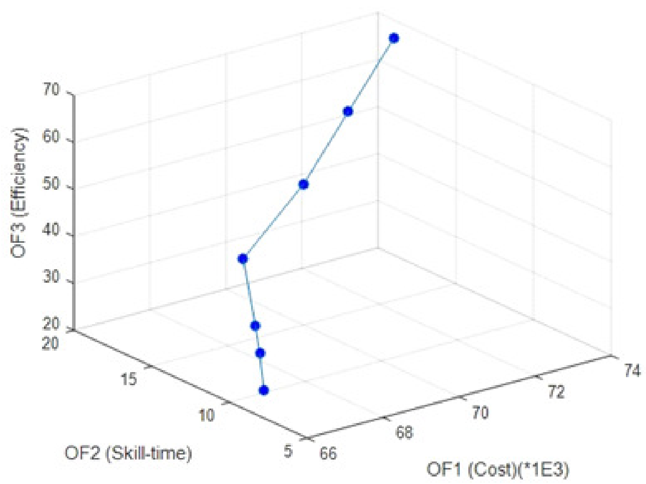

Figure 6: The Pareto optimal set for problem number 4

The value of the total cost and two other objective functions is shown in Figure 6. Additionally, as shown in Figure 6, efficiency increases, and time decreases as the cost increases and the model confirms that the cost objective function is in conflict with two other objective functions. Because the main goal is to minimize total cost while maximizing the total skill which leads to a reduction in the time of the new product development process and maximizing efficiency. The minimum cost is obtained 66500 but the efficiency rate is 23. Furthermore, maximum cost is achieved 74200 and the efficiency rate is 66. Therefore, the pareto optimal set helps DMs to make the decision by considering the whole picture based on DMs preference. For example, if the DM prefer efficiency and less time to cost, the higher cost is chosen as the best solution.

6 Conclusion

In this study, we propose a new multi-objective model for a team formation problem for simultaneous optimization of cost, time, and productivity (the most important factors in team formation problems). We applied the Augmented Epsilon- Constraint method and the set of Pareto-optimal solutions, generated by the Augmented Epsilon Constraint method, show the trade off between the three objectives, and provide important insights for the problem. We show an application of our work in a case study from the pharmaceutical industry. In this research both minimize labor cost and maximize the quality of workforces by hiring workers with high skill level and minimizing the time of new product development process. The model can help DMs to form a team in an effective and efficient way in different stages of a project. Several promising new research directions could be explored beyond the current research. Additional objectives such as maximizing collaboration between individuals who work in the same department can be considered. Application and sensitivity analysis of the presented work in various industries would also constitute promising avenues of future research.

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