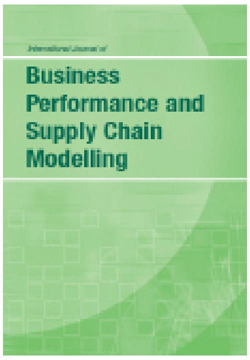

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Elham Shadkam

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Investigating the multi-objective optimisation problem of supplier selection using the new COTOP hybrid method

Elham Shadkam

Department of Industrial Engineering,
Faculty of Engineering,
Khayyam University,
Mashhad, Iran
Email: e.shadkam@khayyam.ac.ir

Abstract: In recent years, selecting the best supplier in the supply chain problem has become a strategically important issue. The nature of this problem is usually complex and there are conflicting objectives. Selecting the best supplier will significantly reduce the cost of purchasing materials and the delivery time. It also increases the level of competitiveness of organisations. The purpose of this paper is to present a new approach to solve multi-objective optimisation problems. The proposed method in this paper has been used to solve the evaluation and selection of the appropriate supplier. The proposed hybrid method is a combination of the cuckoo optimisation algorithm (COA) and the TOPSIS method and is therefore called COTOP. The speed and accuracy of the results from the implementation of the proposed COTOP method on the supplier selection problem show the efficiency of the algorithm in solving multi-objective problems, and this method can well identify the Pareto frontier of the problem. Due to the use of the cuckoo optimisation algorithm, the proposed COTOP method can be used in large-scale problems, and due to the use of the TOPSIS method, there is no concern in terms of the number of objective functions.

Keywords: supplier selection; supply chain; TOPSIS; cuckoo optimisation algorithm; hybrid method.

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Biographical notes: Elham Shadkam received her BSc in Industrial Engineering in 2007, MSc in Industrial Engineering in 2010, Khajeh Nasir Toosi University, and PhD in Industrial Engineering in 2015, Isfahan University of Technology. In 2012, she joined the Industrial Engineering Department, Khayyam University as a faculty member. Her research lies in the area of supply chain, metaheuristic methods, simulation/optimisation, and decision making.

1 Introduction

Optimisation methods and algorithms are divided into two categories of exact and approximate algorithms. Exact algorithms are able to find optimal solutions with high accuracy, but they are inefficient for large-scale optimisation problems and their solution time is high (Shadkam et al., 2021c). Approximate algorithms are able to find good (near-optimal) solutions to large-scale problems in a short period of time. Approximate algorithms are divided into two categories: heuristic and meta-heuristic algorithms. The main problem of heuristic algorithms is local solutions and non-application for various problems. Meta-heuristic algorithms have approaches to get out of local solutions and can be used in a wide range of problems. One of the new meta-heuristic algorithms that has a very high ability to find general optimisation solutions is the cuckoo optimisation algorithm (COA). This algorithm is one of the newest and most powerful evolutionary optimisation algorithms that has been introduced so far. The cuckoo algorithm is inspired by the lifestyle of a bird called the cuckoo. Due to the efficiency of COA algorithm, other research has been done on it and improved versions of it have been provided (Shadkam and Bijari, 2020). Most real-world problems are multi-objective, which must simultaneously optimise multiple objectives that are often in conflict with each other. For this reason, optimal solutions are often unattainable in multi-objective problems, and Pareto frontiers provide good solutions. Now, if the scales of the multi-objective problem are large, it is difficult to find a suitable solution that can created Pareto frontiers accurately in a reasonable time.

In this research, a new approach has been developed using the cuckoo optimisation algorithm and the TOPSIS method, which can optimise such large-scale multi-objective problems. In fact, the cuckoo optimisation algorithm does not have the ability to solve problems with several objective functions, and with the use of the TOPSIS method, this deficiency is solved and the COTOP hybrid method is presented. Also, many multi-objective problem solving methods have limitations in terms of the number of objective functions, which in the proposed approach due to the use of TOPSIS method is not limited in this regard. The hybrid methods are usually more successful than individual tools, and much research has been done in the field of hybrid methods, such as Mirmozaffari et al. (2021a) combined the two methods data envelopment analysis (DEA) and stochastic frontier analysis (SFA) for assessing efficiency, Mirmozaffari et al. (2022) presented an artificial intelligence method composed of optimisation, machine learning and data envelopment analysis (DEA), Mirmozaffari et al. (2021b) combined of the efficiency measurement method and SFA, Shadkam (2022b) presented a hybrid method with data envelopment analysis and response surface method, and Shadkam and Cheraghchi (2021) combined AHP and TOPSIS methods for prioritisation of earthquake relief.

The COTOP hybrid method is implemented on the supplier selection problem. This problem is an important issue in the real world and with the increasing importance of procurement and procurement activities, purchasing decisions have become more important. The organisations today have become more dependent on suppliers, the direct and indirect consequences of incorrect decision making are more apparent. In fact, choosing the appropriate of suppliers to work with is crucial to a company's success. Recently, with the advent of the concept of supply chain management, most researchers, scientists and managers have realised that choosing the appropriate supplier and managing it is an approach that can be used to increase supply chain competitiveness.

Therefore, selecting a supplier is an important and strategic decision in the supply chain. In fact, the research questions in this paper are as follow, which will be answered during the article.

1 Are hybrid methods effective?

2 Is it possible to create an efficient approach to multi-objective problems by combining cuckoo algorithm and TOPSIS methods?

3 Can the hybrid cuckoo and TOPSIS approach be used for practical supplier selection problems?

4 Is the hybrid cuckoo and TOPSIS method superior to other similar approaches?

In the following, after reviewing the literature related to the hybrid optimisation methods and supplier selection problem, a brief introduction of the cuckoo optimisation algorithm is given. Then the proposed hybrid approach of this paper is presented under the title of COTOP method. In order to investigate the algorithm, the mathematical model of the multi-objective supplier selection problem is introduced and this problem is optimised using the COTOP hybrid method. The results show the optimal performance of the proposed algorithm in finding the Pareto frontier of the problem compared to similar optimisation methods. At the end, a conclusion and summary is presented.

2 Literature review

There are several articles in the field of supply chain and have been reviewed in various fields and industries, including Liu and Liu (2021), which have examined the design of a participatory and value-added supply chain for BMW company. Also, Mashaqbeh et al. (2021) analyses the impact of supply chain risks on the strategic performance of power generation companies with a system dynamics approach.

One of the most important parts of the supply chain is the selection of appropriate suppliers. Many criteria are effective in selecting suppliers, such as cost, delivery time, assurance in meeting the order, etc. In most cases, it is impossible to find a supplier who excels in all of these criteria. Therefore, finding a supplier is a difficult problem. As mentioned, there are several criteria in choosing a supplier or seller, so this is basically a multi-criteria problem. There are many researches in the field of supply chain selector selection that are discussed below.

