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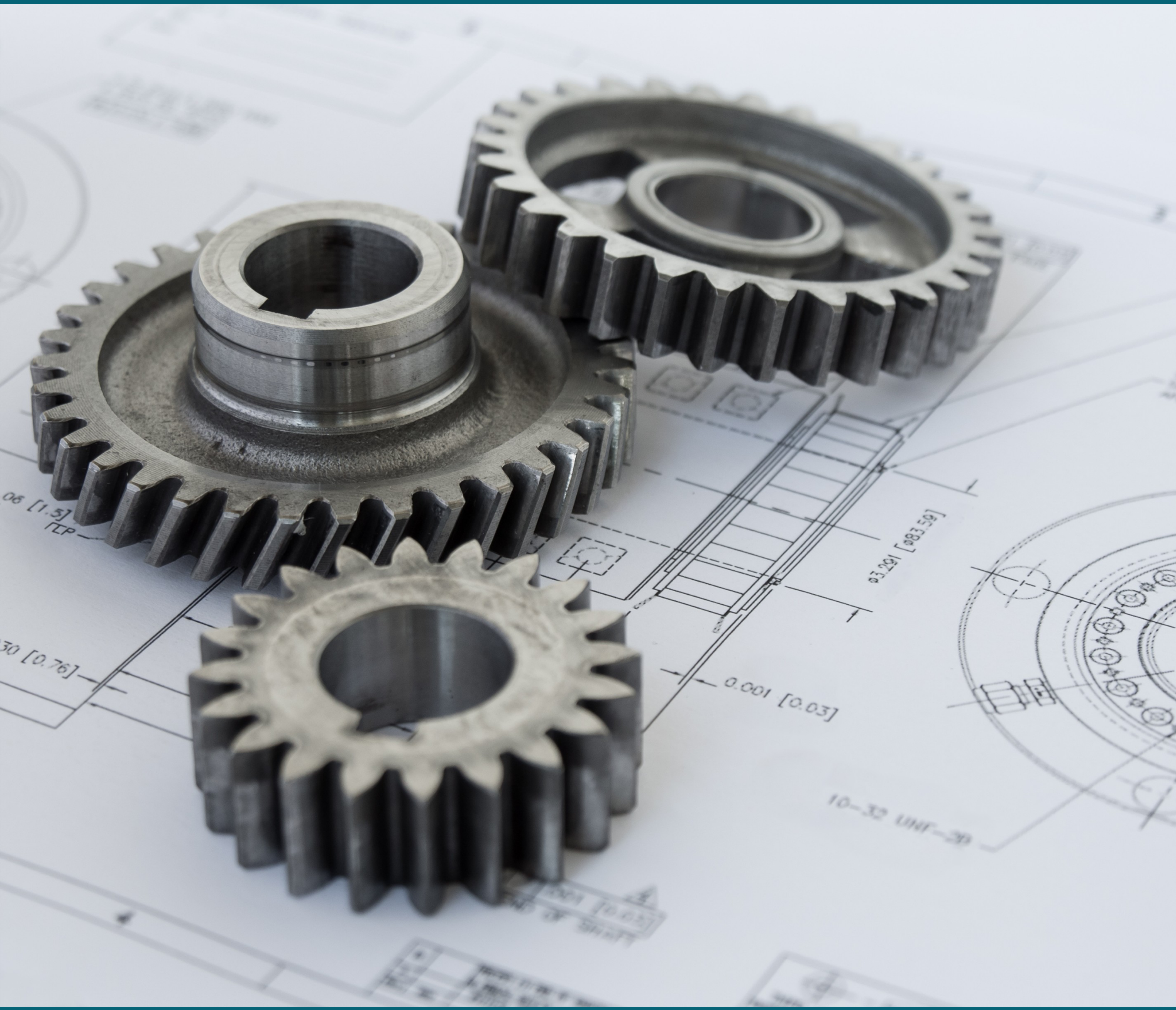

Print ISSN: 2538-5110
Online ISSN: 2676-6167
www. journal-aprie.com

Journal of Applied Research on Industrial Engineering
www.journal-aprie.com

Journal of Applied Research on Industrial Engineering
www.journal-aprie.com
JARIE
J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 155–339.

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E-ISSN: 2676-6167 | P-ISSN: 2538-5100

Journal of Applied Research on Industrial Engineering

www.journal-aprie.com

J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 155–166.

Paper Type: Research Paper

A Variable Service Rate Queue Model for Hub Median Problem

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Citation:

Saeedi, S., Poursabzi, O., Ardalan, Z., & Karimi, S. (2023). A variable service rate queue model for hub median problem. *Journal of applied research on industrial engineering, 10*(2), 155-166.

Received: 26/08/2021 Reviewed: 24/09/2021 Revised: 18/10/2021 Accept: 16/12/2021

Abstract

Hub Location Problems (HLP) have multiple applications in logistic systems, the airways industry, supply chain network design, and telecommunication. In the HLP, the selected nodes as hubs perform the principal role in processing the inflow arising from other nodes. So, congestion would be inevitable at hub nodes. This paper considers a p-Hub Median Problem (pHMP) with multiple hub node servers delivering service at variable rates. Since the service rates are limited and variable, a queue is formed at each hub server. To tackle this problem, we developed a mixed-integer linear programming model that optimizes the selected hub nodes to reduce congestion under an allowable defined queue length at each server and minimize the total costs of the model, including transportation and hub establishment costs. We utilized the Civil Aeronautics Board (CAB) dataset containing 25 USA cities, which is a valuable source for designing numerical examples in the HLP, to prove the model's efficiency. The results obtained from the designed sample problems show that strategic decisions on defining the number of hubs and maximum acceptable queue length at each hub server will significantly impact the hub location network design.

Keywords: Hub location problem, P-hub median, Queuing system, Congestion, Variable service rate.

1 | Introduction

Hub Location Problem (HLP) involves designing a network consisting of multiple locations with inflows and outflows. The goal is to design a network to minimize the distribution and delivery costs while minimizing the costs of routes establishment between locations. To achieve this goal and design an optimal network of nodes, some locations will be chosen as hub locations, which act as the interface, with other locations connected to them. In other words, mutual transportation flow between nodes should be established. The established flow between any two nodes (hub or non-hub nodes) must be established through the hub nodes without using any intermediate node. On the other hand, each established flow should pass through at least one arc and, utmost, two arcs.

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https://doi.org/10.22105/jarie.2021.301634.1372

There exist four principal types of HLPs in the literature, which are: 1) capacitated and uncapacitated HLP, 2) p-Hub Median Problem (pHMP), 3) p-Hub Center Problem (pHCP), and 4) Hub Covering Location Problems (HCLPs).

The capacity of hub nodes may be capacitated/limited (LHLP) or uncapacitated/unlimited (UHLP). pHMP minimizes the total cost of transportation in the network by optimally locating p hubs. In this case, the number of hubs is given. The main goal in the pHCP is to minimize the farthest distance by finding the optimal location of p hubs and the allocation of non-hub nodes to the hubs. The number of hubs is unknown in the HCLP and the main issues here are locating hubs and allocating non-hub nodes to them. This problem also includes cover constraints, meaning that each hub has a limitation on the number of non-hub nodes it can serve. Generally, HLPs can be categorized into two types, i.e., single and multiple-allocations problems. In the former, each non-hub node should be allocated to precisely one hub, while in the latter, a non-hub node can be allocated to more than one hub.

According to the surveyed literature in the HLP, the p-hub median and the p-hub center location problems seem far more appealing to the researchers. However, the p-hub center location problems are more useful when studying emergency facility locations or circumstances concerning perishable products in transportation networks [1]. The primary goal in this paper is not to curb the scope of the study to cover merely such kinds of problems. Therefore, this paper addresses a pHMP with hubs with a limited number of serves that process the network inflow at variable service rates. State-dependent service rates simulate the real-world conditions, as servers, in practical situations, process the inflow at different rates due to the established equipment's dissimilarity (dissimilarity rooted in efficiency, function type, etc.). On the other hand, these variable rates are the principal reason for forming a queue at each server. So, the limitation of service rates engenders congestion at hub nodes leading to a queue. On the other hand, a maximum queue length is assumed at each hub which avoids server collapse. Therefore, the proposed model in this paper aims to provide the most optimal set of hub nodes to minimize the costs (including the establishment of hubs and transportation costs) while considering the implied constraints on each hub's queue system. It may seem conspicuous to determine extra nodes as hubs or even equip the servers of each hub nodes to deter forming a queue at these nodes. The discount rates of flow between hubs may even bolster the idea of more hubs establishment. However, when it comes to the foundation huge expenses, it is the total costs of the model that.

2 | Literature Review

Three coverage criteria were proposed by Campbell [1]. The origin-destination pair (i, j) is covered by hubs k and m if:

I. The cost from i to j via k and m does not surpass a given quantity.
II. The cost of each arc from i to j via k and m does not surpass a given quantity.
III. Each of the origin–hub, and hub–destination arcs satisfies different given values.

The multiple-allocation and the uncapacitated single-allocation problems were studied decades ago, and it was Campbell [1] who proposed the first mathematical model for the multiple-allocation problem. Later, O'Kelly [2] developed several models for HLPs. They modeled the organization of a single and two hub networks. Klincewicz [3] proposed an effective algorithm for the uncapacitated HLP. Skorin-Kapov et al. [4], Ernst and Krishnamoorthy [5], Mayer and Wagner [6] proposed multiple advances to the HLP, while Hamacher et al. [7] Marín et al. [8] studied the problem in a polyhedral manner. More advances have been presented by Marín [9] Canovas et al. [10]. O'Kelly [11], Klincewicz [12], Skorin-Kapov et al. [4], Aykin [13], Ernst and Krishnamoorthy [5] studied single-allocation. Furthermore, Aykin [14], Ebery et al. [15], Campbell, [1], Boland et al. [16], and Marín [17] studied the capacitated multiple-allocation problem. The capacitated single-allocation problem has also been studied by Ernst and Krishnamoorthy [18], Labbé et al. [19], Contreras et al. [20], [21], and Aguilar [22]. Studies of Campbell

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et al. [23], Alumur and Kara [24], Ebery [25], Adler and Hashai [26], O'Kelly et al. [27] will be extensive sources for eager readers.

Riedi et al. [28] proposed a model for Multi-Scale Queuing (MSQ). Ashour and Le-Ngoc [29] developed an MSQ model for Variable-Service rate Multi-Scale Queuing (VS-MSQ) to evaluate priority queues. They presented an analytical framework to estimate the length of the queue and delay survivor functions for a priority queuing system with varying service rates. Marianov and Serra [30] considered congestion in the network and proposed a mathematical model to find optimal locations of hub nodes. They considered the most congested airports and modeled them as M/D/c queuing systems. To solve the proposed model, they linearized the probabilistic constraint and employed a tabu search algorithm. Elhedhli and Xiaolong [31] modeled the congestion effect at a particular hub utilizing a convex cost function that increases exponentially as more flows are directed through that hub. Mohammadi et al. [32] modeled hubs as the most crowded network parts, as M/M/c queuing systems. Rahimi et al. [33] considered congestion and uncertainty in the hub simultaneously to design a network with multiple objective functions. In their study, Zhalechian et al. [34] focused on social responsibility and congestion in the hub and spoke problem. Khodemoni-yazdi et al. [35] studied hierarchical HLP applying a two-objective model while incorporating the queuing system in their study. Karimi-Mamaghan et al. [36] proposed a novel bi-objective model to consider congestion in both hubs and hub-to-hub connections in a hub-and-spoke network. The goal of the model was to minimize the time and cost of transportation. They also developed a new model based on the GI/G/c queuing system to study the congestion in the bub nodes, while a traffic model was utilized for the flow congestion between hubs.

Bütün et al. [37] developed a model to optimize the hub-and-spoke network for the shipping sector under congestion in the hub nodes. In their capacitated directed cycle hub location and cargo routing problem, the nonlinear costs of congestion were then linearized using a linear approximation. Alumur et al. [38] mentioned that congestion in hub the HLP will be a significant issue for passenger and cargo delivery due to the extra costs it imposes on the model that usually makes the hub location models nonlinear. Najy and Diabat [39] studied a multiple-allocation uncapacitated HLP that incorporates economies of scale and congestion in nodes. They utilized a Benders decomposition approach to solve their proposed model. Alumur et al. [40] modeled the congestion in the hubs and proposed a measure for congestion value in the HLP. They showed that ignoring congestion in the hubs can even make the hub model infeasible.

Several studies in the HLP have been conducted to cover some novel aspects of the HLP in recent years, which are mentioned here. Sadeghi et al. [41] regarded the budget for travel time in p-hub covering problems. Environmental aspects of the HLP were studied by Zhalechian et al. [42] by proposing a mathematical model involving noise pollution of the transportation facilities. Korani and Eydi [43] proposed a bi-level programming model whose first level was to minimize the cost of establishing a hub network, and in the second level, the service level loss was reduced. They solved the model by developing a two-stage penalty heuristic method utilizing penalty functions. Mahmoodjanloo et al. [44] utilized a bi-level programming model to consider the customer loyalty of a transportation company and minimize the transportation pricing by designing a competitive hub. They tackled the hubs' location and assignment decisions first, while pricing decisions were considered next. To solve the model, they utilized a scatter search algorithm and a metaheuristic method. Golestani et al. [45] focused on tackling an HLP for transportation of multiple perishable goods in a cold supply chain whose maintenance temperatures were not the same. They proposed a bi-objective model to minimize the hub establishment, transportation, and CO2 costs while adjusting the storage temperatures. Further studies in this regard can be reached in Alizadeh Firozi et al. [46], which has focused on solving a single-allocation HLP by an improved genetic algorithm [47]-[49].

In the HLP literature, multi-server hubs with different service rates are not addressed, and this was our primary motivation to incorporate this real-world characteristic of the problem into the model. In this paper, we obtain the distribution rate of each node. The service capacity of each node should be studied to determine the probability distribution of the service rates. Having the service rates determined, other variables, including the queue length, waiting time, and system time, can be achieved using mathematical queueing equations. Since each node has the role of collector and distributor, each hub has a service system that includes one server or more. Given each hub's arrival and service rates, the whole system can be analyzed as a queuing system. In the proposed system, each hub node comprises several servers that handle the inflow to the hub node. Each server has a service rate, which depends on the system status and the number of customers in the system.

An example is given here to illustrate the proposed model in this paper. Suppose that several cities should be interconnected owing to their mutual demand and supply interactions. So, the cities are considered nodes *Fig. 1*, and if a city in this network is selected as a hub, it can have multiple servers to process the flow from/to other cities. Therefore, the hub median model with multiple allocation modes can be used in this example. By selecting a specific city as a hub, some facilities should be established, imposing an establishment cost on the model, which is added to the transportation costs of the model. If l is the number of servers in a hub city, then the city is assumed to be assigned with β_l% of the whole load. The service rate follows an exponential pattern in the cargo service centers at each hub while remaining finite. On the other hand, while the number of customers in each hub is desired to be less than a given value, this will not always be the case. Furthermore, the output of each server is identical in every respect, and each server offers the same service quality as other servers. Consequently, in this instance, in the presence of service rate limitation and the excess number of customers in the system, it will be inevitable for a queue to be formed at each hub.

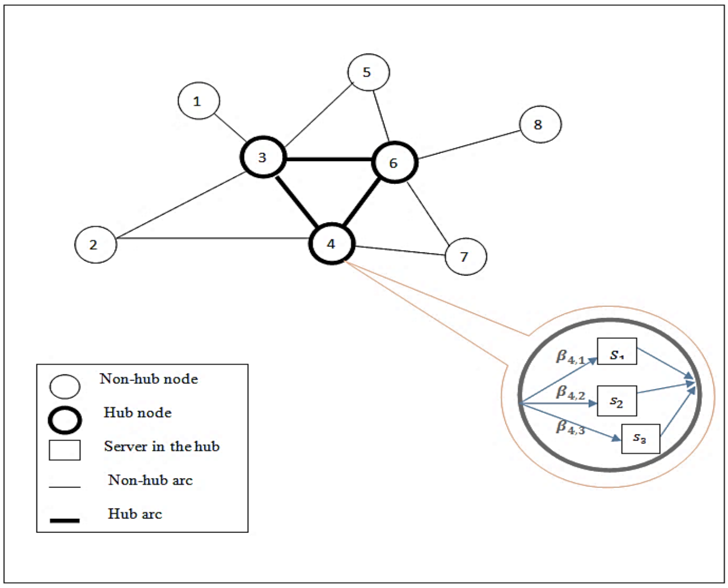

Fig. 1. The schematic form of the proposed approach.

3 | Modelling

This paper addresses a HLP based on the p-hub median model that considers the limited number of customers in the queue for each hub, and the objective is to minimize the total costs, including transportation and establishments costs. P-hub median models use three-part paths for collection, transfer, and distribution. Campbell [1] considers the cost for an origin-destination path as $C_{ijkm}=d_{ik}+\alpha d_{km}+d_{mj}$ where d_{km} is the distance between two hubs (k and m), and d_{ik} and d_{mj} depict the distances between the hub and non-hub nodes. The parameter α $(0 \leq \alpha \leq 1)$ represents the discount amount corresponding to hub arcs to reflect the lower transportation cost due to the higher transportation scales.

The variables and parameters of the mathematical model are as follows:

Decision variables

X_{ijkm}: The fraction of flow from node i (origin) to node j (destination) from path i-k-m-j.

$$Y_k: \begin{cases} 1, & \text{if node i is allocated to hub k,} \\ 0, & \text{otherwise.} \end{cases}$$

Parameters

C_{ijkm}: The transportation cost from node i to node j from path i-k-m-j.

W_{ij} : The flow (e.g., freight volume) to be transported from node i to node j.

F_k : The fixed cost of opening a hub at node k.

F_{km}: The fixed cost related to the establishment of an arc between hub nodes k and m.

P: The number of hubs.

$\theta_{q,kl}$: The maximum acceptable value for the probability of an excessive queue length at the l^{th} server of hub k.

b_{kl}: Maximum acceptable queue length at the l^{th} server of hub k.

$$\text{Min} \sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\sum_{k=1}^{n}\sum_{m=1}^{n} C_{ijkm} W_{ij} X_{ijkm} + \sum_{k=1}^{n} F_k Y_k + \sum_{k=1}^{n-1}\sum_{m=k+1}^{n} \frac{1}{2} F_{km} X_{kmkm}, \quad (1)$$

Subject to

$$\sum_{k=1}^{n}\sum_{m=1}^{n} X_{ijkm} = 1 \quad \text{for all} \quad i,j,k,m) \mid i<j, \quad (2)$$

$$\sum_{k=1}^{n} Y_k = P\,, \quad (3)$$

$$X_{ijkk} + \sum_{m\neq k}(X_{ijkm} + X_{ijmk}) \le Y_k \quad \text{for all} \quad i,j,k,m) \mid i<j, \quad (4)$$

$$P\left[\text{queue length at the } l^{th} \text{ server of hub k } > b_{kl}\right] \le \theta_{q,kl} \quad \text{for all} \quad k,l), \quad (5)$$

$$X_{ijkm} \ge 0, \quad i,j,k,m), \quad (6)$$

$$Y_k \in \{0,1\} \quad \text{for all} \quad k), \quad (7)$$

$$0 \le \theta_{q,kl} \le 1 \quad \text{for all} \quad k,l). \quad (8)$$

The objective *Function (1)* minimizes the total cost, including the variable costs (collection, distribution, and transportation) and fixed costs (hub and arc establishment). *Constraint (2)* ensures that each origin-destination flow goes through at least one hub node. The selection of exactly p hubs is guaranteed in *Constraint (3)*. *Constraint (4)* ensures that the flow between every two nodes should pass through at least one hub. *Constraint (5)* demonstrates that the probability of exceeding the maximum acceptable queue length in the l^{th} server of hub k is, at most, equal to a pre-defined maximum value at this hub. *Constraints (6)* define variables' sign and acceptable value, and *Constraint (8)* shows the upper and lower bound of θ.

It is assumed that the service rate is in each server is a function of the system status. Therefore, by changing the system status, the service rate is changed. In this paper, it is assumed that the relationship between service rate and the system status is as follows:

$$\mu_n = n^c.\, \mu, \quad (9)$$

where μ is the average system rate when one client is in the system.

μ_n is the average system rate when n clients are in the system.

n^c is a constant factor that represents the state dependency of the service rate.

Also, it is assumed that the input rate follows a Poisson process with parameter λ . Thus, the arrival rate is as follows:

$$\lambda_n = \lambda. \tag{10}$$

As mentioned before, each node consists of some servers, and the servers function independently. The customers are allowed to choose each server on each node and wait in its queue. The arrival rate of each node k is λ_k which follows a Poisson process, and the arrival rate of server l at node k, i.e. λ_{kl} is calculated as follows:

$$\lambda\_kl = \beta\_kl.\ \lambda\_k \quad \text{for all (k,l).} \tag{11}$$

and

$$\sum_{l=1}^{L} \beta_{kl} = 1, \text{ for all } (k). \tag{12}$$

The probabilistic *Eq. (5)* needs to be rewritten in an analytic form to make the mathematical model solvable. In order to obtain a deterministic linear constraint corresponding to this equation, p_s is defined as the steady-state probability of existing s customers in the system with one server. Then, *Eq. (5)* can be written as

$$\sum_{s=b_{kl}+2}^{\infty} p_s \le \theta_{q,kl} \quad \text{or} \quad 1 - \sum_{s=0}^{b_{kl}+1} p_s \le \theta_{q,kl}. \tag{13}$$

While both forms of *Eq. (13)* convey the same concept, the left-hand side in either form illustrates the probability of exceeding the maximum acceptable clients waiting in a queue at the l^{th} server of hub k.

In the forthcoming steps, p_s will be supplanted by an equivalent expression to be substituted in the primary model.

The arrival and service rates of the system are assumed to be λ and μ respectively so, the arrival and service rates of each state will be $\lambda_n = \lambda$ and $\mu_n = n^c.\ \mu$, respectively.

Also, for the considered queueing system in this paper (i.e., an exponential model with variable service rates), the probability of the presence of no customer in the hubs is:

$$p_0 = \left[1 + \sum_{n=1}^{\infty} \frac{\left(\frac{\lambda}{\mu}\right)^n}{n!)^c}\right]^{-1}. \tag{14}$$

The probability of existing n customers in the system is:

$$p_n = \left(\frac{\lambda}{\mu}\right)^n \frac{1}{n!)^c} p_0. \tag{15}$$

As there are infinite numbers of terms in *Eq. (13)*, we propose a method to simplify the computation of p_0. In this method, we define M as a big number and replace the ∞ with M. Thus, the p_0 can be written as

$$p_0 = \left[1 + \sum_{n=1}^{M} \frac{\left(\frac{\lambda}{\mu}\right)^n}{n!)^c}\right]^{-1}. \tag{16}$$

The more quantity of M, the more accuracy in computing p_0. We define ε as a minimum required accuracy for p_0.

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$$\left[1+\sum_{n=1}^{s-1}\frac{\left(\frac{\lambda}{\mu}\right)^{n}}{n!)^{c}}\right]^{-1}-\left[1+\sum_{n=1}^{s}\frac{\left(\frac{\lambda}{\mu}\right)^{n}}{n!)^{c}}\right]^{-1}<\varepsilon. \tag{17}$$

Then we consider $M = s$ to compute p_0.

$$p_0=\left[1+\sum_{n=1}^{s}\frac{\left(\frac{\lambda}{\mu}\right)^{n}}{n!)^{c}}\right]^{-1}. \tag{18}$$

Thus, the *Constraint (13)* and consequently the *Constraint (5)* can be rewritten as *Eq. (19)*:

$$\sum_{n=0}^{b_{kl}+1}\left(\frac{\lambda}{\mu}\right)^{n}\frac{1}{n!)^{c}}\left[1+\sum_{n=1}^{s}\frac{\left(\frac{\lambda}{\mu}\right)^{n}}{n!)^{c}}\right]^{-1}\geq 1-\theta_{q,kl}. \tag{19}$$

Turning to the arrival rate to the hub k, *Eq. (20)* shows this value for the hub k as follows:

$$\lambda_k=\left(\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{m=1}^{n}a_{ij}x_{ijkm}+\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{m=1}^{n}a_{ij}x_{ijmk}\right)\quad \text{for all } k). \tag{20}$$

Furthermore, the arrival rate to the l^{th} server of hub k is given by:

$$\lambda_{kl}=\beta_{kl}\times\left(\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{m=1}^{n}a_{ij}x_{ijkm}+\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{m=1}^{n}a_{ij}x_{ijmk}\right)\quad \text{for all } l,1). \tag{21}$$

where a_{ij} is the peak hour transportation flow from node i to node j by using hub k. In the meantime, the total arrival rate to the hub k is the sum of arrival rates from origin i and hub m.

According to Marianov and Serra [30], we can numerically solve *Eq. (19)* and find the maximum value of variable λ indicated by λ_{max}. All the possible values for the λ that are less than λ_{max} can satisfy *Eq. (19)*. Therefore, *Eq. (19)* is equivalent to the following equation:

$$\lambda\leq\lambda\_max. \tag{22}$$

If the value of λ_{max} is computed for each server of node k (assuming that there is a difference between nodes in terms of service time), we could rewrite $\lambda_{kl}\leq\lambda_{max,kl}$ as follows:

$$\beta_{kl}\times\left(\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{m=1}^{n}a_{ij}x_{ijkm}+\sum_{i=1}^{n}\sum_{j=1}^{n}\sum_{m=1}^{n}a_{ij}x_{ijmk}\right)\leq\lambda_{max,kl}. \tag{23}$$

To solve the model, the following steps (that are proposed by Marianov and Serra [30]) are as follows:

I. Estimating the service rate for each server of hubs.
II. Finding the $\lambda_{max,kl}$ for each server of hubs.
III. Solving the following model by using the value of $\lambda_{max,kl}$:

$$\text{Min}\sum_{i=1}^{n-1}\sum_{j=i+1}^{n}\sum_{k=1}^{n}\sum_{m=1}^{n}C_{ijkm}W_{ij}X_{ijkm}+\sum_{k=1}^{n}F_kY_k+\sum_{k=1}^{n-1}\sum_{m=k+1}^{n}\frac{1}{2}F_{km}X_{kmkm},$$

Subject to:

$$\sum_{k=1}^{n}\sum_{m=1}^{n}X_{ijkm}=1\qquad \text{for all } \ i,j,k,m)\mid i<j,$$

$$\sum_{k=1}^{n} Y_k = P,$$

$$X_{ijkk} + \sum_{m \neq k} (X_{ijkm} + X_{ijmk}) \leq Y_k \quad \text{for all} \;\; i, j, k, m) \mid i < j,$$

$$\beta_{kl} \times \left(\sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{m=1}^{n} a_{ij} \, x_{ijkm} + \sum_{i=1}^{n} \sum_{j=1}^{n} \sum_{m=1}^{n} a_{ij} \, x_{ijmk} \right) \leq \lambda_{max,kl}, \tag{23}$$

$$X_{ijkm} \geq 0 \quad \text{for all} \;\; i, j, k, m),$$

$$Y_k \in \{0,1\} \quad \text{for all} \;\; k),$$

$$0 \leq \theta_{q,kl} \leq 1 \quad \text{for all} \;\; k, l).$$

4 | Numerical Results

To evaluate our proposed approach, we conduct a numerical experiment on the Civil Aeronautics Board (CAB) dataset that includes the distance and flow (i.e., intercity passengers) among 25 cities in the United States [27] portrayed in *Fig. 2*. Several instances are designed based on different values of transportation cost discount rates (α = 0.2, 0.5, and 0.8), the number of hubs (p = 4, 8, and 12), and the acceptable number of customers in the queue (b = 5, 20).

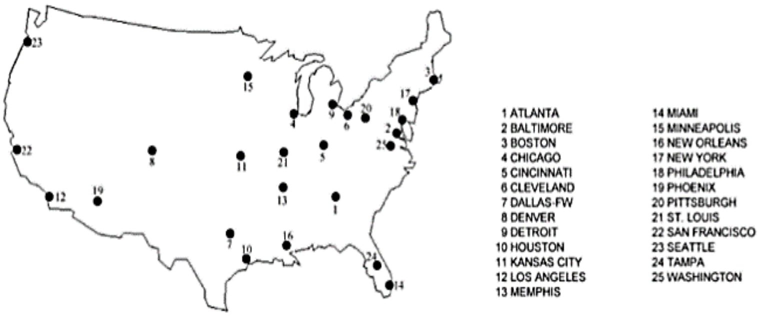

Fig. 2. CAB data set illustrating 25 cities in the United States.

In the generated sample problems, a fixed cost was considered for establishing hub nodes and hub-to-hub arcs. It is assumed that each hub includes three servers with different service rates. The service rates of each server is a function of the number of people in the queue ($c = 0.2$, $\mu_{kln} = \mu_{kl} * n^{0.2}$). Another assumption was that the customers entrance to the first, second, and third server with β_{k1} =0.5, β_{k2}=0.2 and β_{k3}=0.3 respectively. For each server, the value of λ_{kl} was calculated based on the $\theta_{q,kl}$ = 0.95, and was imported to the model. The model was coded and solved in GAMS 22.2 optimization software. The results of the solutions (the values of objective function and the nodes selected as hubs) corresponding to each problem are represented in *Table 1*.

According to *Table 1*, by increasing the value of α, the total cost increases. Also, it is observed that the total cost fo p = 8r is less than the total cost for p = 4 and p = 12. This means that if the number of hubs is increased from 4 to 8, the transportation cost will decrease because the distances between non-hub and hub nodes will be reduced, and the number of arcs with a discounted fee will increases. In such a situation, the transportation cost saving is more than the establishment costs for extra hubs. Conversely, by increasing the number of hubs from 8 to 12, the establishment cost would be higher than the transportation cost saving. Therefore, a network with eight hubs is more cost-efficient than a network with 4 or 12 hubs. The critical point is that if the maximum acceptable value for the queue length is altered from 5 to 20, the total cost decreases because the problem is less restricted. In more detail, in the cases with lower allowable queue length, the model is forced to reduce the number of customers in the queue by assigning higher service rates to the hubs (which implies higher establishment fixed costs to the model). In most solutions, increasing the allowable length of the queue does not change the selected hubs; it changes the assignment of non-hub to hub nodes, however, leading to a reduced total cost (for instance, the problem with = 8 , α = 0.5 and b_{kl} altering from 5 to 20).

Table 1. The resulting solutions for designed problems.

α	p	b_{kl}	Objective Function's Value	Hub Nodes
0.2	4	5	5332	8, 14, 15, 17
		20	4335	1, 8, 17, 20
	8	5	3361	2, 4, 6, 12, 13, 14, 17, 23
		20	3061	2, 4, 6, 12, 13, 14, 17, 23
	12	5	3412	1, 2, 4, 6, 8, 13, 14, 15, 17, 21, 22, 23
		20	3344	1, 2, 4, 6, 7, 13, 14, 16, 17, 19, 21, 23
0.5	4	5	5730	8, 14, 15, 17
		20	4825	4, 8, 17, 20
	8	5	4149	1, 4, 12, 13, 14, 17, 20, 23
		20	4037	1, 4, 12, 13, 14, 17, 20, 23
	12	5	4269	1, 2, 4, 6, 13, 14, 16, 17, 19, 21, 22, 23
		20	4252	1, 2, 4, 6, 13, 14, 16, 17, 19, 21, 22, 23
0.8	4	5	5831	8, 14, 15, 17
		20	5105	4, 8, 17, 20
	8	5	4833	1, 4, 14, 16, 17, 19, 20, 23
		20	4780	1, 4, 14, 17, 19, 20, 21, 23
	12	5	5084	1, 2, 4, 6, 13, 14, 15, 16, 17, 19, 21, 23
		20	4952	1, 2, 4, 6, 13, 14, 15, 16, 17, 19, 21, 23

The results of two computational solutions are shown in *Fig.* 3 and *Fig. 4*. *Fig. 3* indicates the hub nodes and hub arcs for the problem with p = 4, α = 0.2, and b_{kl} = 5. *Fig. 4* indicates the hub nodes and hub arcs for the following parameters p = 4, α = 0.2, and b_{kl} = 20.

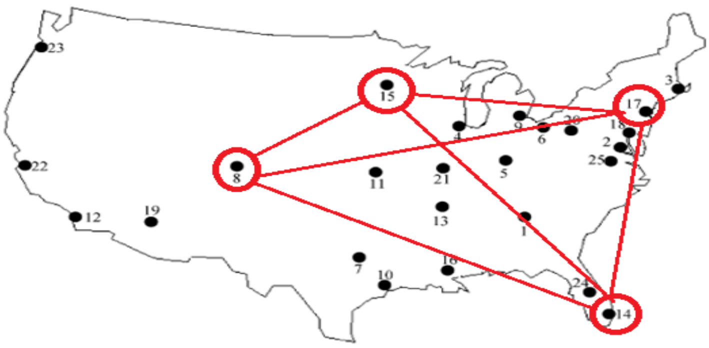

Fig. 3. Hub nodes and related arcs for a problem with p = 4, α = 0.2 and b_{kl} = 5 .

Fig. 4. Hub nodes and related arcs for a problem with p = 4, α = 0.2 and b_kl = 20.

4 | Conclusion and Future Research

In this paper, a pHMP was addressed, in which several servers at each hub provide service to the customers with limited service rates so, a queue with a confined queue length will be created at each hub. The goal is to restrict the queue length to prevent congestion in the hubs. We proposed a Mixed-Integer Linear Programming (MILP) model to minimize the total costs, including transportation and fixed establishment costs, by considering the queue length constraint at each hub. A numerical experiment based on the CAB dataset was conducted to evaluate the proposed approach. The numerical experiment results indicated the impact of restricting the queue length on the solutions by changing the total costs and, in some cases, changing the selected hub nodes. For example, decreasing the allowable queue length increases the total cost due to establishing more equipped hubs with higher service rates and establishment costs. Consequently, strategic decisions regarding how many nodes should act as hubs and how many customers are allowed to receive service at each hub server impact the total costs of the model.

To provide a guideline for future research, the proposed model in this paper can be extended to involve more real-world conditions such as environmental, social, and energy considerations when establishing a hub. Then, if such constraints were added to the model, the model's complexity would undoubtedly increase, making the researchers inevitable of utilizing metaheuristics methods to tackle such complexity.

Conflicts of Interest

All co-authors have seen and agree with the manuscript's contents, and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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E-ISSN: 2676-6167 | P-ISSN: 2538-5100

Journal of Applied Research on Industrial Engineering

www.journal-aprie.com

J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 167–185.

Paper Type: Research Paper

Pricing Under the Policy of Guaranteeing the Return of Money in a Two-Channel Supply Chain Using the Game Theory Approach (Case Study: Lorestan Food Industry Company)

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Citation:

Beiranvand, M., & Davoodi, S. M. R. (2023). Pricing under the policy of guaranteeing the return of money in a two-channel supply chain using the game theory approach (case study: Lorestan food industry company). *Journal of applied research on industrial engineering, 10*(2), 167-185.

Received: 22/10/2021 Reviewed: 20/11/2021 Revised: 08/01/2022 Accept: 15/02/2022

Abstract

Today, one of the topics in supply chain management is "multiple sales channels" and "pricing". In this research, a food producer (West Sahar Dasht Company) has been selected, and several retailers and wholesalers have been considered as the company's customers. Main contribution of this research is, present a pricing model using game theory according to the return of money in the two-channel supply chain. This research dynamically solves the model through the game theory method. To obtain the equilibrium point and Stockelberg, the lower level optimal values (retailers and suppliers) are calculated based on the higher-level values (manufacturer), which turns the multi-level model into a single-level model to calculate the higher level optimal values. By presenting a case study and analyzing the sensitivity of the parameters, it was shown that some changes in the parameters have a significant effect on the problem variables, and its equilibrium model is better. Because game theory is proposed to solve problems on a small scale, and because the present problem is so complex, genetic algorithm meta-heuristic and particle aggregation optimization have been used to solve medium and large problems. To validate their results, they are compared with the results obtained from the mathematical model. Finally, comparing the performance of the two meta-heuristic algorithms through statistical analysis has shown that the particle aggregation optimization algorithm performs better than the genetic algorithm.

Keywords: Two-channel supply chain, Pricing, Money return guarantee policy, Game theory, Meta-heuristic algorithms.

1 | Introduction

The manufacturing industry in its traditional frameworks is facing increasing challenges that are mainly due to poor communication between producer and customer [1], lack of accurate information [2], and lack of appropriate technologies [3]. On the other hand, rapid changes in consumer purchasing behavior and supply chain redesign have led both existing and new retailers to implement a variety of new inventory management strategies [4]. In an unstable business environment accompanied by widespread uncertainty, supply chain managers must determine how to deliver their products and services to customers [5]. Supply chain management involves integrating strategic tools to achieve top management of upstream and downstream processes [6]. The integration of supply, production, and consumption, along with the integration of activities and cooperation between supply chain members, is considered one of the most important supply chain structures [7]. The main

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https://doi.org/10.22105/jarie.2021.311604.1395

advantage of the supply chain is the creation of synergy between the supply chain members, which emphasizes increasing competitiveness and reducing costs [8]. On the other hand, supply chain management, by monitoring and controlling unforeseen events and implementing appropriate strategies through a coordinated approach between supply chain members, reduces risk and creates effective risk management throughout the supply chain, especially timely delivery. According to Forbes magazine, companies like Wal-Mart are recognized as the largest companies in terms of sales [9]. The success of these companies is strongly related to the appropriate supply chain operations strategy [10]. Companies that recognize supply chain management as a strategic asset and use it in their day-to-day processes have an average of 70% higher financial performance [11]. Supply chain management includes several core business disciplines, such as accounting, finance, human resources, information systems, and strategy [12]. Proper supply chain management enables companies to optimize purchasing, production, distribution, retail, and even after-sales service by carefully requesting inventory and executing orders and optimizing purchases and production [13]. Many manufacturers have used multichannel distribution systems to gain access to unknown markets and reduce distribution costs [14]. In today's modern and competitive world, managers are looking to establish and implement an efficient and effective supply chain and be accountable for their logistics and support network due to the increasing number of competitors, fierce competition in the market, and reducing costs. The supply chain includes all actions and operations related to the flow and conversion and exchange of goods from the first stage, the raw material to the last stage, delivery to the customer and the end user, and related information flows. Although many companies and factories used only the traditional retail channel to sell and deliver their products, other companies and factories, which understood the development of technology and the emergence of e-commerce and the desire of customers and end user to buy online and offline, decided to use a direct channel to sell their products and services. Therefore, companies must manage and lead end user and consumers in this two-channel structure [15]. Considering that the overall activity of the supply chain has a continuous and complex relationship with the structure and method of supply chain components and its management principles, there is a need for solidarity and coordination at different decision-making levels to achieve better performance and improve conditions. It can be said that the method that can proportionately, in this regard, interpret, analyze, and model the interactions of decisions made in a supply chain against competitors is the game theory approach [16]. Given the above issues, the approach of focusing on distribution channels in the supply chain has led us to do this research. This issue originates from two main areas. On the one hand, researchers' research shows that there is a lack of research in the field of pricing under the policy of guaranteeing the return of money in a two-channel supply chain, and the knowledge gap in this area is clearly visible. Therefore, the present study answers the following basic question.

How is pricing done under the policy of guaranteeing money return in a two-channel supply chain using the game theory approach (case study: Lorestan Food Industry Company)?

To answer the above question, the most important contribution of this research is as follows:

I. Provide a mathematical model based on the game theory for pricing in a two-channel supply chain.
II. Proposed a suitable Nash equilibrium for considered supply chain in small and large scale.
III. Investigated the proposed Model in Stackelberg form and collaboration for two-channel supply chain.

Remaining of the paper organized as follows: in Section 2, prepared a literature review, in Section 3, presented research methodology, in Section 4, presented results and finally in Section 6, presented conclusion and further research.