Rahmani et al. (2017) presented a new data envelopment analysis model to identify the most efficient decision-making unit with imprecise data. The above model has identified efficient suppliers and ranked them by considering imprecise data for 18 suppliers. Also, they presented a comprehensive data envelopment analysis model to determine the best supplier with imprecise data and weight constraints. In this model, weight constraints are considered to take into account the opinion of decision makers about the weight of the criteria. The proposed model is able to determine the best supplier by solving a linear integer programming model. Pasandideh et al. (2011) considered the problem of determining the optimal order quantity by selecting the appropriate supplier and solved their model using genetic algorithm. One of the significant results of this study was a significant reduction in existing costs. Luan et al. (2019) proposed a hybrid model for supplier selection decision making and solved their model using a genetic algorithm. In this research, in addition to considering both categories of quantitative and qualitative factors; it also examines maintenance, ordering, and purchasing costs in the form of an inventory model and determines each supplier's share of total demand. Hamdan and Cheaitou (2015) examined the combined model of fuzzy TOPSIS and ideal planning for supplier selection. According to the results of solving the two-stage model, it can be claimed that the proposed model is able to simultaneously solve the problem of selecting a supplier and assigning orders to them by considering quantitative and qualitative criteria. Weber and Current (1993), first addressed the problem of multi-objective mathematical planning in supplier selection. They set three goals: minimising cost, delivery time, and the number of returned parts as the objectives of supplier selection. They also added to the problem by constraints such as the fixed number of suppliers to be selected, the limited production capacity of each supplier, and the limited amount of budget allocated to purchase from each supplier. Dickson (1966) first identified and analysed the importance of twenty three criteria based on a study of purchasing managers on supplier selection. He concluded that the three factors of quality, delivery time and costs are essential and very important factors that are considered in selecting a supplier. Rao and Kiser (1980), considered sixty indicators for supplier selection. Ghodsypour and O'Brien (2001), first to evaluate and select suppliers, proposed a one-objective model whose main purpose was to minimise costs. In their model, product quality is considered as one of the limitations of the model. In the second model, quality is also added to the objectives and a multi-objective function is defined. In both models, nonlinear integer programming is used. Degraeve and Roodhooft (2000) presented a nonlinear integer programming to evaluate and select suppliers for different time periods. They emphasised that the characteristics of suppliers, such as quality, delivery time, etc., vary in different time periods, so this problem should be considered dynamically. Rezaei and Davoodi (2011), in their research developed a multi-objective nonlinear mixed model. This model is a multi-period, multi-product and multi-supplier model and meets the objectives of cost, quality and service level. Finally, the model was solved using the Genetic algorithm method and the results were compared in two cases of fraction non-acceptance and fraction acceptance. Ebrahim et al. (2009), in their research designed a model that includes different types of discounts. Constraints such as supplier capacity and demand are also included in the final model. In this research, the final model designed using the meta-heuristic dispersive search (SSA) method was solved and the results obtained in different modes of using discounts were compared with each other. Sharma et al. (1989) propose a nonlinear model, mixed and ideal for supplier selection. Costs, quality, delivery and service are included in this model and all criteria are considered in the objective format. Benton (1991) has developed a nonlinear program and an innovative procedure for selecting a supplier under multiple products, multiple suppliers, resource constraints, and discounts based on number of purchases. The objective function of the model is to minimise the sum of purchase, storage, relocation and purchase costs. Storage and investment constraints are given as constraints in the model. Awasthi et al. (2009) considered the problem of supplier selection under the conditions of possible demand with a limitation on the minimum and maximum order size and solved their model using an innovative algorithm. Nobari et al. (2018) addressed the problem of the two-objective model of supplier selection in the supply chain. The purpose of the present study is to develop a new mathematical model on the problem of supplier selection, taking into account the flexibility of suppliers. Due to the NP-hard nature of the problem, an efficient algorithm based on a genetic algorithm is used to solve it. Chaudhry et al. (1993) used linear and complex integer programming to select suppliers. Their model includes price, delivery, quality and discount. The objective function of this model is to minimise the integration price by considering both cumulative and visual discounts. Quality and delivery time are modelled as constraints.

In addition to the papers mentioned, which were mostly related to the field of supplier selection modelling, a lot of research has been done in the field of hybrid methods to solve the problem of supplier selection. Table 1 presents the relevant researches in the field of supplier selection problem, which has been solved by using hybrid methods.

Table 1 Classification of hybrid method for supplier selection problem

Authors (year)	*The objective function*	*Type*	*Application*	*Method*
Dejam et al. (2012)	Single	Deterministic	In many companies to allocate facilities to locations	Cuckoo and tabu search algorithms
Abolpour and Mohebbi (2013)	Single	Stochastic	Estimated compressive strength of 28-day concrete	Cuckoo algorithm and fuzzy logic
Kahramanli (2012)	Single	Deterministic	Engineering optimisation	Modified cuckoo optimisation algorithm
Yang and Deb (2013)	Multi	Deterministic	multi-objective problems	a new multi-objective cuckoo algorithm
Addeh et al. (2014)	Single	Deterministic	Statistical process control	Neural networks
Bhargava et al. (2013)	Single	Deterministic	Equilibrium phase calculations	Cuckoo algorithm
Valian et al. (2013)	Single	Deterministic	Reliability optimisation problems	Advanced cuckoo search
Kaydani and Mohebbi (2013)	Single	Deterministic	Prediction Permeability	Artificial neural networks
Rabiee and Sajedi (2013)	Single	Deterministic	Work schedule in network computing	Cuckoo optimisation algorithm
Shadkam and Bijari (2014)	Single	Deterministic	Comparison	Cuckoo optimisation algorithm
Balasubbareddy et al. (2015)	Multi-single	Deterministic	Single- and multi-objective optimisation problems	A new multi-objective cuckoo optimisation algorithm
Gorjestani et al. (2015)	Multi	Deterministic	Multi-objective optimisation problems	Cuckoo algorithm and data envelopment analysis

Table 1 Classification of hybrid method for supplier selection problem (continued)

Authors (year)	*The objective function*	*Type*	*Application*	*Method*
Akbarzadeh and Shadkam (2015)	Single	Deterministic	Production planning problem	Cuckoo and Genetic algorithms
Borhanifar and Shadkam (2016)	Multi	Deterministic	A number of multi-objective experimental problems	Cuckoo algorithm and simple average weighed method
Shadkam and Bijari (2017)	Multi	Stochastic	selecting suppliers and determining order quantities	Simulation, cuckoo algorithm and general data envelopment analysis
Ghosh et al. (2012)	Single	Deterministic	Multi-objective supplier selection problem	Simulated annealing and AHP method
Boran et al. (2009)	Multi	Stochastic	Multi-criteria group decision making in Supplier evaluation	Fuzzy method and TOPSIS
Kota (2012)	Single	Deterministic	Selecting the suppliers for the ordered quantity of a product	Firefly optimisation
De Boer et al. (2001)	Multi	Deterministic	Supplier selection	Decision-making methods and techniques
Tsai et al. (2010)	Multi	Deterministic	Decision making in a dynamic business environment	Ant colony algorithm
Sadeghieh et al. (2012)	Multi	Deterministic	Supplier selection	An integrated genetic algorithm based on grey target programming
Haldar et al. (2014)	Multi	Stochastic	Supplier evaluation	Fuzzy method and TOPSIS
Kahraman et al. (2003)	Multi	Stochastic	Selecting the best supplier	Fuzzy analysis and AHP
Ayhan (2013)	Multi	Stochastic	Select the best supplier	Fuzzy analysis and AHP
Allouche and Jouili (2017)	Multi	Stochastic	Multi-criteria supplier selection problem	Fuzzy analytical hierarchy process and imprecise goal programming
Khalili-Damghani et al. (2013)	Single	Stochastic	Supplier selection problem	Fuzzy method and artificial neural network
Karsak and Dursun (2015)	Multiple	Stochastic	Multi-criteria suppliers selection	Quality performance development and fuzzy