2 | Literature Review

In this section, the studies are reviewed. For example, Zegordi and Zarouri [17] presented dynamic pricing in a two-channel supply chain with a fixed amount of product in the event of disruption and random demand. In this article, Nash equilibrium game theory is used and cooperative play is introduced

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as a strategy of confrontation or confrontation against disorder. Papi et al. [18] presented a hybrid approach based on decomposition methods and meta-heuristic algorithms to solve the supply chain network design problem. For this purpose, presented an accurate hybrid solution approach based on Banders decomposition method and genetic algorithm. The proposed approach inherits the solution speed from the meta-heuristic and problem-solving algorithms and ensures convergence to the optimal solution from the Banders method. Honarvar et al. [19] presented a pricing model in a two-channel supply chain environment. In the proposed framework considered a competitive consideration of outsourcing policy in conditions of uncertainty. In this research, two models based on continuous and discrete function of expected profit are presented. The discrete model is based on a scenario and is solved using GAMS software and its solution is considered as a continuous model solution. The results show that there are more suitable options for the manufacturer, domestic production and sales than the online channel. Saeed Mohammadi and Kazemi [20] presented a model for coordination in pricing and participation in a supply chain by considering discounts using game theory. In this study, using game theory, two models of the relationship between producer and retailer are considered, including non-cooperative Nash and cooperative play. The bargaining model is proposed to distribute additional joint profits in the cooperative game based on players' risk and bargaining power. The results show that the retail price has the lowest value when the chain components decide to cooperate, while the producer and retailer's advertising costs in the cooperative game have the highest value. Mozaffari and Qashqaei [21] studied a Collaborative pricing and advertising in the two-tier supply chain with a game theory approach. In this paper, used the game theory approach to modeling and solving price variables, economic order, advertising costs of the retailer and manufacturer at the equilibrium point of the game. Results showed that in the collaborative game, the cost of advertising is imposed on the chain relative to the decentralized chain but increases profits and customer satisfaction, which means a win-win decision-making system for managers and consumers of the chain. Modak and Kelle [22] presented a framework for management of a dual supply chain under price and random time-dependent demand. In this paper, examined the dual supply chain under price and demand dependent on delivery time to the customer. Also, presented mathematical models motivated by profit maximization. Finally, analyzed centralized and decentralized systems for the unknown distribution function of random variables and the known distribution function through a free-distribution method. Jabarzare and Rasti-Barzoki [23] presented an approach to game pricing and quality determination through cooperation contracts in a dual supply chain including manufacturer and packaging company. Model in the research considered the content of the strategy under three scenarios: 1) a non-cooperative game, 2) a co-operative game through a revenue-sharing contract, and 3) a co-operative game through a profit-sharing contract. The results show that the competitive game of the manufacturer and packaging company is very beneficial for customers in price search. Pourghader Chobar et al. [24] presented a pricing decision model in a two-channel supply chain using non-stochastic information. In this research, developed and tested a supply chain screening model in which a dominant manufacturer and a retailer operate under asymmetric information. Results show that the manufacturer had to adjust prices -online and offline- based on various factors such as demand uncertainty, market size, and demand sensitivity to price for each channel. Azami and Saidi-Mehrabad [25] presented a bi-level robust optimization model is developed as a leader-follower problem using Stackelberg game in the field of Aggregate Production Planning (APP). The leader company with higher influence intends to produce new products, which can replace the existing products. The follower companies, as rivals, are also seeking more sales, but they do not have the intention and ability to produce such new products. The price of the new products is determined by the presented elasticity relations between the uncertain demand and price. Fassihi et al. [26] presented a Taguchi hybrid method and data envelopment analysis to determine the parameters and operators of meta-heuristic algorithms such as genetic algorithm to solve the problem of re-entry permutation workshop flow. The efficient units are determined and ranked to determine the best algorithm operators according to the objective function in the shortest possible time. Yadegari et al. [27] studied a waste supply chain network design with price-dependent demand. Main results in this paper categorized in two main global trends: 1) economize the collection and recycling of bottles, 2) cost-effective consumption of plastic bottles. Finally, in this research used the learning and teaching optimization algorithm to solve the proposed model. Zhou et al. [28] presented a model for behavior-based price discrimination in a two-channel supply chain with disclosure of retail information. This study explores price-based discrimination strategies of a manufacturer in a two-channel supply chain in the presence of retail information disclosure service checks. Liu et al. [29] presented a different study for pricing of products with customer network acceptance in the dual-channel supply chain. In this paper, created the basic demand and profit performance by maximizing the utility for the consumer. Then, used game theory to analyze optimal decisions under single-channel and dual-channel supply chains and examined the impact of different consumer network acceptances on optimal pricing, demand, and supply chain profits. Barman et al. [30] presented an optimal decision making and optimal pricing in a two-channel supply chain. The supply chain model examines maximum profit in both centralized and decentralized decision-making structures. Moreover, the Stalkberg game method has been used to solve the scenarios. According to the numerical findings and sensitivity analysis, the focused scenario is more profitable than the decentralized scenario. Azami and Saidi-Mehrabad [31] presented a seller-buyer model for perishable products under competitive factors. For this purpose, a new demand function is defined considering the price, advertisement, freshness, and encouragement strategies. Finally, a hierarchical heuristic approach is proposed using the genetic algorithm and Benders decomposition algorithm. Azami et al. [32] develops a bi-objective optimization model for the integrated production-distribution planning of perishable goods under uncertainty. The first objective seeks to maximize the profit in a specific supply chain with three levels: plants, distribution centers, and in the last level, customers. Since transportation is one of the major pollution sources in a distribution problem, the second objective is to minimize their emission. In the considered problem, the decisions of production, location, inventory, and transportation are made in an integrated structure.

According to the above mentioned in this study, the combination of Nash and Stockelberg equilibrium game theory has been investigated so that there is a first type of game in the category of suppliers. Suppliers compete with each other to obtain more raw materials from the manufacturer and in the category of retailers. Moreover, the producer is the second type of game that members compete for more profit. Therefore, addressing the issue of pricing in the supply chain and determining the optimal interaction between retailer, manufacturer, and customer is one of the issues that can always be addressed as a good way for supply chain managers.

3 | Research Methodology

In terms of the general approach of this research, it is classified as quantitative due to the use of mathematical models. In terms of inductive-inferential classification, this study falls into the field of inferential studies due to the use of specialization of a general theory in a specific situation and application. In other words, in this research, an attempt is made to use the concept of game theory to create a mathematical model of a two-level competitive supply chain to achieve equilibrium points of the game. In order to collect data, we compile literature and research background from theses available in universities, scientific databases available on the Internet, books, IEEE, and related articles. Especially in this research, a collection of articles published by reputable associations was used. In order to collect data to answer research questions and achieve goals, companies' databases were used, which include the database of production unit (production capacity of machines, amount of orders received), marketing unit (marketing costs, number of wholesalers, and retailers with a history of 5 years or more), accounting unit (sales, revenue, profit, cost of the product) and warehouse unit (inventory, shortage and maintenance costs). The statistical population of this research includes producers, retailers, and wholesalers (customers of producers) in the food industry in Lorestan province in 2019-2020, whose database has been used to price products in the supply chain. To confirm the validity of this study, the Nash and Stockelberg equilibrium models were compared, which showed that the Nash equilibrium model has better performance. In *Fig. 1* depicted proposed conceptual model.

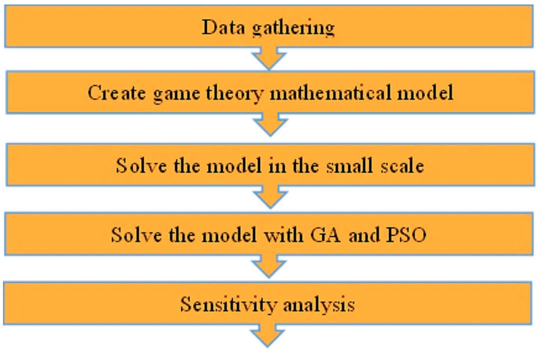

Fig. 1. Conceptual model.

3.1 | Problem Statement

Supply chain structure

In this research, suppose that, there are K retailers in the supply chain that each retailer produces their product from only one manufacturer. In *Fig. 2* shown that the considered supply chain. In general, the consequence of each retailer is the difference between his income and his expenses. In such a situation, the retailer is faced with the costs of ordering, maintenance costs, marketing costs, and a refund for each product. On the other hand, the profit margin of each retailer is the result of the difference between the price paid to the manufacturer for bulk purchase and the selling price to the customer. The variables and parameters used to calculate the retailer outcome are listed and introduced in *Table 1*. It is worth noting that since the final product of each manufacturer is shipped to only one retailer, the number of manufacturers and retailers is equal.

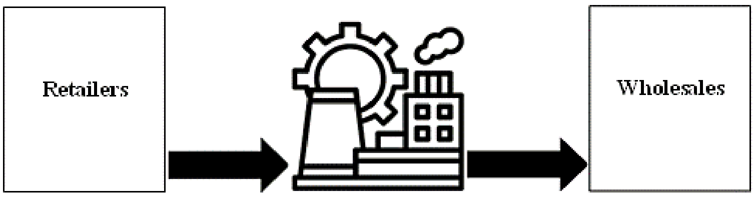

Fig. 2. Supply chcain structure.

Table 1. Symbolism of the general model of retailers.

Number	Symbol	Description
1	G_R	Profit margin of rth retailer
2	P_{rn}	The selling price of the nth product by the rth retailer to the end customer
3	P_n	Bulk selling price of the nth product by the nth manufacturer to the retailer
4	D_n	Demand function of nth product
5	C_m	Marketing costs incurred by the retailer for the nth product
6	k, α, β	Constant demand function, demand price elasticity coefficient and advertising impact factor
7	C_s	Fixed order and purchase costs for the retailer r in each time that the product is purchased
8	Q_r	Order quantity of product n by retailer r
9	K_n	Share of maintenance cost from the purchase price of the product n
10	TR_r	Total revenue of retailer r
11	TMC_r	Total money returns of retailer r
12	TSC_r	Total ordering costs of retailer r
13	THC_r	Total maintenance costs of retailer r
14	TC_r	Total costs of retailer r
15	Z_r	Consequences of retailer r

The general function of each retailer, taking into account demand constraints and sales margins, and if generalized to the entire supply chain, is as follows:

$$\text{MaxZ}_1 = (K.P_{rn}^{-\alpha}.C_{mn}^{\beta}[P_{rn} - P_n - C_{mn} - C_{sm}.Q_{rn}^{-1})]) - \frac{1}{2} \times Q_{rn} \times k_n \times P_n,$$

$$\begin{aligned} &\text{s.t.} \\ &P_{rn} - P_n \geq 0, \\ &Dn = K.P_{rn}^{-\alpha}.C_{mn}^{\beta} \geq 0, \\ &Dn \leq PC_n, \\ &k \succ 0, \alpha \succ 1, 0 \prec \beta \prec 1, \alpha - \beta \succ 1. \end{aligned} \quad (1)$$

Develop the profit function of producers

There are N manufacturers in the supply chain that each manufacturer offers its product to only one retailer. On the other hand, the manufacturer receives the materials needed to produce its products from M suppliers active in the supply chain that each raw material can have a different share in meeting the production needs of different products. Each manufacturer earns income from selling the product to the retailer, and on the other hand, it faces different costs for production, supply of raw materials, possible shortages, ordering, and setting up the production line. Therefore, in this section, preparing the outcome of producers active in the supply chain is desired. The variables and parameters used to calculate the manufacturers' outcomes are listed and introduced in *Table 2*. It is worth noting that since the final product of each manufacturer is sent to only one retailer, the number of manufacturers and retailers is equal $(n = r)$.

Table 2. Symbolism of the general model of manufacturers.

Number	Symbol	Description
1	K_s	Consumption coefficient of raw material s in production of nth product
2	C_p	Purchase price of each unit of raw material s
3	C_s	Fixed start-up cost to produce each product n for producer n
4	C_o	Fixed cost of ordering each unit of raw material from supplier s to produce nth product
5	U,Y	Fixed function of production cost per nth product and impact coefficient of scale advantage of gamma
6	C_h	The cost of maintaining each unit of product n
7	B_n	The amount of money returned on the product n for the producer n
8	C_b	Unit cost of shortage for the nth end product and nth manufacturer
9	G_n	Profit margin of the product n and the producer n
10	TR_n	Total income of the producer n
11	TBC_n	Total purchase costs from suppliers for the nth manufacturer
12	TOC_n	Total commissioning and ordering costs for the manufacturer n
13	TPC_n	Total production costs for the producer n
14	THC_n	Total maintenance costs of the end product for the manufacturer n
15	TSC_n	Total cost of product shortages for the producer n
16	PC_n	Production capacity for the producer n

According to the symbolism and items mentioned in the table above, the general model of a manufacturer in the desired supply chain and its constraints is determined in the following model:

$$\begin{aligned} \text{MaxZ}_n = {} & [(P_n - \textstyle\sum_{s=1}^{m}(k_{sn}.C_{pi}) \times D_n] - [\textstyle\sum_{s=1}^{m}(CO_m) + C_{sn}) - [C_{hn} \times \frac{\lambda.Q_{rn} - B_n}{2.\lambda_n.Q_{rn}}] \\ & \times \frac{D_n}{Q_{rn}} - [u.k^{1-y}.P_{rn}^{\alpha.(y-1)}.C_{mn}^{\beta.(y-1)}] - \frac{B_n B_n^2}{2.\lambda_n.Q_{rn}}, \end{aligned}$$

$$\begin{aligned} &\text{s.t.} \\ &P_n - \textstyle\sum_{s=1}^{m}(k_{sn}.C_{pt}) \geq 0, \\ &CP_n \geq D_n, \\ &D_n = k.P_{rn}^{-\alpha}.C_{mn}^{\beta}, \\ &k \succ 0, u \succ 0, \alpha \succ 1, 0 \prec \beta \prec 1, 0 \prec y \prec 1, \alpha - \beta \succ 1. \end{aligned} \quad (2)$$

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First period, mass production period: the production period should be consumed because industries have purchased a large volume of fresh raw materials; in other words, industries (producers) do not have the inventory of unused raw materials, and all of them have converted to products.

Second period, production as much as customer demand: in this period, due to the perishability of raw materials, limited supply of fresh raw materials as much as the amount of retail, wholesale orders (customer) for raw material products are purchased, and all manufactured products are sold.

4 | Findings

In this research, a food producer (West Sahar Dasht Company) has been selected, and several retailers and wholesalers have been considered as the company's customers. These customers have a history of more than 5 years of cooperation with the company and in the distribution of the company's products. In the marketing and distribution process, there are 5 products produced by the company and for distribution. This chain's customers (retailers and wholesalers) have the same demand for products, which causes the same price to offer products to wholesale customers and retailers. Since the price of raw materials varies in different periods, to cover the costs of purchase and order, the manufacturer increases the price of products in proportion to the price of raw materials for future periods according to maintenance and production costs. The duration of receiving raw materials in the second period is after the completion of all raw materials in the first period. The producer mass-produces in the first period, and in the second period buys and produces raw materials as much as the retail and wholesale orders. This is due to the perishability of raw materials, reducing waste and storage costs, and responding to orders in different periods.

The products produced are priced by the manufacturer and have a certain quality according to the price. Also, the effect of this quality is reflected in the price of the product. In other words, the higher the price for products, the lower the percentage of unusable products between them. In this chain, the transfer of products takes place through the routing of means of transportation. In other words, there is a set of means of transportation with specific costs and capacities that are selected to send products in each period. In each period, the transportation vehicles that serve each customer (retailer and wholesaler) are determined. They started their journey from the manufacturer and referred to the assigned customers to deliver the requests and receive the returns. Then, they travel to the collection center to deliver the returns, and again at the end of the route, they return to the producer. Also, the money for the wasted products is returned to the retailers and wholesalers. In each period, one to a maximum of v transport vehicles can be used, and none of them can load more than their capacity along the way. In this issue, we seek to determine the price of products, order raw materials, determine the location of the collection center and select and determine the route of transportation; in such a way that the profits of retailers, wholesalers, and producers are maximized.

4.1 | Model in Nash Equilibrium

4.1.1 | Production of sample problem on a small scale

To evaluate the performance of the model presented in this section, a sample problem is determined and examined. The sample problem was implemented in Lingo software. The sample supply chain problem presented in this section includes (FL_l) 10 customers, 3 potential locations for the construction of the collection and dismantling center. The construction costs in each location are 670000, 860000, and 700000, respectively. The number of vehicles is 2, the capacity of each vehicle (CV_l) is 170,000 and 150,000, respectively. There are three types of raw materials whose volumetric coefficient (W_r) is 2, 1 and 1, respectively, and the rate of materials that can be used after disassembly (Q_r) is 0.71 and 0.74, respectively. The number of products is equal to 2 and their volume coefficient (W_m) is 9 and 6, respectively. This is an example for 2 planning periods. Also, the coefficient of consumption of raw materials in product 1 is 1, 1 and 3, respectively, and in product 2 is equal to 3, 1 and 3, respectively.

By implementing the presented problem to minimize costs, the result of the model is obtained after spending 12 minutes. The minimum total cost of the chain is equal to 70822706 Rials—the costs of ordering, purchasing, maintenance, using vehicles, routing vehicles, and construction of the collection and disposal center for spoiled food is equal to 2243500, 65569810, 1200726, 490000, 648670 and 670000, respectively. Location 1 has been selected to construct a collection center for the collection and disposal of spoiled food. In the first period, both vehicles of transportation were used. The first vehicle traveled from the manufacturer to customers 9, 6, 5, 7, 10, respectively. After traveling to the collection and disposal center of spoiled food, it returned to the manufacturer. Customers 2, 8, 3, 4, and 1 are served by the second vehicle during the same period, respectively. In the second period, only the second vehicle of transportation is used. After serving the customers, 8, 2, 9, 6, 5, 7, 10, 1, 3, and 4, this vehicle travels to the collection and disposal center, and finally, it returns to the producer.

4.1.2 | Validation of meta-heuristic algorithms

The average relative deviation percentage index for examined algorithms is calculated as follows:

$$\mathrm{RPD} = \frac{(\mathrm{A\lg sol}) - \mathrm{Bestsol}}{\mathrm{MinBest}} \times 100, \tag{3}$$

and is the best value calculated for each experiment by all the proposed algorithms. The exact method is used to validate genetic and particle swarm optimization algorithms and compare them. For this purpose, in the above, the value of $\mathrm{Best}_{\mathrm{sol}}$ is equal to the result obtained from the exact method. The results of this comparison for the presented sample show that the percentage of relative deviation of the genetic algorithm and particle swarm optimization algorithm is very small. In this example, the exact solution method has obtained the optimal amount of profit equal to 70822706 Rials, and the value obtained for the profit function using GA and PSO algorithms are equal to 70817748 Rials and 70819873 Rials, respectively, which have RPD equal to 0.007 and 0.004, respectively. The value of less than one percent of PRD indicates the proper performance of these two algorithms.

4.1.3 | Numerical examples

The parameters in these problems are generated randomly at specified intervals. The nodes for the sample problems are also randomly generated in a square space with a side of 200 units distance, and the $\mathrm{DIST}_{\mathrm{IJ}}$ (distance between them) is calculated based on the step distance. The efficiency of meta-heuristic algorithms is directly related to setting its parameters, so that choosing the correct values of the parameters of an algorithm increases its efficiency. In this research, the control factors of Taguchi method include the parameters of genetic algorithm and particle swarm optimization algorithm. In this method, the aim is to find the optimal levels of important controllable factors and minimize the effect of perturbation factors. Qualitative characteristics measured from the experiments are converted to signal (S / N) ratio. This rate indicates the amount of deviations displayed in the response variable. The reduction of algorithm deviations is when the genetic algorithm parameters are set at 125 for the initial population, 130 for the number of generations, 0.95 for the intersection rate and 0.50 for the mutation rate, respectively. Also, the parameters of the particle swarm optimization algorithm are equal to 100 for the number of particles, 115 for repetition, 0.8 for the weight of inertia and 0.2 for the maximum speed, respectively, which are the best values for the proposed algorithm in this research. *Table 3* shows the levels of each parameter.