Table 1 Classification of hybrid method for supplier selection problem (continued)

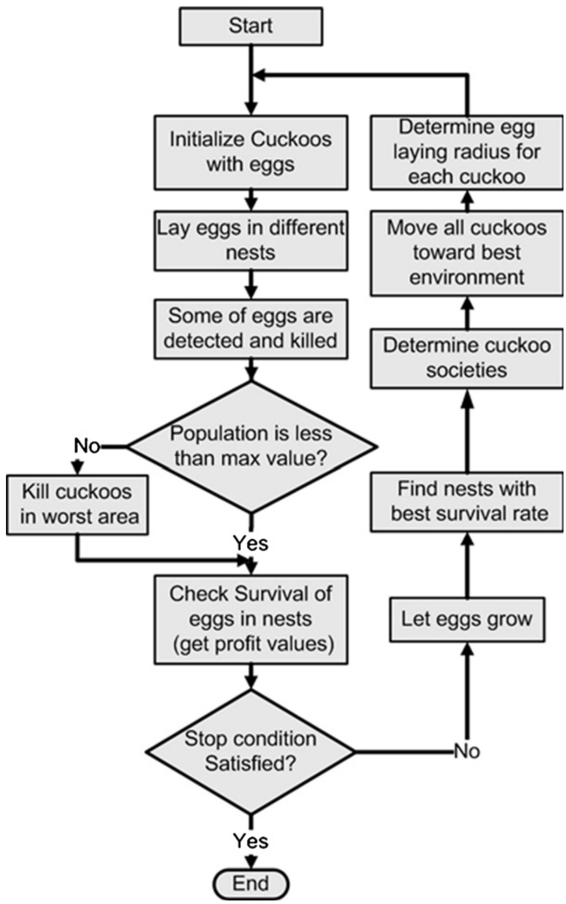
Authors (year)	*The objective function*	*Type*	*Application*	*Method*
Kanagaraj and Jawahar (2009)	Single	Deterministic	Reliability-based total property cost model (RBTCO)	Nonlinear integer programming (NLIP)
Parhizkari et al. (2013)	Multi	Stochastic	Inventory control model and selecting the best supplier	LP-NORM
Ghorbani et al. (2013)	Multi	Stochastic	Selection of suppliers	Fuzzy and TOPSIS
Rostamzadeh (2014)	Single	Stochastic	Selection of suppliers	Fuzzy AHP and fuzzy TOPSIS
Azadeh et al. (2014)	Multi	Deterministic	Select best suppliers and reduce delivery time and final production costs	Simulation + genetic algorithm
Fallahpour et al. (2016)	Single	Stochastic	Selecting the best green suppliers	DEA and genetic algorithm
Türk et al. (2015)	Multi	Stochastic	Selecting best supplier and inventory control	IT2FS and simulated annealing algorithm
Junior et al. (2014)	Multi	Stochastic	Selecting best supplier	Fuzzy AHP and fuzzy TOPSIS
Shadkam (2021b)	Multi	Deterministic	Multi-objective supplier selection	COA and simple additive weighting
Shadkam et al. (2021b)	Multi	Deterministic	Multi-objective problems	COA and ε-constraint

As can be seen in the Table 1, the TOPSIS method has been used in combination with other approaches (except COA) due to its many advantages. The TOPSIS method is a relatively simple method with high accuracy that can achieve acceptable results. Also, the COA algorithm has also been used in combination with other methods (except TOPSIS) due to its many advantages. The COA algorithm can solve large-scale problems in a short period of time and obtain acceptable solutions. A review of the literature shows that a wide range of approaches have been studied on the problem of supplier selection and so far the hybrid approach of the cuckoo algorithm and the TOPSIS method has not been used in research. In this paper, due to the simultaneous use of these two applied methods of cuckoo algorithm and TOPSIS, the hybrid approach of COTOP is created. Therefore, in this research, the advantages of both methods are used simultaneously and an efficient method is presented to solve multi-objective optimisation problems. Also, one of the multi-objective optimisation problems is examined using this proposed approach. This approach will be very effective in practice because it can be used both for large-scale problems due to the use of COA algorithm and for multi-objective problems with a large number of objective functions due to the use of TOPSIS method.

3 Introduction of COTOP method tools

This section provides a brief description of the COA and TOPSIS algorithms that have been used to create the COTOP hybrid method and as mentioned, the name of the COTOP method is also taken from these tools.

Figure 1 The flowchart of the COA algorithm

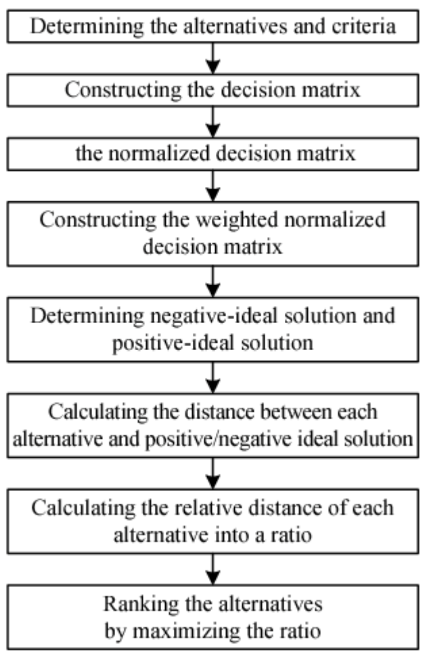


Source: Rajabioun (2011)

3.1 Cuckoo optimisation algorithm

This algorithm is one of the newest and most powerful evolutionary optimisation algorithms that has been introduced so far. The cuckoo algorithm is inspired by the life of a bird called the cuckoo, which was developed by Yang and Deb (2009). The cuckoo algorithm was fully explored in more detail by Rajabioun (2011). All the birds in the world have the same way for egg laying, but there are birds called parasites, and the most famous of them is the cuckoo, which never builds a nest for itself and lays its eggs in the nests of other birds. They lay their eggs in the host nest by imitating the colour and pattern of the eggs in each nest so that the eggs look like the eggs in the host nest. Among them are birds that distinguish cuckoo eggs from their eggs and expel them from the nest. The interesting thing is that only one egg per nest can grow because cuckoo chicks hatch faster than host chicks and grow faster. In most cases, cuckoo chicks throw eggs or host chicks out of the nest, and even if they come out of the host chicks later, they eat most of the food that the host bird brings and the host birds die. After the cuckoos become adult, they form groups that each group has an area for their habitat, and the best habitat for all groups will be the next destination of the cuckoos in the other groups. All groups are migrating to the best area. Taking into account the number of eggs that the cuckoos will lay as well as the distance of the cuckoos from the current optimal area for habitation. A number of eggs are considered for each cuckoo and then the cuckoos lay randomly in nests within their egg laying radius. Again, the eggs become adult birds, and the process continues until the stop condition is satisfied. The flowchart of the COA algorithm is shown in Figure 1 and can be referred to the Rajabioun (2011) for more details. The COA algorithm has been used for various problems such as portfolio selection (Shadkam et al., 2015), assembly line balancing (Shadkam and Ghavidel, 2021), production-distribution planning in the supply chain (Shadkam et al., 2021a), reverse logistics for COVID-19 waste management (Shadkam, 2021a), resource levelling problem in multi-project mode (Shadkam, 2021b), centralised and production planning problem (Shadkam, 2022a).