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Table 3. Levels of each main parameters of the problem.

Levels	Parameters
50,30,15,10	The number of customers
5,3,2	The number of products
15,10,5	The number of potential locations
4,3	The number of vehicles
7,5,3	The number of time periods

Table 4 shows the results of the proposed algorithms. Computational time and RPD indices are used to compare the performance of each algorithm. According to *Table 4*, the average error of the genetic algorithm and particle swarm optimization algorithm equals 0.0128 and 0.0451, respectively, which indicates the PSO algorithm's better performance than the GA algorithm.

Table 4. Computational results from the comparison of (GA; PSO) and Exact method.

Problem	The Number of Products	The Number of Periods	The Number of Customers	The Number of Potential Locations	The Number of Vehicles	RPD	CPU Time	RPD	CPU Time	RPD	CPU Time
1	2	3	12	5	3	0.001	71	0.0062	56	0.0004	42
2	3	3	15	5	3	0.0076	90	0.003	67	0.0001	56
3	5	3	30	5	3	0.0435	136	0.0249	98	0.0000	78
4	2	5	50	5	3	0.0156	365	0.0088	275	0.0006	150
5	3	5	70	5	3	0.0629	653	0.0046	546	0.0003	330
6	5	5	100	5	3	0.0854	1057	0.0004	777	0.0004	650
7	2	7	10	5	3	0.0636	203	0.0114	148	-	-
8	3	7	15	5	3	0.0795	245	0.0274	179	-	-
9	5	7	30	5	3	0.0818	384	0.0196	282	-	-
10	2	3	50	5	3	0.00095	279	0.0009	229	-	-
11	3	3	70	10	3	0.0069	451	0.0001	329	-	-
12	5	3	100	10	3	0.022	460	0.0043	339	-	-
13	2	5	10	5	3	0.0396	136	0.0018	101	-	-
14	3	5	15	10	3	0.0612	180	0.0047	123	-	-
15	5	5	30	10	3	0.043	290	0.0099	230	-	-
16	2	7	50	10	4	0.0192	986	0.0488	740	-	-
17	3	7	70	10	4	0.0668	1607	0.0159	1187	-	-
18	5	7	100	10	4	0.0837	2672	0.0123	1999	-	-
19	2	3	15	5	4	0.0038	97	0.001	73	-	-
20	3	3	15	10	4	0.0151	100	0.0118	77	-	-
21	5	3	30	15	4	0.0109	202	0.0032	198	-	-
22	2	5	50	15	4	0.0647	613	0.0078	464	-	-
23	3	5	70	15	4	0.0974	978	0.0175	726	-	-
24	5	5	100	15	4	0.0673	1601	0.0205	1193	-	-
25	2	7	10	15	4	0.0085	305	0.0307	188	-	-
26	3	7	15	15	4	0.0996	300	0.015	226	-	-
27	5	7	30	15	4	0.0513	480	0.035	359	-	-
28	2	3	50	15	4	0.0029	239	0.0007	215	-	-
29	3	5	70	15	4	0.0443	992	0.0063	742	-	-
30	5	7	100	15	4	0.0946	2896	0.0317	2139	-	-
Mean						0.0451		0.0128		0.0018	

4.2 | Model in Stackelberg form and Collaboration

4.2.1 | Game theory based on competitive / non-competitive discussion in the manufacturer-distributor supply chain

Competition between producer and distributor

In this method, all the producers play in pairs with the distributor. In other words, in each game, two producers and one distributor compete with each other. Profit ratio as the matrix data of the pairwise comparisons of the two producers is given as input to the model, and after solving it, the producers are weighted in terms of profit in the supply chain. These comparisons are made based on three decision criteria separately.

I. Based on the producer's profit: In this comparison, the producer's profit ratio for a two-player game is considered as the result of a pairwise comparison in the comparison matrix.

II. Based on customer satisfaction: In this comparison, the customer satisfaction ratio for a two-player game is considered as the result of a pair comparison in the comparison matrix. Customer satisfaction is calculated from the following formulation for each participant.

$$W_1\left({P_i}/{P_j}\right)+W_1\left({S_i}/{S_j}\right)+1, \quad (4)$$

where w1 is the weight of the price for the customer and w2 is the weight of the service for the customer.

III. Based on the distributor's profit: In this comparison, the ratio of profit that is distributed to the distributor from each producer is considered for a two-player game as a result of a pair comparison in the comparison matrix.

Results of producers' pair game with customers (wholesalers and retailers)

Table 5 presents a case study of supply chain pricing in dynamic mode.

Table 5. Product data.

Products	Service Cost Coefficient	Production Cost	Market	Price Unit (Rial)		Service Levels	Sensitivity of the Market			
				Wholesaler	Retailer		Differences of Services	Services	Differences of Prices	Price Unit (Rial)
tomato sauce	1200	2000	4200	2800	4500	15	4	5	6	8
canned beans	1400	2800	5800	4000	5000	15	4	5	6	8
canned apple	1600	1750	6000	2400	4300	10	4	5	6	8
pickle	1200	2180	4700	3000	6000	6	4	5	6	8
cucumber	2000	1800	4500	2670	4600	15	4	5	6	8

The level of service in this game is quality. Because after the price, quality has the highest rank. That is, producing a quality product is a competitive advantage.

Optimal game-based outputs defined in the case study

Table 6. Wholesale price of the first participant of Stackelberg producer (prices are in Rials).

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	3239,886	3342,806	3353,092	3303,665	3243,082
canned beans	3775,75	3878,665	3888,945	3839,531	3778,98
canned apple	3830,113	3933,044	3943,325	3893,904	3833,346
pickle	3571,628	3674,563	3684,846	3635,422	3574,853
cucumber	3255,232	3358,1	3368,379	3318,986	3258,445

Table 7. Retail price of the first participant of Stackelberg producer (prices are in Rials).

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	2620,821	2672,295	2677,4	2652,745	2622,49
Canned beans	2789,122	2840,573	2845,671	2821,028	2790,805
canned apple	2791,526	2842,991	2848,09	2823,441	2793,211
Pickle	2836,84	2888,309	2893,411	2868,759	2838,518
Cucumber	2528,208	2579,614	2584,712	2560,087	2529,875

Tables 6 and *7* show wholesale and retail prices of the first participant of Stockelberg producer. Each of them shows how the wholesale and retail prices are compared to each other, and in different pricing conditions, how has it been able to attract market traction?

Table 8. Level of service of the first participant of Stackelberg wholesale (prices are in Rials).

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	6,199332	6,714031	6,765462	6,518325	6,215408
Canned beans	8,232291	8,661104	8,703937	8,498046	8,24575
canned apple	9,455061	9,922926	9,969658	9,745017	9,469753
Pickle	7,007753	7,49792	7,546888	7,311535	7,023109
Cucumber	4,547599	4,869063	4,901185	4,746832	4,557641

Table 9. Service level of the first participant of Stackelberg retail (prices are in Rials).

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	6,208214	6,722365	6,773996	6,527446	6,224903
Canned beans	8,246682	8,67122	8,713927	8,508567	8,256708
canned apple	9,468951	9,936624	9,982639	9,758553	9,483732
Pickle	7,01753	7,507605	7,556293	7,32151	7,033502
Cucumber	4,551219	4,872366	4,904449	4,750544	4,561717

Tables 8 and *9* show the service level of the first participant in Stackelberg wholesalers and retailers. Each of them shows the service level of the first participant in comparison with each other and in different service level conditions; how has it been able to pull the market?

Table 10. Wholesale price of the first participant for the producer Stackelberg (prices are in Rials).

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	4247,258	4576,688	4616,565	4400,801	4300,966
Canned beans	5238,195	5567,58	5607,45	5391,709	5291,911
canned apple	5356,121	5685,529	5725,401	5509,649	5409,839
Pickle	4729,418	5058,836	5098,71	4882,953	4783,131
Cucumber	4389,726	4719,047	4758,913	4543,202	4443,432

Table 11. Retail price of the first participant for the producer Stackelberg (prices are in Rials).

Products	tomato Sauce	Canned Beans	canned Apple	Pickle	Cucumber
tomato sauce	4245,821	4575,085	4614,906	4399,275	4299,593
Canned beans	5236,336	5565,573	5605,388	5389,771	5290,122
canned apple	5354,022	5683,274	5723,09	5507,466	5407,809
Pickle	4727,81	5057,068	5096,886	4881,259	4781,591
Cucumber	4388,607	4717,794	4757,608	4542,015	4442,375

Tables 10 and *11* show the retail price of the first participant for the manufacturer Stackelberg. Each of the numbers shows how the retail prices of the first participant are compared to each other, and in different price conditions, how has it been able to pull the market.

Table 12. Wholescale profit of producer Stackelberg (prices are in Rials).

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	9973032	11697796	15243666	12545842	10036661
Canned beans	25332658	28040522	12698896	12622321	23651147
canned apple	28075500	30215333	16214723	16452133	26541233
Pickle	14051198	75123655	18321456	18200142	27651884
Cucumber	13748500	86662175	21003647	17698227	29654133

Table 13. Retail profit of producer Stackelberg (prices are in Rials).

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	42316622	56412330	853211572	145336415	50182364
Canned beans	36251123	54321566	814236990	162013366	65421369
canned apple	35621422	57148330	891452300	175431146	65795133
Pickle	33154210	55124788	751489963	146521333	69230145
Cucumber	36214501	52145698	652314778	132564822	706821369

Tables 12 and *13* show the wholesaler and retailer profit of the producer Stackelberg. Each of the numbers shows how the producer profit is compared to each other, and in different conditions, how have the retailer and wholesaler been able to influence the company?

Table 14. Wholesale profit from Stackelberg producer (prices are in Rials).

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	81256453	84512698	145987230	4895317532	458796213
Canned beans	82146977	54786138	465231785	659822133	458752156
canned apple	26541333	226793314	326541230	451236640	452330214
Pickle	48765231	154793138	123658463	154796211	495621479
Cucumber	54786231	157433999	479923156	985611456	512365987

Table 15. Retail profit from Stackelberg producer (prices are in Rials).

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	65321233	26542300	32654230	45621300	51420321
Canned beans	12542336	28752320	33652144	45627336	56230025
canned apple	15423625	29874123	26214523	49533170	55621352
Pickle	12032654	26543210	12336852	46985032	56587423
Cucumber	14502658	21542398	15987533	47533392	52652239

Tables 14 and *15* indicate wholesale and retail profits for the producer Stackelberg, each of which shows how the wholesale profits in different products are compared to each other and in different profit conditions, how has the retailer been able to influence the company?

Table 16. Wholesale demand of Stackelberg manufacturer (source: research finding).

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	236533301	32102665	654230014	321662300	87542300
Canned beans	125542660	62354236	689523001	362654233	45875126
canned apple	126535595	52314580	985632104	351479257	45169986
Pickle	132652021	56125874	653216622	265325899	56324556
Cucumber	165423017	59321458	587423001	215632866	61182699

Table 17. Retail demand of Stackelberg manufacturer.

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	8070,678	8070,678	8070,678	8070,678	8070,678
Canned beans	1236,326	9563,156	10326,215	9881,216	1288,266
canned apple	1265,654	8451,125	1023,156	9564,123	1123,123
Pickle	1452,698	6542,145	1068,145	9133,541	1060,14
Cucumber	1065,699	1021,654	1022,478	9205,123	1065,584

Tables 16 and *17* indicate wholesale and retail demand for the manufacturer Stackelberg. Each of them shows how the wholesale and retail demands for different products are compared to each other and in different situations; how have different wholesale and retail demands been able to influence the company?

Table 18. Customer satisfaction level comparison matrix - Stackelberg wholesaler and manufacturer.

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	1	0.63256	0.865323	1.03656	1.412365
Canned beans	0.68851	1	10326,215	0.638465	0.638542
canned apple	0.94324	1.063572	1	1.542366	0.68335
Pickle	1.25536	1.255442	0.638461	1	0.638461
Cucumber	0.68851	1.545907	0.940228	1.063572	1

Table 19. Customer satisfaction level comparison matrix - Stackelberg retailer and manufacturer.

Products	Tomato Sauce	Canned Beans	Canned Apple	Pickle	Cucumber
tomato sauce	1	0.638461	0.68851	0.895507	1.545907
Canned beans	0.68851	0.895507	0.829484	0.68851	0.895507
canned apple	0.68851	0.638461	1	1.545907	0.68851
Pickle	0.68851	0.829484	0.638461	1	0.638461
Cucumber	1.102851	0.68851	0.940228	1.063572	1

Tables 18 and *19* show the level of customer satisfaction for the manufacturer Stackelberg according to the demand of wholesalers and retailers. Each of them shows the level of customer satisfaction compared to each other, and in different conditions, how can customer satisfaction affect the company?

5.3 | Sensitivity analysis

Analysis of the producer's profit sensitivity to change a1

First, the changes in producer profits relative to changes in the market base for products are examined. The chart of changes indicates that an increase in the basis of the producer market will lead to an increase in profits for the producer. This increase for the producer whose market base has increased will increase his profit much more than the wholesale and retail profit for the producer, so the increase in profit for the producer is due to the increase in the number of customers who shift from wholesalers and retailers to producers due to price and service sensitivities, which in turn increases the producer's profits. This chart can be used to show the profit changes, to calculate the economic level a1 of each manufacturer in order to overcome the competitor. This decision can be very successful at the managerial level because each manufacturer, assuming the competitive market level is stable and by increasing the size of their market or increasing the level of advertising, can achieve the economic level of their market base. This level is important because over-advertising is as costly as it is profitable.

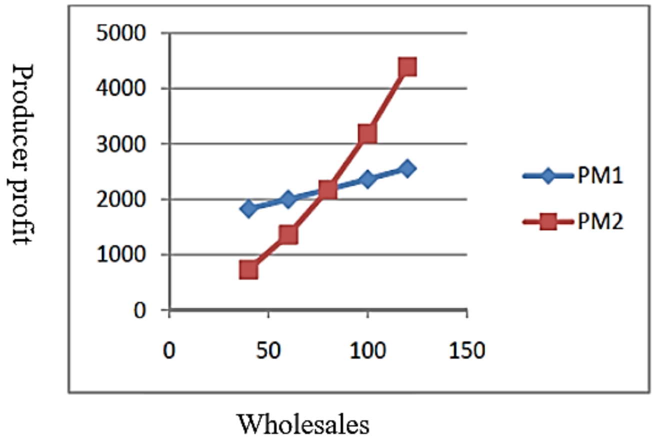

Fig. 3. Analysis of sensitivity of producer profit to a1 change in wholesale Stackelberg.

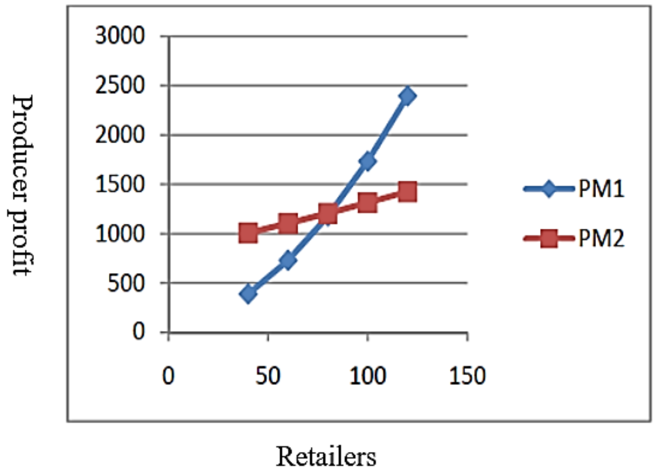

Fig. 4. Analysis of sensitivity of producer profit to a1 change in retail Stackelberg.

Analysis of the producer's profit sensitivity to c1 change

For example, the graph of the change in producer profit by the change in production costs for producers is examined. The change graph shows that a reduction in the cost of production leads to an increase in profits for the producer, while the profits of wholesalers and retailers decrease at the same time. This change is much bigger for a producer whose production cost is reduced than for another producer. Also, it is not far-fetched to increase the profit for each producer by decreasing c. The decrease in profit for the next producer is due to the increase in the number of customers who turn from their customer set to the desired manufacturer because of the price sensitivity and services (the reduction in the wholesale price of the producer whose costs are reduced), which in turn increases the producer's profit.

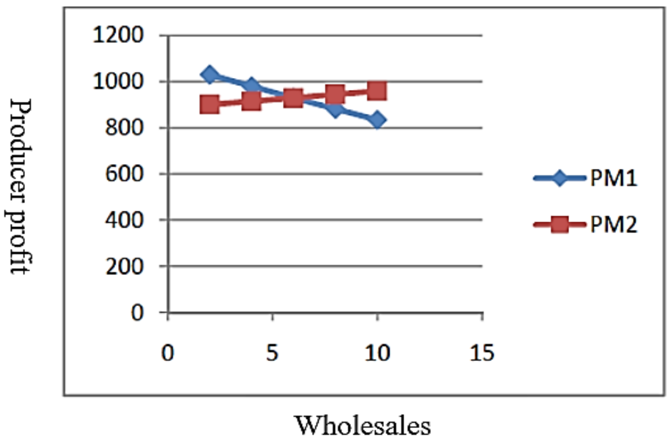

Fig. 5. Analysis of producer profit sensitivity to c1 change in wholesale Stackelberg.

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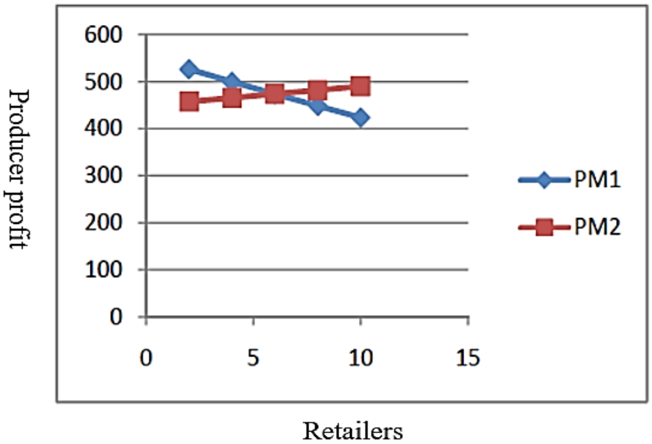

Fig. 6. Analysis of producer profit sensitivity to c1 change in retailer Stackelberg.

Analysis of the distributor's profit sensitivity to change a1

The distributor's profit, like the profit of the producer, increases with the increase of the market base. Increasing the market base will also increase the distributor's profit from cooperating with manufacturers. This increase in profits occurs in two different ways.

I. Increasing profit to increase the retail price: Although wholesale price increases due to increasing market base and consequently increasing demand, the distributor with a higher ratio can increase retail prices due to an increase in service level to balance the game. As a result, the value of the expression pi-wi increases.
II. Increasing profits to increase sales volume: Certainly, increasing the market base affects the number of sales. Distributor profits are also an ascending function of sales volume.

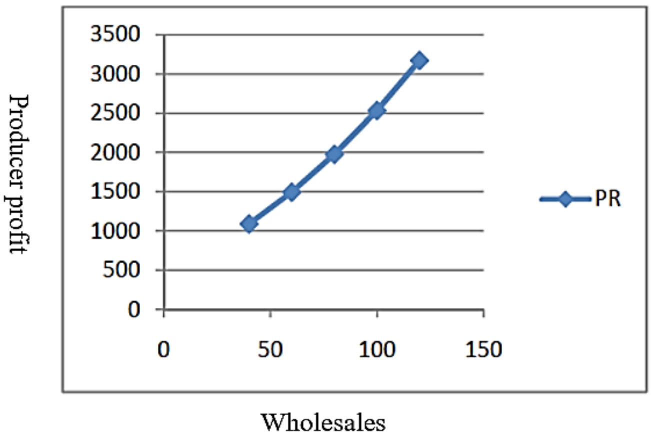

Fig. 7. Analysis of producer profit sensitivity to a1 change in wholesale Stackelberg.

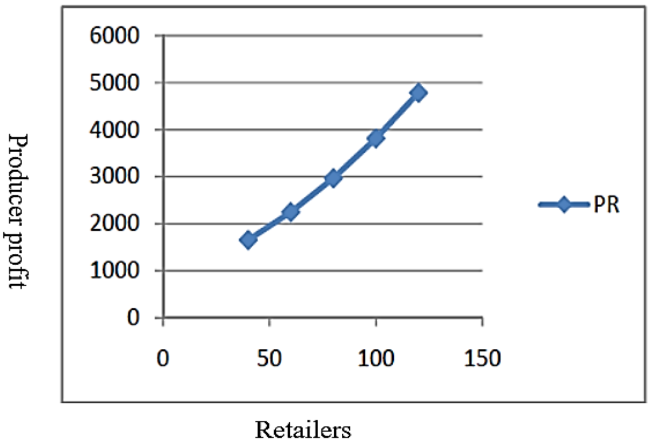

Fig. 8. Analysis of producer profit sensitivity to a1 change in retail Stackelberg.

Analysis of wholesale and retail profits sensitivity to change c1

Certainly, the distributor's profit increases as a result of reduced production costs due to a reduction in wholesale costs. Therefore, in order to maintain its position from the distributor's point of view and improve its competitive position, the manufacturer should seek to reduce production costs. This process can further contribute to the manufacturer's competitive advantage by increasing the market base because the profit for another producer decreases and further improves the producer's competitive position. The decline in other producers' profits is also due to a reduction in demand because the manufacturer attracts more competitor demands by reducing the wholesale price and retail price.

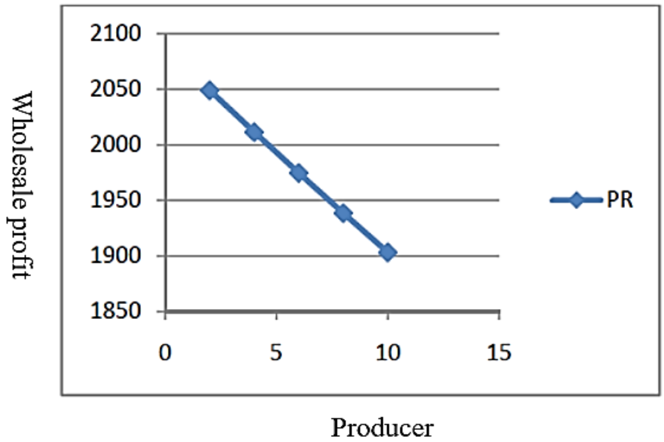

Fig. 9. Analysis of wholesale profit sensitivity to c1 change in producer Stackelberg.

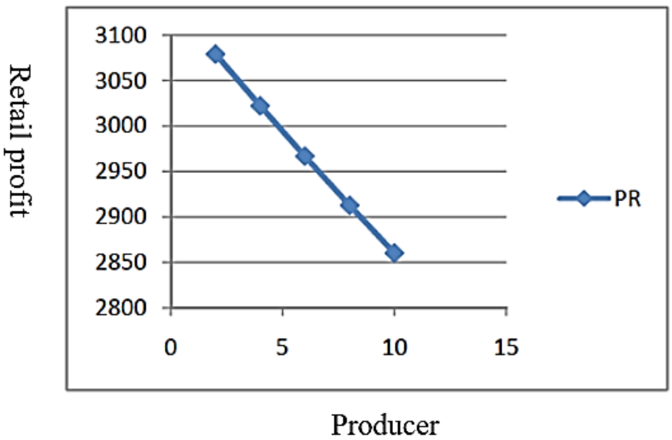

Fig. 10. Analysis of retail profit sensitivity to c1 change in producer Stackelberg.

6 | Conclusion

Given that price fluctuations are high in the Iranian economy, it seems that the pricing modeling of money return guarantee policy and its comparison with static pricing will persuade companies to increase competition by applying pricing money return policy models. Therefore, this paper examines a two-channel supply chain, including several retailers, one manufacturer, and several suppliers. The competition takes place in all three categories of this supply chain, and the manufacturer produces different products and offers to retailers. Competition between chain members is shown in two forms: horizontal competition and vertical competition. Competition and coordination modeling on pricing strategy is presented under a mathematical model. Also, in this model, the relations between the supply chain members in the game are considered cooperative. This model assumes that the producer has more power and imposes its decisions on suppliers and retailers. In other words, the producer has the role of leader, and other members have the role of follower. Finally, sensitivity analysis is performed on the most important parameter of the model, which first introduces problem-solving algorithms. In market structure studies, the horizontal structure for a product is mainly evaluated. While non-competitive behavior is not necessarily related to horizontal behavior, the horizontal structure represents only a part of market power. In fact, market power is the result of a combination of horizontal and vertical competition at different levels of the market. The horizontal structure of the product market is far from competitive, and manufacturers can raise the price of these products above the final cost of production. This means that if there is competition between suppliers or retailers in comparison or other suppliers and retailers, the competition is vertical; otherwise, the competition is horizontal if the retailer or wholesaler does not pay attention to the price of other competitors. Given the complexity of supply chain problems, the proposed problem cannot be solved in a reasonable time for real-world dimensions. Therefore, the meta-heuristic approach in the form of genetic algorithms and particle swarm optimization has been used to solve it. This research is classified in terms of general approach due to the use of mathematical models of quantitative type. In terms of inductive-inferential categorization, this study falls into the field of inferential studies due to the use of specialization of a general theory in a specific situation and application. In other words, in this research, an attempt is made to use the concept of game theory to present a mathematical model of a two-level competitive supply chain and then achieve equilibrium points of the game. In this research, a food producer (West Sahar Dasht Company) has been selected, and several retailers and wholesalers have been considered as the company's customers. These customers have a history of more than 5 years of cooperation with the company and in the distribution of the company's products. In the marketing and distribution process, there are 5 products produced by the company and for distribution. This chain's customers (retailers and wholesalers) have the same demand for products, which causes the same price to offer products to wholesaler and retailer customers. This research was examined in two parts of Nash and Stackelberg equilibrium. The initial model showed that the supply chain pricing capability in Stackelberg mode is suitable with two genetic algorithms and particles. Then the proposed problem is solved by the game theory and dynamic method. It is discussed that in order to obtain the equilibrium point of Stackelberg, the lower level optimal values (retailers and suppliers) are calculated based on the higher-level values (manufacturer), which turns the multi-level model into a single-level model to calculate the higher level optimal values. By presenting a case study and analyzing the sensitivity of the parameters, it is shown that some changes in the parameters have a significant effect on the problem variables, and so the Nash equilibrium model is better. The results of this research can be extended to other industries. The main limitation of this research is the use of recorded data. To overcome the large amount of data, the resulting data is used for one year, which causes an acceptable amount of data to be lost. Also, this research has been done on manufacturers, retailers and wholesalers. Therefore, it does not have the ability to generalize to all components of the supply chain. For this purpose, it is suggested to use collusion games such as Nash-Cornot for further research. Finally, most important managerial insight of the research is as follows:

I. The proposed framework is able to provide a systematic approach to strategic decisions.
II. Predict the outcome of competitive conditions and identify optimal strategic decisions.

Acknowledgment

The authors would like to make special thanks to the three anonymous reviewers for their careful reading of our manuscript and their relevant and useful comments that helped us improve the paper.

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E-ISSN: 2676-6167 | P-ISSN: 2538-5100

Journal of Applied Research on Industrial Engineering

www.journal-aprie.com

J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 186–195.

Paper Type: Research Paper

Implementation of Lean Six Sigma Methodology in a Refractory Company

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Citation:

Solaiyappan, A. (2023). Implementation of lean six sigma methodology in a refractory company. *Journal of applied research on industrial engineering, 10*(2), 186-195.

Received: 29/11/2021 Reviewed: 03/01/2022 Revised: 10/02/2022 Accept: 18/03/2022

Abstract

To enhance the manufacturing process capability of a refractory company, the scope for implementing the Lean Six Sigma (LSS) methodology is analyzed in this work. The DMAIC methodology of Six Sigma is used in this project to determine the Critical To Quality (CTQ) characteristics, defining the possible causes, identifying the variation in sources, establishing the variable relationships, and implementing the control plans. It was found from the DMAIC approach that the quality of Raw Crude, Water Content, and the frequency of using temperature Calibration equipment are the main factors responsible for lowering productivity in Shaft kiln. To improve the productivity of kiln, it was suggested to process the raw crude free of mud, remove the moisture content present in the magnesite stones and take action on changing the frequency of measuring the oil feeding calibration equipment.

Keywords: Lean six sigma, DMAIC, Refractory, Kiln Shaft, Lean manufacturing.

1 | Introduction

Six Sigma methodology includes a set of process improvement techniques and tools which was introduced by Engineer Bill Smith at Motorola Company in 1986. Six Sigma seeks to improve the quality of the product/process by identifying and minimizing the causes of defects and minimizing the variability in manufacturing and business processes. It mainly uses a set of quality management methods such as empirical and statistical tools. Each Six Sigma project is carried out with an organization following a defined sequence of steps and specific targets. Achieving a Six Sigma level means to have a process that generates outputs with 3.4 Defects Per Million Opportunities (DPMO) [1], [2]. Six Sigma is now widely accepted as a high-performing strategy for driving out the defects from the company's quality system. Lean Six Sigma (LSS) concept is the integration of two quality management tools such as Lean Manufacturing (LM) and Six Sigma [3]. LSS attempts to reap the scope and size of improvements that can be achieved by both concepts together.

Therefore, it is an integrated system of LM and Six Sigma. However, some would perceive LSS as two different concepts which are adapted in parallel [4]. The integration between the two quality management concepts varies depending on applications, tools, ideas, and philosophies. Therefore, it

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https://doi.org/10.22105/jarie.2022.317347.1403

leads to many theories on how LM and Six Sigma could be integrated. LM focuses on the reduction of non-value-added activities in production while Six Sigma focuses on the reduction of process variation [5]. The integration would take into account the strength and weaknesses of each concept to make a better concept. The Define, Measure, Analyze, Improve and Control (DMAIC) methodology is used to express the quality performance data expressed as the percentage defect rate that can be converted into a wide range of vital Six Sigma metrics for the development of the company's quality system [6], [7]. In this line, Lean and Six Sigma tools have been successfully implemented in various organizations to reduce its operating costs and increase productivity [8], [9]. Six Sigma methodology was applied successfully to reduce the bearing end plate reworks in a machining process [10]. This methodology was also implemented in the pulp drying process to reduce the dry content variation [11]. The different industrial sectors that include aviation, iron ore manufacturing, printing, rubber gloves manufacturing, extrusion process, grinding, automotive, oil and gas sectors, etc. were experimented with LSS tools and found successful [12]-[21]. Health care, educational industries, IT, and financial sectors also benefitted from this tool [22]-[30]. But no report exists on the implementation of LSS in refractory companies. This motivates to explore the application of LSS to determine the significant process factors capable of obtaining better productivity. LSS utilizes the DMAIC methodology to achieve effective results.

2 | Need for a Case Study in a Refractory Company

The case organization is the small-medium refractory enterprise. It operates in the entire value-chain from the extraction of raw crude (Magnesium Carbonate) from the mines to the finished Magnesium Oxide (MgO) Crystal powders and fire-resistant bricks that are exported to the various needy industries. The main aim is to improve the productivity of the Shaft kiln. In this context, the productivity of the kiln alternatively refers to the conversion of Magnesite (Magnesium Carbonate) bricks to get converted into lightly calcined magnesite. The factors that contribute to the decrease in productivity of the Kiln are analyzed crucially by implementing the LSS framework and the study is continued in the following sections.

3 | Need for a Case Study in a Refractory Company

3.1 | Define Phase

This phase focuses on process understanding of the current reality. Based on the analysis of historical data and assessment of the present situation of the company, the following problems were identified:

I. The decreased productivity of Shaft kiln in the works department due to the various factors is identified as the main problem.
II. Raw crude that comes from the mines is mixed with mud of nearly 25%-30%.
III. More time is consumed due to man-power loading and unloading.

Table 1 shows the statistical capability of the process of the company. It was assessed based on the past functioning of the company. These details are set as the statistical target for the present study.

Table 1. Statistical capability of the process.

Factors	Statistical Quantity
Maximum production capacity	27.5 Tons/day
Current production capacity	14.0 Tons/day
Current defects rate	7.693Tons/day
Opportunity of the defect (per unit)	1
DPMO	549500
Sigma Level	1.376

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3.1.1 | Voice of customer

To determine the Critical to Quality Characteristics (CTQs) of this process, the Voice of Customer (VOC) tool was used. Raymond Mill is their important internal customer. The responses from the Raymond mill are observed as a part of the VOC study. The objective was to identify the parameters for low productivity in the kiln that aims to deliver good quality MgO crystals to Raymond mill. The details of VOC outcomes are presented in *Table 2*. Thus, the factors which emerged out of VOC were raw crude extracted from the mines, man-power loading and unloading time, rain duration, water/moisture content, temperature, and oil feeding calibration equipment.

Table 2. VOC outcomes.

Customer	Observations	Key CTQs	Relevancy to the Project
Shaft kiln	Mud mixed Magnesite crude coming from the mines	20-30% Mud mixed crude	Yes
Raymond mill	Time to load and unload the magnesite stones into the kiln	Loading and Unloading time	Yes
Raymond mill	High variation in moisture content	2-2.2% moisture content	Yes
Raymond mill	It is important to note the temperature and oil feeding at regular intervals to monitor the Kiln temperature.	Need for temperature and oil feeding calibration equipment	Yes

3.1.2 | SIPOC model for process mapping

In this phase of the research, the key metrics of the project were identified, the data collection process was developed and executed. This was done to understand the process in detail. This includes the macro as well as the micro-level of process mapping. The macro-level mapping was done using Suppliers, Inputs, Process, Output, Customers (SIPOC) concept. SIPOC provides important inputs to monitor products and services provided for customer satisfaction. The VOC outcomes are shown in *Fig. 1*.

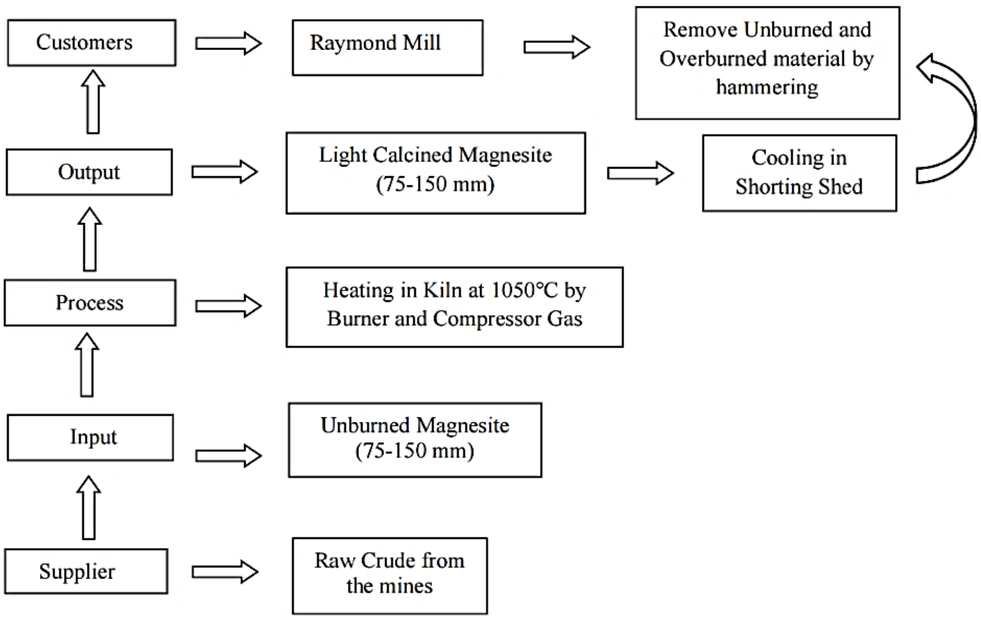

Fig. 1. Schematic diagram of process mapping chart.

3.2 | Measure Phase

In this phase, a standard measuring system is to be established to set the specification limits for the factors that contribute to low productivity in the Kiln. To decide the levels and factors, the measuring system needs to be established. The deliverables (Y) and potential causes or suspected factors (X) are shown in *Table 3*.

Table 3. Identifying the deliverables and causes.

Major Deliverables (Y's)		Specification Limit	Data Type
1	Production time	Depending on the factors below considered in this study.	Continuous
2	Temperature	Depending on the factors below considered in this study.	Continuous
3	Quality	Depending on the factors below considered in this study.	Ok/ Not Ok (Discrete)
Identified Causes (X's)−2 Level		**Specification Limit**	**Data Type**
1	Raw crude	20%-30%	Continuous
2	Moisture content	2%-2.2%	Continuous
3	Loading time	520-754 min	Continuous
4	Mounting above kiln	0-150 min	Continuous
5	Unloading time	240-320 min	Continuous
6	Temperature calibration equipment	110-160 min	Continuous
7	Oil feeding calibration equipment	280-380 min	Continuous

3.3 | Analysis Phase

3.3.1 | Defining possible causes

The Cause and Effect (CE) analysis technique was used to identify all the causes as shown in *Fig. 2*. The CE matrix was used to prioritize the potential causes. Failure Mode and Effect Analysis (FMEA) was also used in capturing potential causes. This was the outcome of a brainstorming session of the concerned managers. Based on the above steps, the major causes were identified in the CE diagram. The major causes are: raw crude from the mines, oil flow rate, Man-power loading and unloading time, Moisture content, mounting above the kiln, Temperature, and oil feeding calibration equipment.

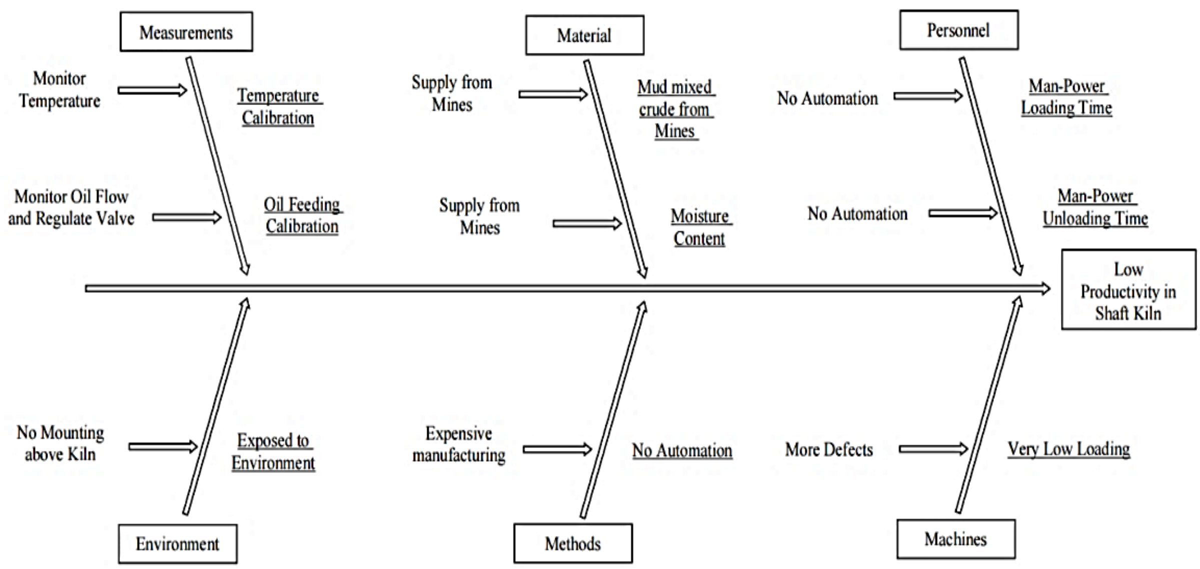

Fig. 2. CE diagram for low productivity in kiln.