Figure 2 The steps of the TOPSIS method



3.2 TOPSIS algorithm

This method was first proposed by Huang in 1981 (Yu et al., 2011), and with the modifications made to it, it is considered as one of the best and most accurate methods of decision making. The theoretical foundations of this technique are based on the fact that it first calculates positive ideal alternative (the most efficient state) and negative ideal alternative (the most inefficient state) for each of the criterion and then the distance of each alternative from the positive and negative ideals is calculated. The alternative chosen is the one that has the shortest distance from the positive ideal and the longest distance from the negative ideal. This technique is designed in such a way that the type of criteria can be included in the model in terms of positive or negative impact on the decision-making and also the weights and importance of each criterion are entered in the model. The steps of TOPSIS method are in accordance with the flowchart shown in Figure 2.

4 New COTOP hybrid method

The proposed COTOP method simultaneously uses the advantages of both the TOPSIS method and the cuckoo optimisation algorithm. Cuckoo optimisation algorithm is one of the practical and efficient optimisation methods in solving nonlinear and integer problems that is not able to solve multi-objective problems. Therefore, by combining this algorithm with TOPSIS method, this weakness can be eliminated and a desirable solution method can be created to solve large-scale multi-objective problems. The steps of the new COTOP method are very similar to the cuckoo optimisation algorithm, except that in the step of assessing the habitats of the cuckoos, instead of considering the value of the objective function, the TOPSIS score is used. In fact, in this step, a decision matrix is created whose alternatives are the habitats of the cuckoos (the decision variables) and its criteria are the objective functions of the problem. The TOPSIS method is implemented on this matrix and a TOPSIS score is calculated for each habitat, which is the basis for the superiority of the cuckoos' habitat. Because the cuckoo optimisation algorithm is unable to simultaneously consider the values related to the objective functions, The TOPSIS score is substituted to represent these values of the objective functions. The diagram of the proposed COTOP approach is shown in Figure 3. The subsection for calculating the TOPSIS score is also described in Figure 4.

Initially, the current habitats of cuckoos (Initial population of candidate solutions) are determined randomly [relation (1)]. In one N_{var} optimisation problem, the Habitat will be a $1 \times N_{var}$ array that shows the current state of the cuckoos' life. This array for each cuckoo is defined as (1):

$$Habitat = [x_1, x_2, \ldots, x_{Nvar}] \tag{1}$$

Therefore, the habitat of the initial population of cuckoos is a matrix of size $N_{pop} \times N_{var}$. Then a number of eggs are assigned to each cuckoo (habitat). The number of eggs assigned to each cuckoo is a random number between the minimum and maximum limits of the number of eggs. Each cuckoo lays its eggs in a certain radius, which is called the egg laying radius (ELR). In an optimisation problem, each variable has a high var_{hi} and a low var_{low} limitation, using which any ELR can be defined. The ELR is proportional to the total number of eggs, the number of current cuckoo eggs, and the upper and lower limits of the variables. ELR is therefore defined as (2):

$$ELR = \alpha \times \frac{Number\ of\ current\ cuckoo\ eggs}{Total\ number\ of\ eggs} \times (Var_{hi} - Var_{low}) \tag{2}$$

α is the variable with which the maximum ELR value is set. An ELR is identified for each cuckoo based on relation (2). Cuckoos lay eggs in the habitats of hosts within their egg laying radius (Figure 5). In COTOP approach, for each adult cuckoo or each egg, the degree of desirability (profit) is determined according to the objective function of the problem according to equation (3). In fact, by placing the coordinates of the habitat of each cuckoo (decision variables) in the objective function and obtaining the value of the objective function, the value of profit is calculated.

$$Profit = f_p(habitat) = f_p\left(x_1, x_2, \ldots, x_{Nvar}\right) \tag{3}$$

Because in multi-objective problems there are several values for the objective functions and in the cuckoo algorithm it is not possible to integrate these values, so at this stage instead of considering several amounts of profit, a value of TOPSIS is used. In order to implement the TOPSIS method at this stage, each habitat is considered as an alternative of the decision matrix [relation (4)] and each value of the objective function is also considered as a criterion in the decision matrix and a matrix with below dimensions is formed:

$$Number\ of\ cuckoo\ population \times number\ of\ objective\ functions\ of\ the\ problem$$

Then, for this decision matrix, the TOPSIS method is implemented and positive ideal, negative ideal and distance alternatives to the ideals are determined. Finally, the TOPSIS score is calculated for each alternative (each habitat) which will be considered as an index for cuckoo superiority (profit).

$$Decision\ matrix = \begin{bmatrix} f_{1,1} & \cdots & f_{1,N_{Objectives}} \\ \vdots & \vdots & \vdots \\ f_{N_{pop},1} & \cdots & f_{N_{pop} \times N_{Objectives}} \end{bmatrix}_{N_{pop} \times N_{Objectives}} \tag{4}$$

Following the COTOP approach after egg laying, some of eggs are detected by the host birds and are destroyed. The eggs that scoreless TOPSIS are supposed to be destroyed. The remaining eggs turn into mature birds and the habitat of the theses cuckoos is then ranked using the TOPSIS score. Due to limited food resources, only a few adult cuckoos can survive at any one time. The maximum number of cuckoos that can live is determined. Therefore, cuckoos with high TOPSIS scores remain and cuckoos with low TOPSIS scores are destroyed and removed from the set of solutions. Remained cuckoos are grouped using the k-mean clustering method and the best cuckoo group is identified as the target habitat. The best cuckoo group has the highest average score of TOPSIS. The other population of cuckoos move to the location of the best cuckoo group. Finally, if the stop condition is met, the algorithm is terminated and otherwise the egg laying process is repeated. Cuckoos do not travel all the way when migrating to the target point. They have travelled only a part of the route and have all the deviations in that route. This movement is clearly seen in Figure 6. As can be seen from the Figure 6, each cuckoo travels only λ% of the total path to the current ideal target and also has a radian deviation φ. These two parameters help cuckoos to search for more environments. λ is a random number between 0 and 1, and φ is a number between –π/6 and π/6. The formula of the migration in the COTOP approach is as (5) and *F* is the parameter that causes the deviation.

$$X_{newHabitat} = X_{currentHabitat} + F\left(X_{GoalPoint} - X_{currentHabitat}\right) \quad (5)$$

After the cuckoos migrate to new places, a number of eggs are assigned to each cuckoo again, and the cuckoos lay these eggs in the ELR, and some of them are identified and destroyed, and some of them become adult cuckoos. The re-migration process takes place. This process must continue until the stop condition is satisfied, and in fact the cuckoos search for the feasible solution area of the problem and converge to the area where the optimal solution lies.