A two-level CE matrix is shown in *Table 4*. There are seven factors listed on the input side as listed below and three factors listed on the output side. As the productivity of the Kiln has a higher impact on temperature, it is rated as number (5) in the CE matrix. The next impact is on the production time and, thus, is rated number (4). As productivity has a lower impact on quality, it is rated as number (3). If the influence of input on the output is more, a higher rating of 5 is given and if the influence is low, a lower rating of 1 is given. Based on the subtotal obtained in the CE matrix, a Pareto analysis chart is drawn to analyze the root cause for low productivity in Kiln.

Table 4. CE Matrix (2-level matrix).

Category	Input	Output Production Time (4)	Quality (3)	Temperature (5)	Subtotal
1	Raw crude	4 16	5 15	5 25	56
2	Man power loading time	3 12	2 6	3 15	33
3	Moisture content	2 8	3 9	2 10	27
4	Mounting above kiln	1 4	1 3	1 5	12
5	Man power unloading time	3 12	2 6	2 10	28
6	Temperature calibration Equipment	4 16	2 15	2 20	51
7	Oil feeding calibration equipment	5 20	4 12	4 20	52
Total		84	66	105	

3.3.2 | Pareto analysis chart

Pareto analysis is a tool to make decisions based on possible impact and importance to customer satisfaction and bottom-line results. It is an 80:20 rule that means that 80% of the problems come from 20% of the process. The Pareto chart is a bar chart showing attributes of the problem on the X-Axis and frequency of occurrence on the Y-Axis. *Fig. 3* shows the Pareto analysis of this process.

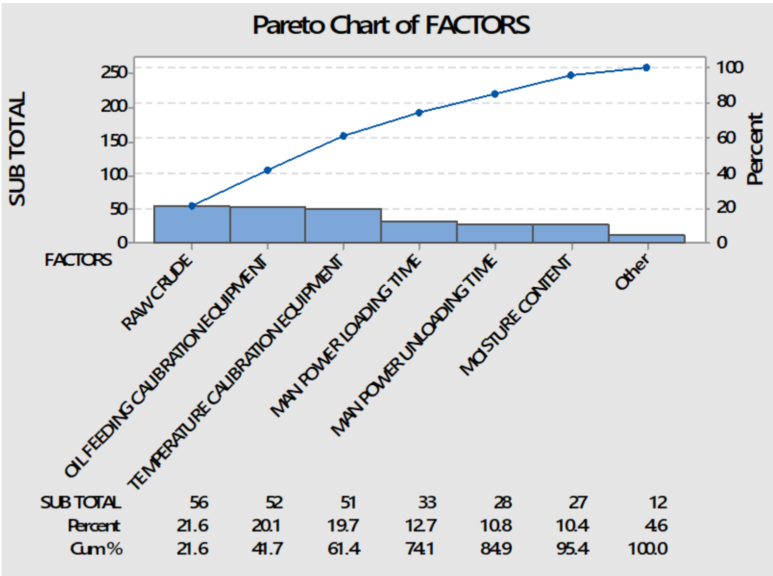

Fig. 3. Pareto chart for low productivity in Kiln.

It lists attributes such as causes of defects or factors with the highest occurrence listed on the left side. Pareto analysis is a great tool to discover the primary causes of a defect quickly for an LSS team to focus on maximizing the results. After the completion of the Pareto analysis, it would be easy for anyone to sort out the contribution of each factor to the output.

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3.4 | Improve Phase

3.4.1 | Factors and level setting

This phase concentrates on improving and optimizing the factors like raw crude, man-power loading and unloading time, moisture content, mounting above Kiln, temperature, and oil feeding calibration equipment that impact the temperature values. In this phase of the project, Design of Experiments (DOE) is conducted by considering Full Factorial Design (FFD) with 2K Model i.e. 2-levels and K-factors. The selected factors and the levels are shown in *Table 5*. As FFD has higher accuracy than Taguchi or Response Surface Methodology (RSM), it is adopted as a DOE strategy. According to FFD for 2 levels and 7 factors, 128 experiments were carried out.

Table 5. Factors and their levels.

Symbol	Factors	Unit	Level	
			-1	+1
RC	Raw crude	%	20	30
MPLT	Man power loading time	min	520	754
WC	Moisture/water content	%	2	2.2
RD	Rain duration	min	0	150
MPUT	Man power unloading time	min	240	320
TCE	Temperature calibration equipment	min	110	160
OFCE	Oil feeding calibration equipment	min	280	380

At the predefined set conditions in the above table, the humidity level of the infrared thermometer *Fig. 4* is set as 0.76. Then a laser light from the infrared thermometer falls on the desired point to give the values of the temperature at the specified point. The values of temperature are observed according to specified conditions of FFD.

Fig. 4. Infrared thermometer for temperature calibration.

3.4.2 | Analysis of variance for process factors

For the experimental observations, the variance is analyzed based on the factors like Degree of Freedom (DF), Sum of Squares (SS), Mean Squares (MS), F-Value, and P-Value. The significance of each factor can be identified from the corresponding P-Value. As Level-of-Significance (LoS) is taken as 0.05 in this case, the factors having LOS less than or equal to 0.05 are considered significant. The Analysis of Variance (ANOVA) parameters are tabulated in *Table 6*.

Table 6 ANOVA for the output of kiln temperature.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	28	109138	3898	74.87	0
RC	1	698	698	13.41	0
MPLT	1	254	254	4.87	0.030
WC	1	201	201	3.86	0.052
RD	1	4	4	0.07	0.795
MPUT	1	64	64	1.22	0.271

Table 6. Continued.

Source	DF	Adj SS	Adj MS	F-Value	P-Value
TCE	1	11	11	0.22	0.643
OCE	1	2403	2403	46.16	0
RC*MPLT	1	1992	1992	38.27	0
RC*WC	1	1269	1269	24.37	0
RC*RD	1	188	188	3.61	0.061
RC*MPUT	1	74	74	1.41	0.238
RC*TCE	1	0	0	0	0.971
RC*OCE	1	3210	3210	61.66	0
MPLT*WC	1	508	508	9.76	0.002
MPLT*RD	1	8	8	0.14	0.705
MPLT*MPUT	1	51	51	0.98	0.324
MPLT*TCE	1	4	4	0.08	0.779
MPLT*OCE	1	111	111	2.12	0.148
WC*RD	1	11	11	0.21	0.651
WC*MPUT	1	59	59	1.14	0.289
WC*TCE	1	3	3	0.07	0.798
WC*OCE	1	549	549	10.54	0.002
RD*MPUT	1	22	22	0.42	0.518
RD*TCE	1	42	42	0.8	0.373
RD*OCE	1	29	29	0.56	0.457
MPUT*TCE	1	6	6	0.11	0.742
MPUT*OCE	1	8	8	0.14	0.705
TCE*OCE	1	1	1	0.03	0.874
Error	99	5154	52		
Total	127	114292			

The coefficient of determination (R^2) value of 93.4% confirms the prediction quality of the developed model as in *Eq. (1)* representing process factors and Kiln temperature.

$$TEMP = 1734 + 11.39*RC - 0.292*MPLT - 167.2*WC - 0.421*MPUT - 2.080*OCE - 0.00674*RC*MPLT - 6.30*RC*WC - 0.00323*RC*RD - 0.00379*RC*MPUT + 0.02003*RC*OCE + 0.1703*MPLT*WC + 0.000135*MPLT*MPUT + 0.000159*MPLT*OCE + 0.170*WC*MPUT + 0.414*WC*OCE + 0.000304*RD*TCE. \quad (1)$$

The residual plots in *Fig. 5* confirm the prediction ability of the developed regression equation and it can be used for further analysis.

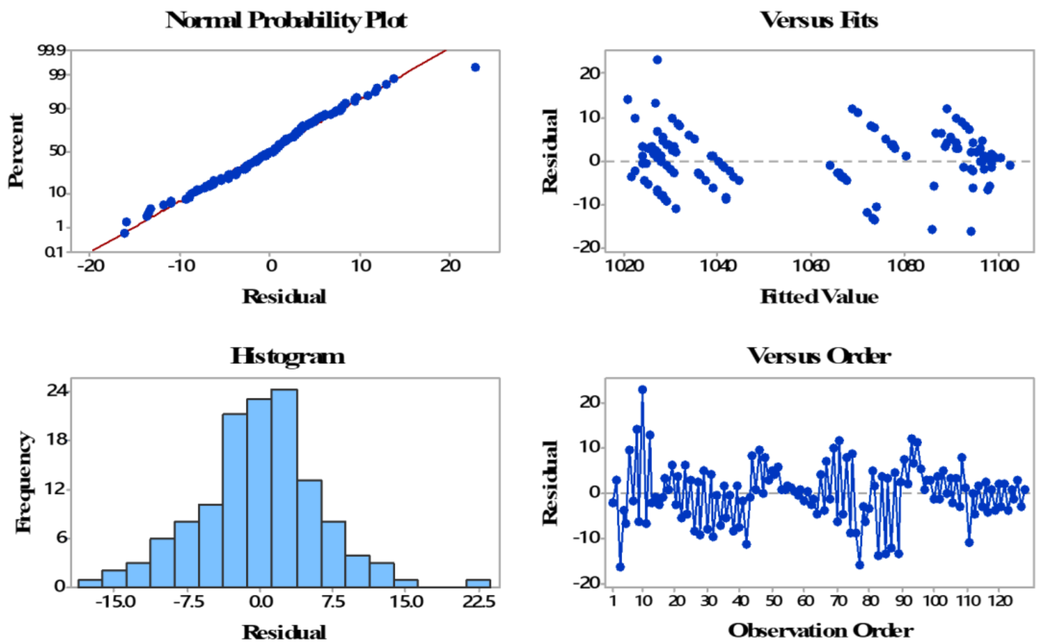

Fig. 5. Residual plots for kiln temperature.

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The main effects plot for Kiln mean temperature variation versus all the factors is shown in *Fig. 6*. It can be observed from the figure that 20% raw crude has a higher mean temperature than 30% raw crude and the slope is quite large for Oil feeding and Calibration Equipment (OCE). Also, OCE used at 280 minutes intervals, has a higher mean temperature than equipment used at 380 minutes intervals. The main effect plot for other factors can also be related similarly.

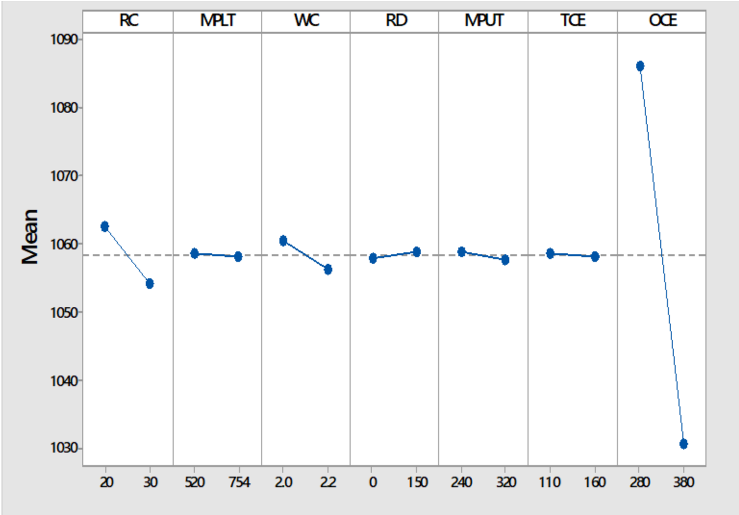

Fig. 6. Main effects plot for kiln temperature (data means).

Interaction plots are most often used to visualize interactions during ANOVA or DOE. The plot as in *Fig. 7* indicates the interaction between the factors within themselves. It can be noted that if OCE interval time is varied between 280-380 minutes, the 20% raw crude has a higher mean temperature than 30% raw crude at 280 minutes interval, while at 380 minutes interval both 20% and 30% raw crudes have same mean temperature. In such a way, the interaction of each factor can be analyzed well in the depicted graphs.

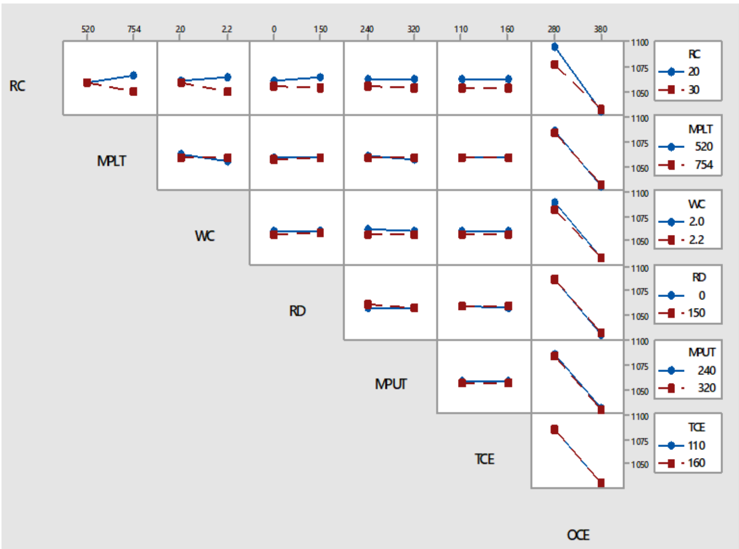

Fig. 7. Interaction plot for kiln temperature (data means).

3.5 | Control Phase

This control phase in the DMAIC process ensures that the process continues to work well, produces desired output results, and maintains the quality level. The X-bar, and R-Chart for the residuals are constructed as in *Fig. 8* to ensure that these residuals are in control within the desired process.

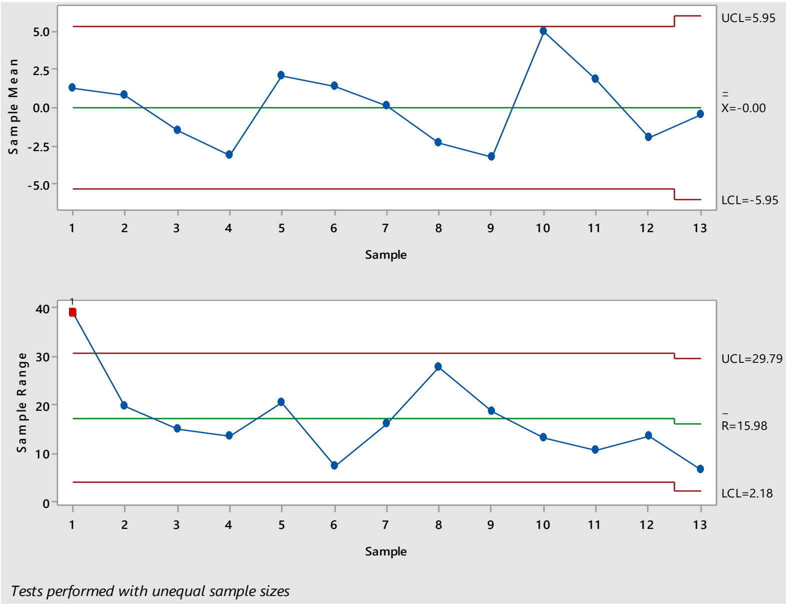

Fig. 8. X-bar and R-charts for residuals.

4 | Conclusion

It is concluded from the application of the DMAIC approach as part of the LSS process in the Refractory Company that raw crude comes from the mines, moisture content in the raw crude, and frequency of using Temperature calibration equipment are the main factors responsible for lowering the productivity in Shaft Kiln. As the crude is mixed with mud, more heat energy is needed to heat the raw crude which, in turn, decreases the productivity of Kiln. Therefore, to improve the productivity of Kiln, the raw crude coming from the mines (mud mixed) must be changed. Secondly, it is suggested to change the frequency of measuring these oil feeding calibration equipment to increase productivity. Finally, the moisture content present in the magnesite stones needs to be decreased to increase productivity.

Acknowledgments

The author would like to thank Mr. Shankar Balaji, M.E. (CAD), Government College of Engineering, Salem - 636011, Tamilnadu, India for his assistance in the collection of data.

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E-ISSN: 2676-6167 | P-ISSN: 2538-5100

Journal of Applied Research on Industrial Engineering

RJARIE

www.journal-aprie.com

J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 196–202.

Paper Type: Research Paper

Assessment of Passenger's Safety Implementation in Water Transportation (a Case Study of Kurutie, Okerenkoko and Escravos Waterways)

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Citation:

Okuma, S. O., & Enughwure, A. A. (2023). Assessment of passenger's safety implementation in water transportation (a case study of Kurutie, Okerenkoko and Escravos waterways). *Journal of applied research on industrial engineering, 10*(2), 196-202.

Received: 18/01/2022 Reviewed: 20/02/2022 Revised: 11/04/2022 Accept: 15/05/2022

Abstract

The purpose of this research is to investigate the safety of inland waterway transportation in Kurutie, Okerenkoko, and Escravos River, Nigeria. The study used a cross-sectional research design, and the study's target group includes passengers who are technical experts, maritime workers, non-academic, academic personnels and students of Nigeria Maritime University, and self-employed passengers who live in the study locations. Questionnaires and field observations were used to obtain data. 378 questionnaires were delivered throughout the study area. According to the study, most cases of maritime boat mishaps beleaguered the inland waterway in the study area due to unskilled boat drivers, overloading/overcrowding of boats, and a lack of enforcement of safety laws by government agencies within the study area. The study recommended that relevant authorities, such as the Nigeria Inland Waterways Authority, enforce safety regulations among jetty operators and boat drivers; that training and certifying boat drivers are enforced; and that government involvement be increased by developing a sensitization program to educate passengers on the importance of adhering to safety practices along the waterways.

Keywords: Safety, Passengers, Implementation, Visualization, Maritime, Boat mishap.

1 | Introduction

Inland waterways have a distinctive role in Nigeria's transportation system, accounting for over 8,600 kilometres and a vast coastland of approximately 852 kilometres, and boasting the second-longest waterways in Africa [1]. According to Ibeawuchi [2], the three major components of water transportation that can be considered in Nigeria are the ocean, coastal water, and inland water transports; Badagry to Warri coastal waterways. The safety of maritime transportation is an establishment based on measures deemed capable of protecting human life, materials, and non-material property associated with marine transport, either directly or indirectly.

Safety at coastal waterways is a fundamental component that can be divided into the following categories: institutions bringing legal regulations, those in charge of implementing and overseeing

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https://doi.org/10.22105/jarie.2022.325274.1440

safety measures and standards, legal instruments related to coastal waterway safety and international maritime conventions, and coastal water users [3].

Passenger boat accidents are prevalent in coastal and interior transportation, particularly when necessary maritime safety laws are not strictly observed and monitored. Commercial passenger boats, on the other hand, are regarded as one of the most successful modes of transportation functioning today, with commercial demand demonstrating its stakeholders and consumers' reliance on it in terms of economical movement of goods and passengers from one destination to another. According to National Inland Waterways Authority (NIWA) [4], the Nigerian waterways system is connected to approximately 880 kilometres of Intracoastal waterways from Lagos via Warri, Port Harcourt, and Calabar. According to the NIWA, there is roughly 3000 km of undeveloped although developable and navigable inland waterways.

Water safety refers to the state of knowing that no detrimental effects will be caused by some agents under specific conditions. Many passengers believe that the government does not take safety concerns seriously. Some waterway travelers have accused the government and stakeholders of failing to take the essential safety precautions to save lives while on the water [5]. In Lagos' waterways, overcrowding of boats, jetties, canoes, and ferries has been identified as a major issue [6]. Passengers, on the other hand, are often unaware of or unconcerned about safety precautions, and opt not to wear life jackets during travels.

According to the water transportation regulating agency in Nigeria, 22 of the 36 states use water as a mode of transportation, and over 296 Nigerians died as a result of boat disasters in 2013 [7]. Despite the potential of the country's inland waterways, Nigeria has a lengthy history of neglect by both the government and the private sector [8]-[13]. Inland water transport systems have received little attention. This is partly due to policy inconsistency, minimal private sector involvement, and disagreements among authorities involved inland water transport management in Nigeria [14].

Other studies on water transportation have been conducted [15]-[19], evaluated the death rates of boat and ferry accidents in Nigeria's inland waterways, with a particular focus on the Port Harcourt waterways. According to [17], the introduction of motorized transportation has expanded our mobility and enriched our lives by widening our perspectives; but, it has also raised the cost of transportation in terms of human lives and suffering caused by accidents. Ill-equipped marine police, nonfunctional boats, and wrecks are all factors responsible for boat mishap [20]. Several studies have also been conducted on the potential and problems of water-based transport, as well as its origin and management of water [19]-[21], [26], [27] discovered in their respective investigations, most jetties in Nigeria and indeed Africa are poorly constructed.

The data from Nigeria Watch revealed that 1,607 lives were lost in 180 boat accidents between June 2006 and May 2015, according to Nwankwo and Ukoji [1]. According to these figures, water transportation has come to play a pivotal place in the nation's economy, especially given the complexities of road transportation.

Mishaps involving boats are more common than ever in Nigeria, owing to the growing use of water transportation, although water transport is one of the safest modes of transportation when compared to road transport, the safety and utilization of commercial passenger boats in developing countries still need to be improved. Passenger boat safety is an issue in most poor countries, and Nigeria is no exception, as seen by the frequency of recent commercial boat disasters. Passenger safety is a vital component, this article aims to investigate passenger safety in inland waterways in Kurutie, Okerenkoko and Escravos, as well as the best strategies to improve safety implementation in these coastal waterways' transportation.

2 | Materials and Methods

2.1 | Study Area

The study was limited to the coastal islands of Kurutie, Okerenkoko, and Escravos because these communities rely solely on marine transportation as the only means of movement of goods and services from one community to another. Nigeria is a coastline nation with a coastline of 853 km and a land mass of about 923,768 sq.km, the coastline lies on the Gulf of Guinea is bordered on the south by the Republic of Benin, and on the north by the Republic of Niger. Nigeria is geographically located between longitudes 30 E and 150 E and latitudes 40 N and 140 N [14].

2.2 | Study Design

The cross-sectional research design was chosen in the study because it allows the investigator to measure both the result and the exposures in the study participants at the same time. To accomplish this goal, the researcher used structured questionnaires that were distributed to passengers, boat operators, and government authorities in the study area.

This is to ascertain their opinion and awareness of the risks involved in inland water transportation, as well as how these risks might be managed to the greatest extent possible.

2.3 | Sample and Sampling Technique

The operators, passengers, and government regulators in the research areas are the targeted population for the study; this population is direct target who commonly use the services of these coastal waterways'transportation [28], [29]. The survey is aimed at 12,000 respondents, including inland waterway operators, passengers, and government regulators in the Warri South Local Government Area of Delta State. As a result, Taro Yamane's formula was used to compute the study's sample size. The formula is as follows:

$$n = \frac{N}{1 + Ne^2} \text{ - - - - - - - - - - - - - - } 2.3,$$

where n = Sample Size, N = Study Population, e = Margin error (5%).

Therefore

$$n = \frac{12000}{1 + 12000\,(0.05^2)},$$
$$n = 387.$$

2.4 | Statistical Analysis

To examine the results of these subjective judgments for quantitative data analysis, statistical techniques were employed as input data, and suitable tests were run. The outcomes of this investigation are analyzed using descriptive analysis. The statistical findings were provided in table form with detailed descriptions and assessed in conjunction with qualitative data.

3 | Result and Discussion

After collecting and reviewing the data for null and/or missing values, various visualizations were built to depict the demographic parameters of the respondents, as shown in *Fig. 1*. This survey has 387 participants. Only 28.94% of the respondents were female. The majority of survey participants are between the ages of 20 and 29, accounting for 39% of the total. This statistic has a good correlation with our findings in the occupation category, where 100 of the survey contributors were students, resulting in a 25.84% correlation. Only 16.28% of respondents have primary education as their highest level of education, implying that the majority of respondents comprehended the survey questionnaires.

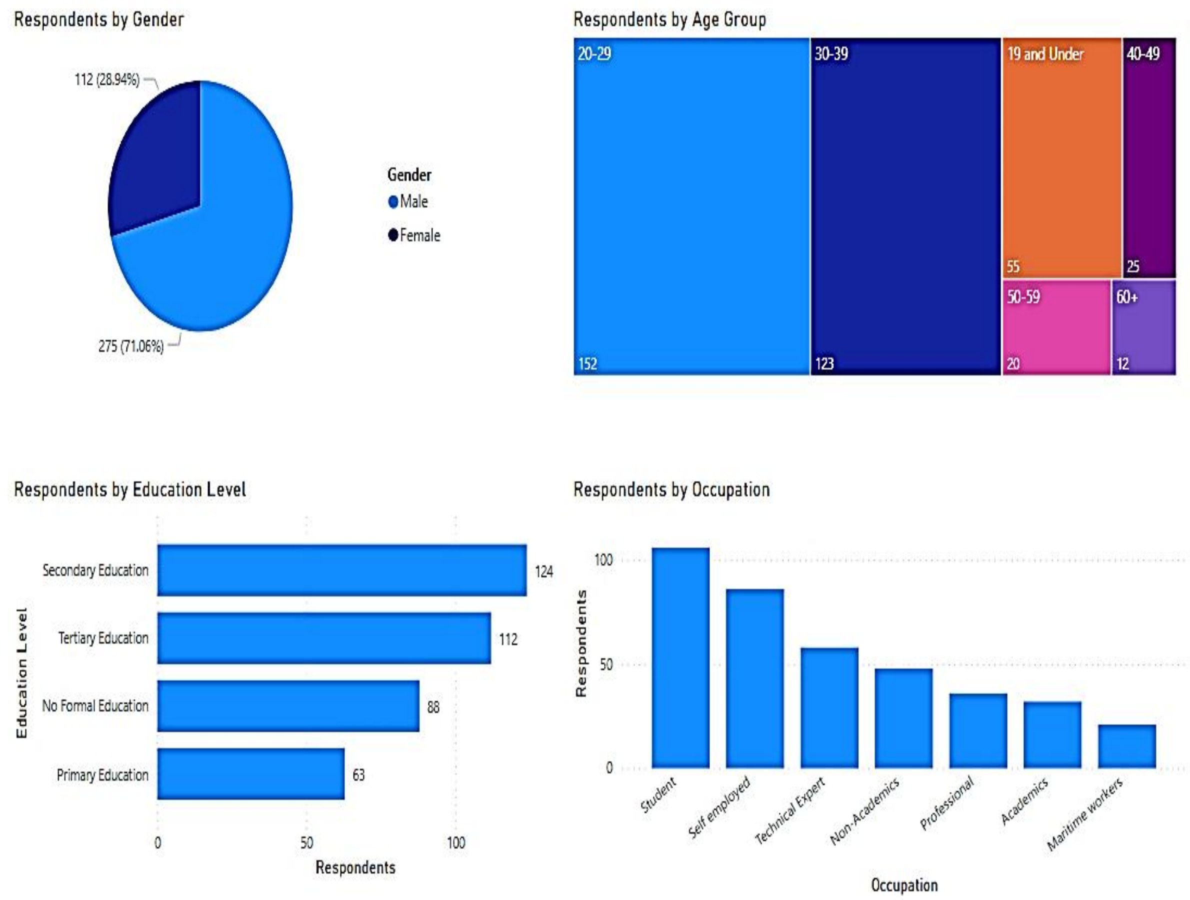

Fig. 1. Demographic visualization on respondent data.

What are the factors responsible for boat mishap in Kurutie, Okerenkoko and Escravos waterways?

The survey responds to the question "what variables are responsible for boat mishaps in the Kurutie, Okerenkoko and Escavos waterways?" *Table 2* clearly shows that 64.1% of participants disagree that boat incidents in the research area are caused by poor boat maintenance.

This assessment has a strong correlation with the faulty engine malfunction question where only 20.67% of the survey contributors suggest that it is the main reason for boat mishap. 32.56% believe boat grounding due to unfamiliarity with the waterway routes is responsible for boat mishaps. This suggests most of the boat drivers are quite familiar with the waterway routes in the study area. 58.40% pointed at the boat driver inexperience as a factor of the boat mishaps in these locations in recent times. 54.5% perceive that the lack of enforcement of safety regulation by government agencies has led to boat mishaps in this study area. This factor most likely played a role in the overloading/overcrowding of boats by jetty operators where three-quarters of the survey partakers suggested it is the reason for boat mishaps. 41% strongly agree that overloading is the main cause of boat mishaps. The findings in these questionnaires reaffirm the earlier study of [30].

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Table 2. Respondent data on the causes of boat mishap.

S/N	Causes of Boat Mishap	SD	D	N	A	SA	% in Agreement
1	Poor maintenance of the boat	103	89	56	54	85	35.9
2	Faulty engine malfunction	167	96	44	34	46	20.67
3	Weather condition/high tide	68	74	66	93	86	46.25
4	Lack of enforcement of safety regulation by government agencies against defaulter	55	63	58	103	108	54.5
5	Boat grounding as a result of unfamiliarity with waterway routes	121	98	42	41	85	32.56
6	Inexperience on the part of the boat driver	45	61	55	121	105	58.4
7	Over loading/overcrowding of boat by jetty operators	55	45	21	132	159	79.19

To what extent will be enforcement of life vest/Safety gadgets on boat improve safety.

Table 3 shows the impacts of the enforcement of safety vests as a way to reduce boat accidents in the study area. 54.5% of the survey respondent suggested that the lack of enforcement of safety regulation by government agencies played a role in the boat mishap in this study area. There was a need to access the respondents' views on enforcing the use of safety gadgets in a bid to reduce boat accidents in the interesting waterways. 71.83% perceive that the use of a safety vest can reduce fatality in case of water accidents. 38% stood strongly on this call: the use of safety vests by passengers as they ply these routes. 24.81% feels the enforcement of the use of a safety vest will boost their confidence level when boarding a boat while 24.55% believes it will also improve the quality of service provided by the transporters.

Table 3. Respondent data on the enforcement of safety gadgets as a way to reducing boat accidents.

S/N	Enforcement Safety Vest	SD	D	N	A	SA	% in Agreement
1	It will reduce fatality in case of water accidents.	58	46	62	131	147	71.83
2	It boosts the confidence level of passengers when boarding a boat.	117	98	76	34	62	24.81
3	It will improve on the quality service provided by the transport provider.	65	73	154	60	35	24.55

Table 4. Respondent data on the measures that can implement passengers' safety.

S/N	Enforcement Safety Vest	SD	D	N	A	SA	% in Agreement
1	Creation of awareness program on safety in water transportation by related agencies	67	56	83	98	83	46.77
2	Training and certification of boat operators and drivers	52	73	55	96	111	53.49
3	Strict measures should be taken by government agencies on jetty management/boat operators	66	45	61	147	109	66.15

What are the measures that can be taken to implement safety of passengers?

Table 4 above outlines the potential measures that could be used to ensure the safety of passengers. Only 46.77% of respondents believe that safety awareness programs run by associated agencies can help with the safety call. Training and certifying boat operators and drivers, according to 53.49%, will increase passenger safety on these waterways. Respondents made a strong request to governmental agencies to guarantee that they oversee the operations of jetty managers and boat operators. This was reflected in their responses, which revealed that 66.15% of them agreed. These findings have a good correlation with the result in previous study [12].

4 | Conclusion

According to the study, it is worth noting that the attributing factors that lead to the increase in boat accidents in the study areas include poor maintenance of the boat, faulty engine malfunction, high tide/unfriendly weather condition, drivers' unfamiliarity with waterway routes, drivers' lack of experience, overloading and overcrowding and lack of enforcement of safety regulations by government agencies. These findings support [31] work that states that these factors have a high correlation with boat accidents in Lagos waterways. One key finding in this study shows that overcrowding and overloading of boats in the study area is the main reason for boat mishaps and passengers' perceive the following measures will minimize the occurrence of water accidents to a great extent: the use of safety gadgets like safety vest, adequately loading of the boats, training and certification of the boat drivers to ensure they know the basics maritime transportation law and practices, government involvement by creating sensitization program to educate passengers on the need to adhere to safety practices as well as monitor and control the boat operators' quality of service at the jetty and on the waterways. We recommend government stamp their authority on the jetty and boat management systems, provide an awareness program for passengers in a bid to sensitize them on their compliance to safety measures as well as training courses for boat operators.

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E-ISSN: 2676-6167 | P-ISSN: 2538-5100

Journal of Applied Research on Industrial Engineering

www.journal-aprie.com

J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 203–217.

Paper Type: Research Paper

A Modification of Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) through Fuzzy Similarity Method (a Numerical Example of the Personnel Selection)

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Citation:

Ebrahimi, E., Fathi, M. R., & Sobhani, S. M. (2023). A modification of technique for order preference by similarity to ideal solution (TOPSIS) through fuzzy similarity method (a numerical example of the personnel selection). *Journal of applied research on industrial engineering*, *10*(2), 203-217.

Received: 20/07/2021 Reviewed: 21/08/2021 Revised: 15/09/2021 Accept: 01/11/2021

Abstract

Multiple Criteria Decision-Making (MCDM) is well known nowadays as a methodology in which a set of techniques are integrated to evaluate a set of alternatives with specified criteria for the purpose of selecting or ranking. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is well-established methodology frequently considered in MCDM analysis. TOPSIS has a sound logic of human choice and is a scalar value simultaneously taking into account both the best and worst alternatives. Moreover, it has a simple computation process that could be easily programmed and finally it has the ability to rank alternatives on attributes to be visualized on a polyhedron, in at least two dimensions. Despite the advantages of this method, the process of ranking alternative according to related criteria may need more consideration. Typically, there are contributions in this article. First, a new similarity measure has been introduced followed by a modification applied to TOPSIS analyses. Second, the modified similarity technique was subsequently extended in the fuzzy context to cope with the uncertainty inherently existing in human judgments. A numerical example of the personnel selection was presented to demonstrate the possible application of the proposed method in human resource management. The outcome of applying fuzzy similarity method showed a significant distinction in ranking alternatives compered to TOPSIS method. Therefore, the modification is sound to be a proper solution.

Keywords: Multiple criteria decision-making, Fuzzy set theory, Modified similarity, Personnel selection, TOPSIS.

1 | Introduction

Multiple Criteria Decision-Making (MCDM) has been introduced and implemented as a procedure, by which a set of techniques are integrated to evaluate alternatives having a number of qualitative and/or quantitative criteria consisting of different measurement units with the aim of selecting or ranking [1]. It provides the users with the ability to comprehend the outcomes of integrated assessments, including tradeoffs among policy objectives, and using such results in a more systematic and defensible way to develop policy for purposeful recommendations [2]. The MCDM makes evaluation on a set of alternatives with respect to three objectives: 1) choosing the best alternative among a set of alternatives, 2) sorting the alternatives into relatively homogeneous groups or arranging them in a preferable order, and 3) ranking the alternatives in a descending or ascending order [3]. Since complexities in making a decision are increased nowadays, decisions are

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https://doi.org/10.22105/jarie.2022.296088.1359

mainly made by groups of decision makers rather than individuals [4]. Therefore, Multiple Criteria Group Decision Making (MCGDM) problems have become common rather than MCDM, where a group of decision makers express their preferences, opinions and judgments about some alternatives in accordance with a set of criteria [5]. Nevertheless, personalization and predilection of opinions of decision makers could undeniably, have been involved in judgments [6]-[9]. Significant efforts in the field of developing and improving MCDM (and also MCGDM techniques) resulted in numerous approaches for effective addressing of multiple general criteria analysis decision problems [10]. The applications of these methods depend on the structure of decision problems [1]. Among all the different MCDM methods, the method Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) developed by Hwang and Yoon [11] is one of the most commonly used techniques, which was applied to many different areas such as production and operation management [12], human resource management [13], knowledge management [14], financial management [15], risk management [16], information technology [17], environmental management [18] and natural resources management [19]. Ranking alternatives in the TOPSIS method is based on the shortest distance from the Positive Ideal Solution (PIS) and the farthest from the Negative Ideal Solution (NIS). Some scholars such as [20], [21] and addressed four advantages of the TOPSIS method: 1) a sound logic that represents the rationale of human choice, 2) a scalar value simultaneously considering both the best and worst alternatives, 3) a simple computation process that could be easily programmed, and 4) ability of the performance measures of all alternatives on attributes to be visualized on a polyhedron, in at least two dimensions. Despite these advantages, the process of calculating the performance index for each alternative according to all criteria in the TOPSIS approach may need more consideration [22]. Mathematically, comparing two alternatives in the form of two vectors is better represented by the magnitude of the alternatives and the degree of conflict between each alternative and the ideal solution, instead of just calculating the relative distance between them [10]. To avoid this concern about TOPSIS, the most preferred alternative in the similarity method should have the highest degree of similarity to the PIS and the lowest degree of similarity to the NIS. The overall performance index of each alternative, according to all criteria, is determined based on the combination of these two degrees of similarity concepts using alternative gradient and magnitude. In other words, it should be better to measure the angle between alternatives and the ideal solution other than just calculating the distance between them. Deng [10] rectified this concern in his proposed similarity method, because the logic of calculating ideal solutions is the same but in the similarity method, this distance is calculating by the angle which is a better criterion. Some other authors used that as a technique to rank alternatives based on certain criteria. For example, similarity technique is used to risk analysis [23], [24], rank services for reliability estimation of Service-Oriented Architecture (SOA) [25] and also evaluating companies based on Corporate Governance (CG) measures [26]. In this article we show that the similarity method introduced by Deng [10] and used by the authors of this paper might also require additional consideration. In other words, the problem caused by relative similarity of the alternative to the NIS in Deng method is explained, and a proper modification for it is introduced. In summary, there are several MCDM techniques such as MABAC [27], COPRAS [28], RAFSI [29], VIKOR [30], [31] each of which, in addition to the advantages, are also having some disadvantages. The TOPSIS technique is no exception to this rule, and in addition to the advantages that make it one of the most common MCDM techniques, it has shortcomings that have been partially covered by the similariy technique but not completely eliminated.

The COPRAS quantitative multicriteria tool is applied with maximization and minimization of variables' values. It allows the user to compare and check calculated results easily. Going more deep into the comparative analysis of the COPRAS, it can be less stable in comparison with the TOPSIS tools on the case of variation of data; thus the COPRAS is used separately from other methods. In the COPRAS technique, we must have at least one indicator with a negative nature, but in the TOPSIS technique, the indicators can be positive or negative.

The main difference between VIKOR and TOPSIS appears in the aggregation approaches. The VIKOR method provides an aggregating function representing the distances from ideal solution. Addition to TOPSIS, VIKOR method provides a compromise solution with an advantage rate. The normalization

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procedures are different in each method. While the VIKOR method uses linear normalization, TOPSIS method uses vector normalization. In linear normalization, the normalized value does not depend to the unit of the criteria. In TOPSIS method, normalized value could be different for different evaluation unit of a particular criterion. The TOPSIS method uses n-dimensional Euclidean distance that by itself could represent some balance between total and individual satisfaction, but uses it in a different way than VIKOR, where weight v is introduced. Both methods provide a ranking list. The highest ranked alternative by VIKOR is the closest to the ideal solution. However, the highest ranked alternative by TOPSIS is the best in terms of the ranking index, which does not mean that it is always the closest to the ideal solution. In addition to ranking, the VIKOR method proposes a compromise solution with an advantage rate.

Three main advantages of the RAFSI method distinguish it from the other traditional MADM methods, which include: 1) RAFSI method enables DMs to solve complex problems, 2) use a new data normalization technique that converts an initial decision matrix into a unique criterion interval, and 3) resistance of the RAFSI method to rank reversal problems. Compared to the TOPSIS technique, the calculation rate of the TOPSIS technique is less.