Figure 3 The flowchart of the proposed COTOP algorithm

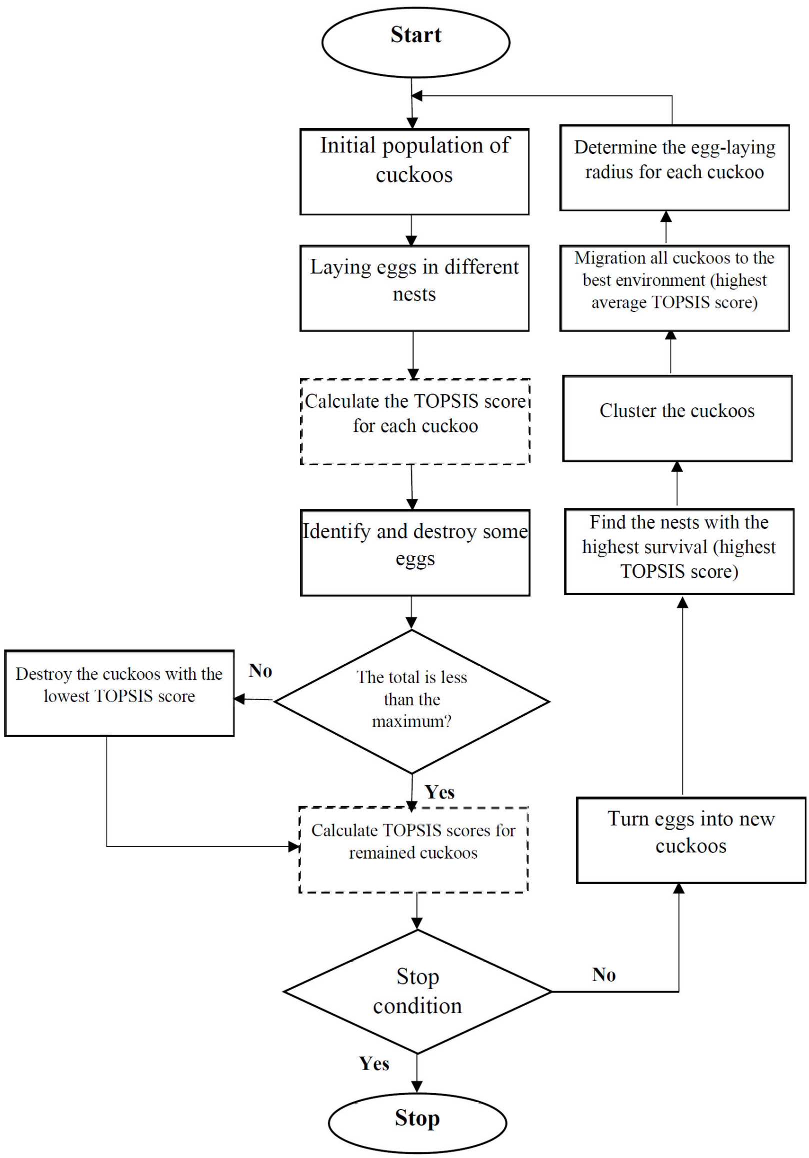


Figure 4 Calculating the suitability of a cuckoo habitat using the TOPSIS method

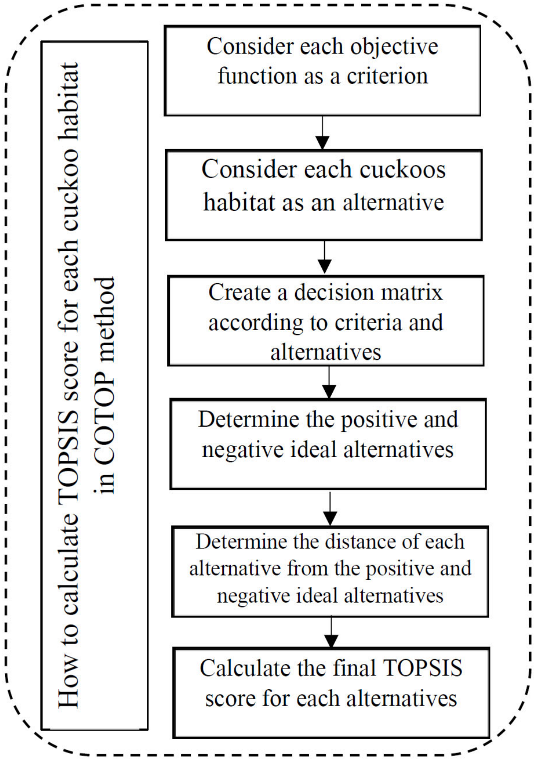


Figure 5 Egg-laying radius (ELR)

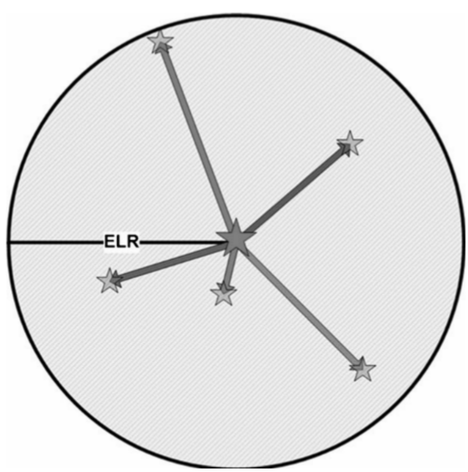
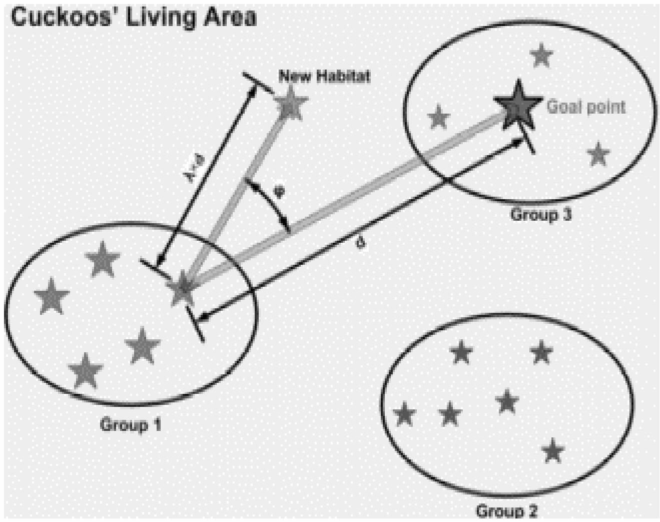


Figure 6 Migration of cuckoos to the target



5 The multi-objective problem of supplier selection

In this paper, the problem of supplier selection is considered with the aim of minimising the objectives of purchase and order costs and defective rates. This model is presented by Wadhwa and Ravindran (2007) which is described below.

The mentioned problem is a multi-objective model of supplier selection with multiple buyers and multiple suppliers (the model can also be used for single buyer mode). In this model, each buyer can buy one or more products from sellers. In short, this model can help any organisation to make the following decisions:

- select a subset of favorite vendors to outsource
- determine how many orders are to be given to each supplier to meet the organisation's demand or production plan.

The parameters and decision variables used in the model are as follows:

Sets:

I Number of product types.

J Number of buyers.

K Total number of potential sellers.

M Number of break points (discount) price.

Parameters:

p_{ikm} Cost of purchasing a type i product unit from seller k at price level m.

b_{ikm} Minimum number of units of product type i, which is considered in the price level m if ordered from the seller k.

d_{ij} Buyer demand *j* from type *i* product.

l_{ijk} Delivery time of type *i* product.

q_{ik} Percent error of seller *i* to supply type *i* product.

CAP_k Vendor supply capacity *k*.

F_k Fixed cost of ordering from the seller *k*.

N The maximum number of vendors that can be selected.

Decision variables:

X_{ijkm} The number of units of type *i* product that is provided at the price level *m* by the buyer *j* from the seller *k*.

Z_k If vendor *k* is selected it is 1 and otherwise it is 0.

Y_{ijkm} If the price level *m* is used is 1 and otherwise 0.

Mathematical model:

$$Min\sum_i\sum_j\sum_k\sum_m p_{ikm}\cdot X_{ijkm}+\sum_k F_k\cdot Z_k \tag{6}$$

$$Min\sum_i\sum_j\sum_k\sum_m q_{ijk}\cdot X_{ijkm} \tag{7}$$

$$\sum_i\sum_j\sum_m X_{ijkm}\le(CAP_k)\cdot Z_k,\quad \forall k \tag{8}$$

$$\sum_k\sum_m X_{ijkm}=d_{ij},\quad \forall i,j \tag{9}$$

$$\sum_K Z_K\le N \tag{10}$$

$$X_{ijkm}\le(b_{ikm}-b_{ikm-1})*Y_{ijkm+1},\quad \forall i,j,k;1\le m\le m_k \tag{11}$$

$$X_{ijkm}\ge(b_{ikm}-b_{ikm-1})*Y_{ijkm+1},\quad \forall i,j,k;1\le m\le m_k \tag{12}$$

$$X_{ijkm}\ge 0,\ Z_k,Y_{ijkm}\in(0,1) \tag{13}$$

In the proposed mathematical model, equation (6) is a function of the first objective of the problem, which minimises the cost of purchasing and ordering the product from suppliers. Equation (7) is a function of the second objective that minimises the rate of defects. Equation (8) indicates the limitation of supplier's capacity. Equation (9) ensures that each buyer receives as much of his demand from different suppliers of products. Equation (10) specifies the maximum number of suppliers. Equations (11) and (12) determine the correct relationship between the variables. Finally, equation (13) shows the type of variables used in the model.

6 Implementation of COTOP method for supplier selection problem

In this section, the problem of supplier selection is examined by the proposed COTOP approach. In order to evaluate the performance of the algorithm, a sample problem is described below and then solved using the proposed algorithm. The problem data is as follows: It is assumed that there are two types of products ($i = 2$), two buyers ($j = 2$) and 3 sellers or suppliers ($K = 3$). Table 2 shows the cost of purchasing a unit of type i product from vendor k. Table 3 shows the fixed cost values for each vendor selection along with vendor capacity. Table 4 shows the demand values of buyers for each type of product. Table 5 shows the defective percentage of products received from different suppliers (sellers) for each type of product.

Table 2 Cost of purchasing the product from sellers

Seller \ *Product type*	*1*	*2*
1	4	2
2	1.5	3
3	0.5	0.6

Table 3 Fixed cost of vendor selection and vendor capacity

Seller	*1*	*2*	*3*
Fixed cost of choosing a seller	8	7	5
Sales capacity	5,000	4,000	6,000

Table 4 The amount of buyers' demand for different types of products

Product type \ *Buyer*	*1*	*2*
1	2,000	2,000
2	1,500	3,000

Table 5 Defective rates of products receivable from sellers

Product type \ *Seller*	*1*	*2*	*3*
1	0.9	0.7	0.5
2	0.6	0.8	0.45

Before implementing the proposed COTOP method for the supplier selection problem, the parameter setting is discussed. Parameter setting is one of the most effective parts of meta-heuristic algorithms, which greatly affects the performance of the algorithm (Shadkam, 2022b). Table 6 shows the values of the COTOP algorithm parameters that have been obtained experimentally. An example of how to create one of these parameters is shown in Table 7. As can be seen from Figure 7, the optimal solution can be obtained at low iterations of the algorithm with 5 for the initial cuckoo population parameter. Other parameters of this method are also shown in Tables 8, 9, 10 and Figures 8, 9 and 10 show the number of iterations of the algorithm to achieve the best solution. It is worth noting that due to the use of TOPSIS score, the best value of one is considered and as soon as the algorithm reaches this value, the problem solving ends and good solutions are provided.

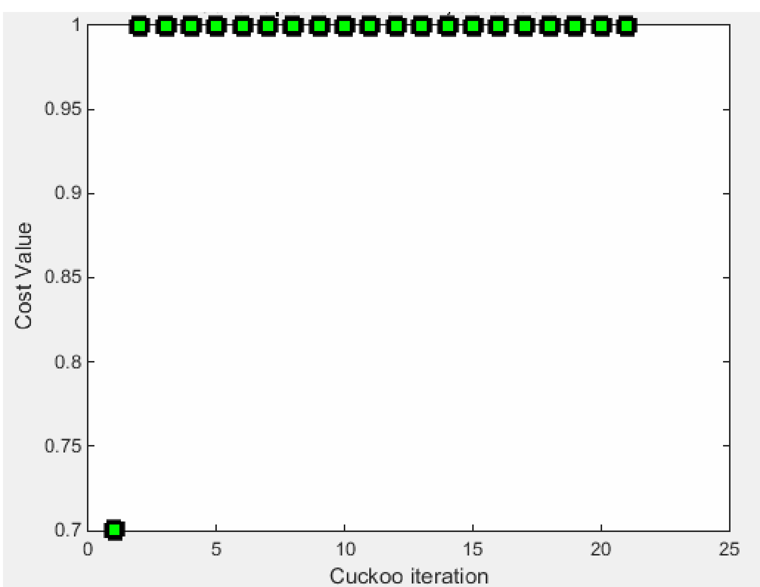
Table 6 The optimal parameters of COTOP approach

Parameter description	*Value*
Number of initial population	5
Minimum number of eggs	2
Maximum number of eggs	6
Maximum number of internal repetitions	20
Number of clusters	2
Motion coefficient	4
The maximum number of cuckoos that can survive at a time	40
Egg-laying radius parameter	5

Table 7 Number of iterations according to the initial population of cuckoos

Iteration	*Number of initial population*			
	5	*10*	*15*	*20*
1	13	5	25	5
2	2	13	2	4
3	8	3	7	43
4	2	6	9	2
5	1	9	3	21
6	16	5	10	2

Figure 7 The graph of the initial population of cuckoos (see online version for colours)



According to Table 8, the range 2–6 was selected, because the final solution is obtained in the first iteration. It should be noted that between 4–10 and 5–10 the time to reach the solution was very long.

Table 8 Number of iterations according to the maximum and minimum number of eggs

Minimum number of eggs	2	2	2	2	4	5
Maximum number of eggs	4	6	5	10	10	10
Iteration 1	10	6	25	17	1	2
Iteration 2	1	4	23			
Iteration 3	2	1				

Figure 8 The graph of the minimum and maximum number of eggs (see online version for colours)

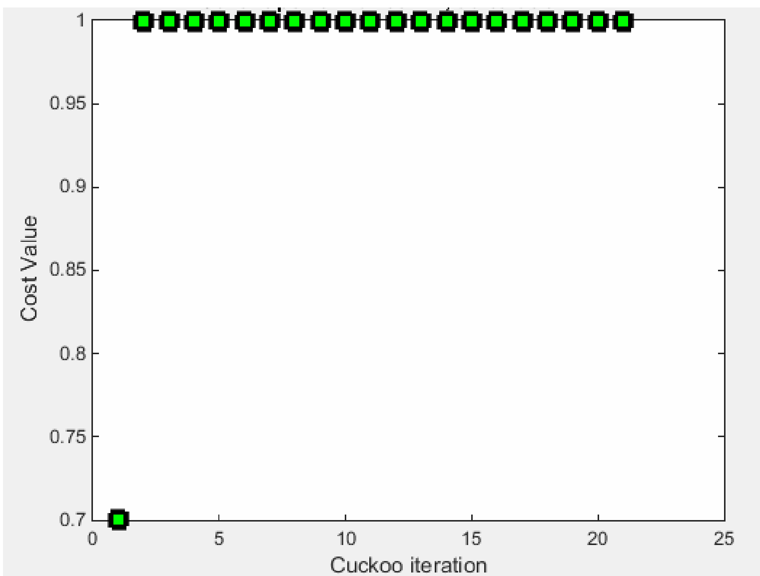


Table 9 Number of iterations according to the maximum repetition parameter

Iteration	*Maximum number of internal repetitions*				
	10	*20*	*30*	*40*	*50*
1	2	5	30	23	6
2	2	1	1	1	8
3	---	6	1	4	14

Figure 9 The graph of the maximum number of internal repetitions (see online version for colours)

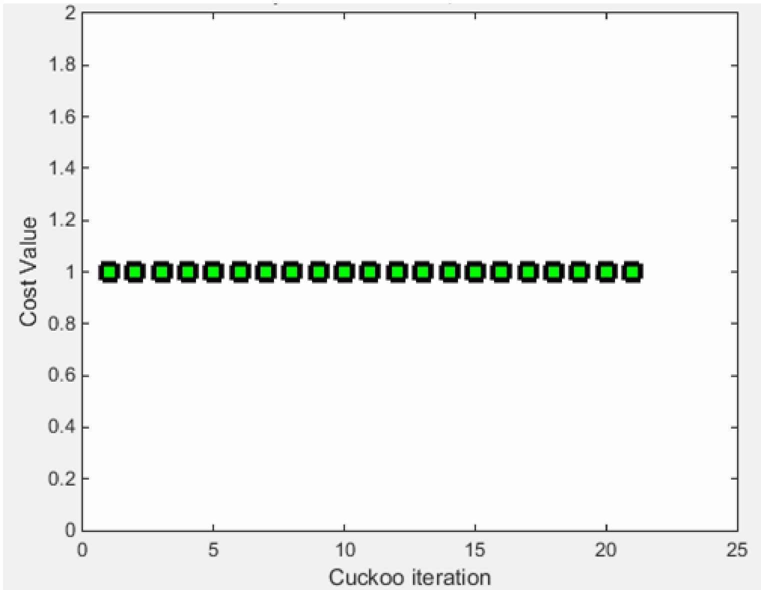


Table 10 Number of iterations according to the parameter of the maximum number of cuckoos that can survive at one time

Iteration	*The maximum number of cuckoos that can survive at a time*				
	10	*20*	*30*	*40*	*50*
1	---	2	---	2	1
2	---	2	14	1	10
3		---		2	13
4				12	

Finally, according to the optimal parameters, the COTOP algorithm is implemented on the supplier selection problem and using the obtained results, the solutions to the problem are in the form of a Pareto frontier in Figure 11.

According to the Table 10, the maximum number of cuckoos that can survive at one time is 40. Because the final solution can be obtained in less iterations.

In order to validate the COTOP method, the supplier selection problem was optimised with the epsilon constraint method, which is one of the most well-known methods in solving multi-objective problems. The Pareto frontier of this problem is plotted in Figure 12. As can be seen, the number of repetitive solutions according to Table 11 in this method is high and it has not been able to identify the real Pareto frontier well.

In order to quantitatively compare these two Pareto frontiers, three indicators are used, which are described below (Chambari et al., 2012).

Figure 10 The graph of the maximum number of cuckoos that can survive at one time (see online version for colours)

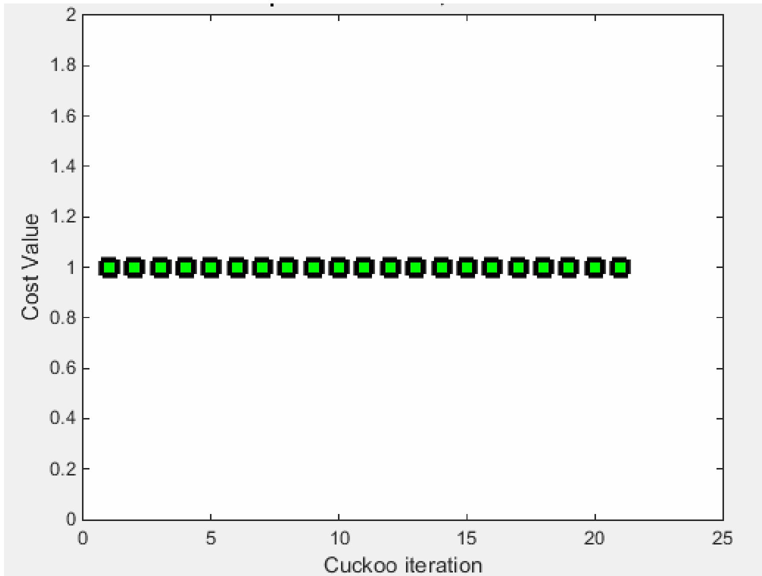


Figure 11 Pareto frontier by COTOP method (see online version for colours)

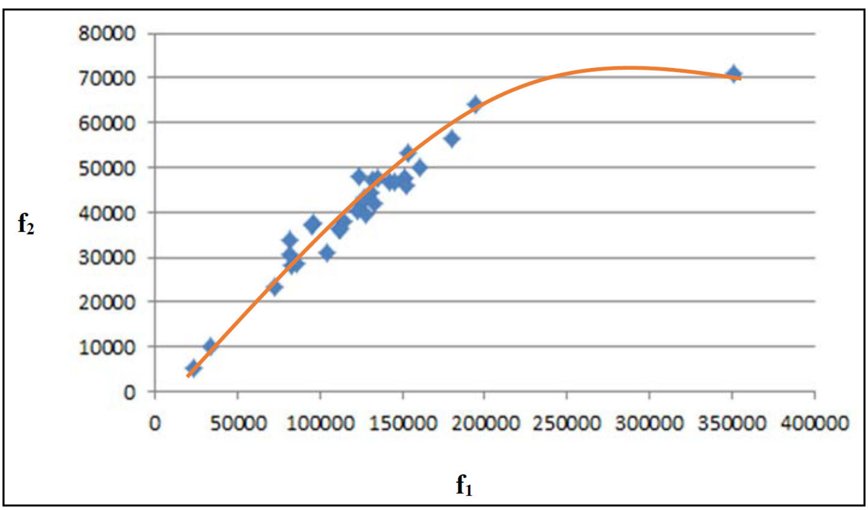
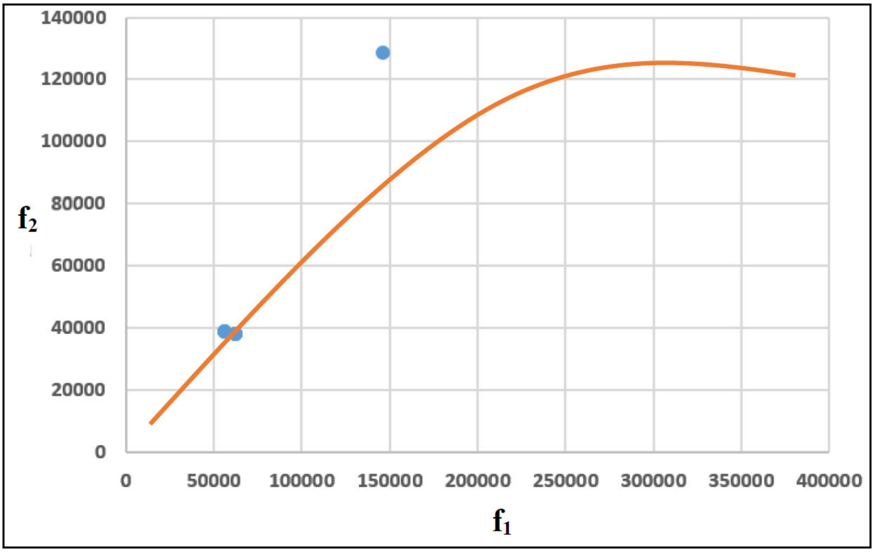


Table 11 Obtained values for objective functions according to the epsilon constraint method

f1	56,000,012	62,000,013	146,000,012	62,000,013	62,000,013	56,000,012	56,000,012	62,000,013
f2	38,750,000	38,000,000	128,750,000	38,000,000	38,000,000	38,750,000	38,750,000	38,000,000

Figure 12 Pareto frontier by the epsilon constraint method (see online version for colours)



6.1 Number of Pareto solution

This index represents the number of Pareto solutions (NPS) obtained from the algorithm. The higher the number of solutions, the better the performance of the algorithm.

6.2 Mean ideal distance

This index indicates the average distance of Pareto points from the ideal solution. The ideal value is equal to the best possible value for each of the objective functions used in all algorithms. This index is calculated from the relation (14). In this regard, *m* represents the number of objective functions, *n* indicates the number of Pareto points, f_i^j is the value of the j^{th} objective function of the i^{th} Pareto solution. $f_{\max}^j$ and $f_{\min}^j$ are the maximum and minimum values of the j^{th} objective function of i^{th} Pareto solution, respectively. The lower the index, the better the performance of the algorithm.

$$MID = \frac{\sum_i^n \sqrt{\sum_{j=1}^m \left(\frac{f_i^j - f_{best}^j}{f_{\max}^j - f_{\min}^j} \right)^2}}{n} \tag{14}$$

6.3 Spacing metric

Using this index, the uniformity of expansion of faulty solutions is measured. When the solutions are evenly and close together, the spacing metric (SM) decreases, so the smaller the index, the better the algorithm performance and is calculated from equations (15) and (16).

$$d_i = \min_{j=1,\ldots,n, j\neq i} \left(\sum_{k=1}^{3} \left| f_k^i - f_k^j \right| \right), \quad \forall i = 1, \ldots, n \tag{15}$$

$$SM = \frac{\sum_{i=1}^{n-1} \left| \bar{d} - d_i \right|}{(n-1)\bar{d}} \tag{16}$$

6.4 Diversification metric

This index shows the Euclidean distance between the initial and final solutions of the Pareto solutions. The larger this index, the more efficient the relevant algorithm. This index is calculated from equation (17).

$$DM = \sqrt{\sum_{j=1}^{m} \left(f_{\max}^j - f_{\min}^j \right)^2} \tag{17}$$

6.5 Elapsed time

This index indicates the elapsed time of each algorithm. If the other indices used to compare the meta-heuristic algorithms are equal to each other, the lower the value of this index, the higher and the performance of the relevant algorithm.

6.6 Quality metric

This index represents the share of the relevant algorithm in the set of Pareto solutions resulting from the combination of Pareto solution provided by all comparable algorithms. The higher the value of this index, the higher the performance of the relevant algorithm.

6.7 Calculate indexes to evaluate the performance of methods

In this section, the six indexes for the COTOP approach and the epsilon constraint method are calculated and the results are shown in Table 12. According to Table 12 it is obvious that the indexes that should have a low value in the COTOP method have lower values than the epsilon constraint method. Also, for indexes that should have a larger value, the COTOP approach has larger values than the epsilon constraint method.

Table 12 The values of 6 indexes to compare methods

Method	*NPS*	*MID*	*SM*	*DM*	*Time (second)*	*QM*
COTOP	30	15	14	254	110.5	0.62
Epsilon constraint	3	114	26	112	200.3	0.38

Given the advantages shown in the Pareto diagram (qualitatively) and the calculated indexes (quantitatively), the elapsed time of this method is almost half the time of solving the epsilon constraint method.

7 Conclusions

One of the meta-heuristic algorithms that has shown excellent performance is the cuckoo optimisation algorithm, which was inspired by the life of the cuckoo. In this research, this algorithm was used to create a hybrid method and this method was used to solve one of the most important multi-objective problems in the real world. Assigning orders to the right suppliers significantly reduces supply chain costs and increases the organisation's competitiveness. Therefore, in this study, the problem of supplier selection was considered with the aim of minimising the cost and defective rate in order to evaluate the performance of the proposed hybrid method. The results of the proposed approach and comparison with several other similar methods showed the good performance of COTOP hybrid algorithm for solving multi-objective problems. According to the Pareto frontier obtained from the COTOP method, we find that the use of proposed method has been very appropriate for the problem of supplier selection because it has a very fast and high convergence speed and has been able to provide acceptable solutions to the multi-criteria supplier selection problem. The results of the proposed method show its superiority over similar methods such as epsilon constraint method. The epsilon r constraint method created only very limited points on the Pareto frontier while the proposed approach generates a large number of these points for the problem, based on the priority of the decision maker, each of these points can be considered as the final solution.

Management is considered equivalent to decision making, and considering that the COTOP approach is used to decide on problems, it is fully used by managers. Given that most real-world problems involve several conflicting objectives and the manager has to make decisions based on them, the manager faces a complex issue. Therefore, the proposed COTOP approach can help managers in this situation. The proposed approach, in addition to solving multi-objective numerical optimisation problems, was also used for the practical problem of supplier selection as observed. In addition to the above, the proposed approach can help supply chain managers in other sectors to make decisions. The level of decisions in which the proposed approach can be used includes strategic (long-term) decisions such as supplier selection, tactical (medium-term) decisions such as production planning, and operational (short-term) decisions such as inventory control planning. In addition to supply chain managers, the proposed approach can help other managers in various other matters such as maintenance managers, project control managers, marketing managers and so on.

The proposed approach is used for deterministic optimisation problems and cannot be used for stochastic problems. One of the approaches for future suggestions can be the development of COTOP approach for stochastic problems and also the following is suggested for future research:

- developing other hybrid approaches using other multi criteria decision making methods and the cuckoo optimisation algorithm
- considering other objective functions in selecting suppliers such as delivery time, shipping cost, etc.
- using the proposed algorithm in this research to solve other real multi-objective problems such as scheduling problems, supply chain, etc.

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