Compared to the TOPSIS technique, MABAC has an easy computational process, organized procedure, and an innovative direction that determines the foundation of real-world decision-making problems. Therefore, the aim of the present article is to completely eliminate the shortcomings of the TOPSIS technique by modifying the similarity technique and also expanding it in a fuzzy atmosphere. The reason to select this techniquein pursuit of modification and optimization is the benefits listed for it and also the researchers' efforts to identify a solution to the issue that has been addressed and other researchers such as Deng [10] have also confirmed it. It is also suggested that investigators take the modification of other techniques into consideration if needed. The reseatch purpose is to develop a modified similarity method in a fuzzy environment to solve an important problem of the TOPSIS method based on the logic that the comparison of alternatives cannot be determined only by the distance from the PIS and NIS. There are two main contributions in this article. First, a new similarity measure has been introduced followed by a modification applied to TOPSIS analyses. Second, the modified similarity technique was subsequently extended in the fuzzy context to cope with the uncertainty inherently existing in human judgments. Rest of this paper is organized as follows. A detailed algorithmic procedure of the modified fuzzy similarity method is described in Section 2. Section 3 contains an illustrative example in human resource management to demonstrate the applicability of the proposed method. Finally, concluding remarks are given in Section 4.

2 | The Proposed Modified Fuzzy Similarity Method

The similarity method was presented in this section in order to use it while making decisions in fuzzy environments.

2.1 | The Similarity Method

In this part, the similarity method introduced by Deng [10] is presented in an algorithmic form. In addition, during the presentation of the method, a solution is provided for resolving a problem that exists in Deng's technique [10].

Step 1. Determining the decision matrix; the performance of each alternative (A_i) with respect to each criterion (C_j) is denoted as x_{ij}.

Step 2. Determining the weighting matrix; the relative importance of the criterion C_j with respect to the overall objective of the problem is represented as w_j.

Step 3. Normalizing the decision matrix through Euclidean normalization.

$$x'_{ij} = \frac{x_{ij}}{\left(\sum_{k=1}^{n} x_{ik}^2\right)^{1/2}}. \quad (2)$$

Step 4. Calculating the performance matrix by multiplying the normalized decision matrix X' by the weight vector W.

$$Y = \begin{bmatrix} w_1x'_{11} & w_2x'_{12} & \dots & w_mx'_{1m} \\ w_1x'_{21} & w_2x'_{22} & \dots & w_mx'_{2m} \\ \dots & \dots & w_ix'_{ij} & \dots \\ w_1x'_{n1} & w_2x'_{n2} & \dots & w_mx'_{nm} \end{bmatrix} = \begin{bmatrix} y_{11} & y_{12} & \dots & y_{1m} \\ y_{21} & y_{22} & \dots & y_{2m} \\ \dots & \dots & y_{ij} & \dots \\ y_{n1} & y_{n2} & \dots & y_{nm} \end{bmatrix}. \quad (3)$$

Step 5. Determining the PIS and the NIS; The positive (negative) ideal solution $I^+(I^-)$ consists of the best (worst) criteria values attainable from all the alternatives.

$$I_j^+ = \max y_{ij}^+ \, , I_j^- = \max y_{ij}^-. \quad (4)$$

Step 6. Calculating the conflict index between the alternatives and PIS and NIS.

As mentioned earlier, according to Deng [10], the logic of TOPSIS method in ranking the alternatives according to their distances from PIS and NIS could be problematic in some circumstances [10]. In this regard some researchers introduced better measures than just distance in order to compare the alternatives to PIS and NIS. Deng [10] introduced the concept of alternative gradient to represent the conflict of alternatives in multiple criteria analysis problems. Assume that A_i is a vector representing an alternative and that I_j^+ and I_j^- are two vectors of the positive and the NISs in a given multiple criteria analysis problem. These vectors can be considered in the m-dimensional real space. The angle between A_i and $I_j^+(I_j^-)$ in the m-dimensional real space, which is being shown by $\theta^+{}_i(\theta^-{}_i)$, is a good conflict measure between the vectors. The above vectors and the conflict degree between them are shown in *Fig.* . The situation of conflict occurs when $\theta_i \neq 0$, i.e., when the gradients of A_i and $I_j^+(I_j^-)$ are not coincident. Thus, the conflict index is equal to one when the corresponding gradient vectors lie in the same direction, and the conflict index is zero when $\theta_i = \pi/2$, which indicates that their gradient vectors have a perpendicular relationship between each other.

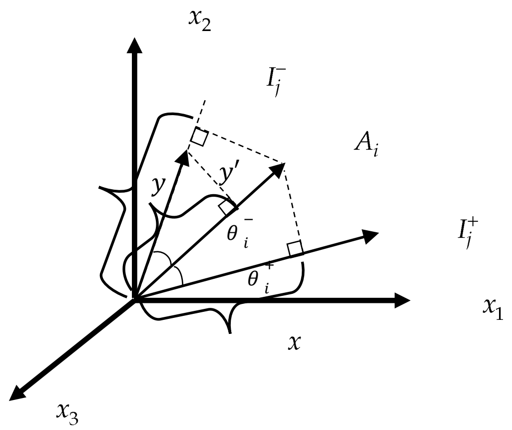

Fig. 1. The degree of conflict between alternatives and $I_j^+(I_j^-)$.

The degree of conflict between alternative A_i and $I_j^+(I_j^-)$ is determined by:

$$\cos\theta_i^+ = \frac{\sum_{j=1}^{m} y_{ij} \times I_j^+}{\left(\sum_{j=1}^{m} y_{ij}^2 \sum_{j=1}^{m} (I_j^+)^2\right)^{1/2}}, \quad i = 1,2, \dots, n,$$

$$\cos\theta_i^- = \frac{\sum_{j=1}^{m} y_{ij} \times I_j^-}{\left(\sum_{j=1}^{m} y_{ij}^2 \sum_{j=1}^{m} (I_j^-)^2\right)^{1/2}}, \quad i = 1,2, \dots, n. \quad (5)$$

Step 7. Calculating the degree of similarity of the alternatives to PIS and NIS.

The similarity degree denoted as S_i^+, measures the relative similarity of the alternative A_i to I_j^+, and the degree of similarity denoted as S_i^- measures the relative similarity of the alternative A_i to I_j^-.

$$S_i^+ = \frac{x}{|I_j^+|} = \frac{\cos\theta_i^+ \, |A_i|}{|I_j^+|}, \quad i = 1,2,\dots,n. \tag{6}$$

The problem caused by S_i^- in Deng's method [10] is that, if we calculate S_i^- just like S_i^+, i.e., if we consider the equation $S_i^- = \frac{y}{|I^-|}$, a number is determined which is not between 0 and 1 for S_i^- and thus an issue is encountered with calculating the performance index in the next step. x is the projection of the alternative vector A_i on the PIS vector I_j^+. Since PIS has the highest value among alternatives, the A_i vector is equal or shorter than it. As a result, we will have a number between 0 and 1 for S_i^+. Similarly y is the projection of the alternative vector A_i on the NIS vector I_j^-. But in this case, as the NIS has the lowest value among alternatives, y is equal or longer than I_j^- and the problem is caused by Deng's method [10]. In order to fix the problem another vector is required and y' is the best choice. y' is the projection of the NIS vector (I_j^-) on the alternative vector (A_i), which is always lower than the alternative vector. Thus, *Eq. (7)* is proposed to overcome the problem related to Deng's method.

$$S_i^- = \frac{y'}{|A_i|} = \frac{\cos\theta_i^- \, |I_j^-|}{|A_i|}, \quad i = 1,2,\dots,n. \tag{7}$$

With this change in the calculation, a number between 0 and 1 for S_i^- and S_i^+ is obtained. This solves a significant problem that Deng [10], as well as some other scholars, have pointed out [10]-[25].

Step 8. Calculating the overall performance index for each alternative according to all criteria.

The overall performance index P_i can be calculated based on the concept of the similarity degree of alternative A_i to the ideal solutions.

$$P_i = \frac{S_i^+}{S_i^+ + S_i^-}, \qquad i = 1,2,\dots,n. \tag{8}$$

In the modified similarity method, which contrasts with the similarity method presented by Deng [10], S_i^- and P_i are always between 0 and 1. To the extent A_i becomes more similar to I_j^+, and less similar to I_j^-, the overall performance index P_i becomes near to 1.

Step 9. Ranking alternatives in the descending order based on the overall performance index value.

2.2 | Fuzzzy Context

MCDM often involves uncertainty, which can be tackled by employing the fuzzy sets theory [32]. Zadeh [33] proposed the "fuzzy sets theory" to model subjective decision-making processes. Therefore, the fuzzy versions of MCDM techniques are more suitable for subjective and qualitative assessments other than the classical MCDM techniques, which apply crisp values [34]-[36]. Thus, as an additional contribution, this article introduces the modified fuzzy similarity method to allow decision-makers to evaluate and rank alternatives systematically based on their specific criteria with different levels of importance (weights).

A fuzzy set $A = \{(x, \mu_A\, x)) \mid x \in X\}$ is a set of ordered pairs. Let the universe of discourse X be the subset of real number R, where $\mu_A\, x)$ is called the membership function, which assigns to each object x a grade of membership ranging between zero and one [37].

A positive triangular fuzzy number A , shown in *Fig. 2*, could be defined as $A = (l, m, u)$ where $l \le m \le u$ and l>0.

According to [38] the membership function $\mu_A(x)$ is defined as:

$$\mu_{\widetilde{A}}(x)=\begin{cases} 0, & \text{if } x<l, \\ \frac{x-l}{m-l}, & \text{if } l<x<m, \\ \frac{u-x}{u-m}, & \text{if } m<x<u, \\ 0, & u<x. \end{cases} \quad (1)$$

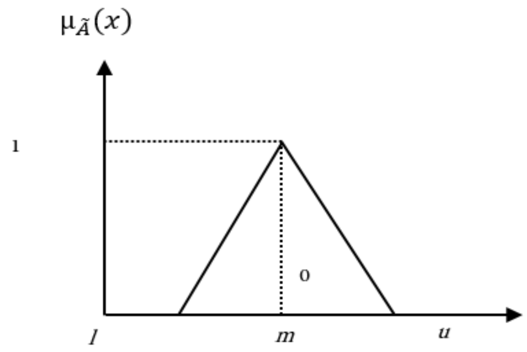

Fig. 2. Membership function of the triangular fuzzy number $\widetilde{A} = (l, m, u)$.

Zadeh [39], [40] offered linguistic variables as a practical means of describing complicated or hard-to-define situations. A linguistic variable is a variable, in which the values are expressed in linguistic terms, which are not numbers but words or sentences in a natural or artificial language.

2.3 | The Modified Fuzzy Similarity Method

Here the similarity method introduced by Deng [10] and its modified version are presented in detail. In this part, a modified fuzzy similarity method was introduced in an algorithmic form.

Step 1. Determining the fuzzy decision matrix.

The decision matrix in the fuzzy environment X is an n×m matrix in which a number of alternatives $A_i(I = 1,2, \dots, n)$ are evaluated against a set of criteria $C_j(j = 1,2, \dots, m)$, however, the data are fuzzy triangular numbers. The performance of each alternative A_i with respect to each criterion C_j, is denoted as x_{ij} so that:

$$x_{ij} = \left(l_{ij}, m_{ij}, u_{ij}\right). \quad (9)$$

Step 2. Determining the fuzzy weighting matrix.

The fuzzy weighting vector $\widetilde{W}$ represents the relative importance of each criterion.

$$\widetilde{w}_j = \left(w_j^{\,l}, w_j^{\,m}, w_j^{\,u}\right). \quad (10)$$

Step 3. Normalizing the fuzzy decision matrix through linear normalization:

A normalized decision matrix X' can be determined as:

$$X' = \begin{bmatrix} x'_{11} & x'_{12} & \dots & x'_{1m} \\ x'_{21} & x'_{22} & \dots & x'_{2m} \\ \dots & \dots & x'_{ij} & \dots \\ x'_{n1} & x'_{n2} & \dots & x'_{nm} \end{bmatrix}.$$

In which

$$\begin{cases} \text{if } c_j \text{ is a benefit criterion then: } x'_{ij} = \left(\frac{l_{ij}}{\max_{i=1,\dots,n}(u_{ij})}, \frac{m_{ij}}{\max_{i=1,\dots,n}(u_{ij})}, \frac{u_{ij}}{\max_{i=1,\dots,n}(u_{ij})}\right), \\ \text{if } c_j \text{ is a cost criterion then: } x'_{ij} = \left(\frac{\min_{i=1,\dots,n}(l_{ij})}{u_{ij}}, \frac{\min_{i=1,\dots,n}(l_{ij})}{m_{ij}}, \frac{\min_{i=1,\dots,n}(l_{ij})}{l_{ij}}\right). \end{cases} \quad (11)$$

Step 4. Calculating the fuzzy performance matrix.

The fuzzy performance matrix *Y* is calculated as below:

$$y_{ij} = x'_{ij} \otimes \widetilde{w}_j.$$

In which

$$y_{ij} = \left(y_{ij}{}^{l}, y_{ij}{}^{m}, y_{ij}{}^{u}\right) = \left(x'^{\,l}_{ij} \times w_j{}^{l}, x'^{\,m}_{ij} \times w_j{}^{m}, x'^{\,u}_{ij} \times w_j{}^{u}\right). \quad (12)$$

Step 5. Determining the fuzzy PIS and the fuzzy NIS:

$$\begin{aligned} I_j^+ &= \left(I_j^{+l}, I_j^{+m}, I_j^{+u}\right) = \left(\max y_{ij}{}^{l}, \max y_{ij}{}^{m}, \max y_{ij}{}^{u}\right), \\ I_j^- &= \left(I_j^{-l}, I_j^{-m}, I_j^{-u}\right) = \left(\min y_{ij}{}^{l}, \min y_{ij}{}^{m}, \min y_{ij}{}^{u}\right). \end{aligned} \quad (13)$$

Step 6. Calculating the conflict index between the alternatives and PIS and NIS:

In this step, the fuzzy performance matrix *Y*, which consists of fuzzy triangular numbers is divided into three lower Y^l, middle Y^m and upper Y^u matrixes. Then *Eq. (5)* is calculated for each matrix separately. For example, the conflict index between the alternatives and PIS and NIS for the lower matrix Y^l is calculated as below:

$$\cos\theta_i^{+l} = \frac{\sum_{j=1}^{m} y_{ij}{}^{l} \times I_j^{+l}}{\left(\sum_{j=1}^{m} y_{ij}^{2l} \sum_{j=1}^{m} (I_j^{+})^{2l}\right)^{1/2}}, \quad i = 1,2,\dots,n,$$

$$\cos\theta_i^{-l} = \frac{\sum_{j=1}^{m} y_{ij}{}^{l} \times I_j^{-l}}{\left(\sum_{j=1}^{m} y_{ij}^{2l} \sum_{j=1}^{m} (I_j^{-})^{2l}\right)^{1/2}}, \quad i = 1,2,\dots,n. \quad (14)$$

Step 7. Calculating the degree of similarity of the alternatives between each alternative and PIS and NIS.

Eq. (6) and *Eq. (7)* are calculated for lower Y^l, middle Y^m and upper Y^u matrices separately. For example, with respect to the lower matrix:

$$S_i^{+l} = \frac{\cos\theta_i^{+} \left|A_i{}^{l}\right|}{\left|I_j^{+l}\right|}, \quad i = 1,2,\dots,n,$$

$$S_i^{-l} = \frac{\cos\theta_i^{-l} \left|I_j^{-l}\right|}{\left|A_i{}^{l}\right|}, \quad i = 1,2,\dots,n. \quad (15)$$

The modification applied to the similarity method in relation to calculating S_i^-, is repeated here for calculating *Eq. (15)*.

Step 8. Calculating the degree of similarity of the alternatives between each alternative and PIS and NIS.

In the fuzzy environment, p_i is a triangular fuzzy number, which is calculated for each alternative as below:

$$p_i = (p_i^l, p_i^m, p_i^u) = \left(\frac{s_i^{+l}}{s_i^{+u}+s_i^{-u}}, \frac{s_i^{+m}}{s_i^{+m}+s_i^{-m}}, \frac{s_i^{+u}}{s_i^{+l}+s_i^{-l}}\right), \; i = 1,2, \dots, n \quad (16)$$

Step 9. Ranking alternatives in the descending order based on the fuzzy overall performance index value.

In this step we have n fuzzy triangular numbers (p_i , $i = 1, 2,\dots,n$), which should be ranked. Thus, we compute the degree of possibility for each p_k fuzzy number to be higher than (n-1) other $\tilde{p}_i$ fuzzy numbers. According to [37] this can be defined as below:

$$V(P_k \geq P_1, P_2, \dots, P_n) = V(P_k \geq P_1) \text{ and } V(P_k \geq P_2) \; \dots \; V(\widetilde{P_k \geq P_n}) = \min V(P_k \geq P_i), \; i = 1,2, \dots, n. \quad (17)$$

In which the degree of possibility of $P_k \geq P_i$ is defined as:

$$V(P_k \geq P_i) = hgt(P_k \cap P_i) = \begin{Bmatrix} 1, & \text{if } m_k \geq m_i, \\ 0, & \text{if } l_i \geq u_k, \\ \dfrac{l_i - u_k}{m_k - u_k) - \; m_i - l_i)}, & \text{otherwise} \end{Bmatrix}. \quad (18)$$

The result of computing *Eq. (17)* and *Eq. (18)* for each alternative are crisp numbers that could be the basis of ranking alternatives.

3 | Numerical Example

In this section, a case study has been demonstrated to illustrate the applicability and validity of the proposed modified fuzzy similarity method. Suppose that a bank intends to choose an officer for the international marketing department from seven candidates named A_1, A_2, A_3, A_4, A_5, A_6, and A_7. A group of decision-makers consisting of three experts (E_1: manager of international marketing department, E_2: an executive from human resource department and E_3: an executive from the credit department) has been formed to assess the candidates, some of whom were already employed by the bank in other departments. The committee intends to rank the candidates based on six assessment criteria. These criteria are general criteria which have used in many research; some of them are shown in *Table 1*.

Table 1. Criteria for employee selection.

Symbol	Criteria	References
C1	Experience in marketing	Nong and Ha [41], Karabašević et al. [42], Polychroniou and Giannikos [43]
C2	Personality characteristics	Nong and Ha [41], Polychroniou and Giannikos [43]
C3	Knowledge of foreign languages	Widianta et al. [44], Nong and Ha [41], Polychroniou and Giannikos [43]
C4	Interpersonal communication skills	Widianta et al. [44], Abdullah et al. [45], Polychroniou and Giannikos [43]
C5	Educational background	Nong and Ha [41], Polychroniou and Giannikos [43], Karabašević et al. [42]
C6	Annual salary request	Polychroniou and Giannikos [43]

It is clear that the five first criteria are benefits (the higher, the better), and the sixth criterion is cost (the lower, the better). So this example, in contrast to many other numerical examples presented in this field (see for example [46]-[51]), includes both two types of criteria (benefit and cost).

The procedure of the modified fuzzy similarity method for ranking candidates (alternatives) based on the six assessment criteria is described as below:

Step 1. Determining the fuzzy decision matrix.

The candidates' assessment by experts based on the six criteria is expressed through linguistic variables. According to [52], the triangular fuzzy conversion scale was used to convert linguistic values into fuzzy scales and is shown in *Table 2*.

Table 2. Linguistic variables and their respected fuzzy numbers.

Linguistic Variables		Corresponding Triangular Fuzzy Number
Evaluating the candidates based on assessment criteria	Importance of assessment criteria	
Very Poor (VP)	Very Low (VL)	(1,1,3)
Poor (P)	Low (L)	(1,3,5)
Fair (F)	Moderate (M)	(3,5,7)
Good (G)	High (H)	(5,7,9)
Very Good (VG)	Very High (VH)	(7,9,9)

The geometric mean of the three experts' judgments for each candidate based on the assessment criteria is calculated through the geometric mean technique in the fuzzy area [53] and is shown in *Table 3*. This table shows the fuzzy decision matrix.

$$X = (x^{1)} \otimes x^{2)} \otimes \ldots \otimes x^{n)})^{1/n}. \tag{19}$$

Table 3. The fuzzy decision matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	(1.44,2.47,4.72)	(2.08,4.22,6.26)	(1.00,2.08,4.22)	(2.08,4.22,6.26)	(1.71,3.98,6.08)	(1.44,3.56,5.59)
A_2	(2.47,4.72,6.80)	(3.00,5.00,7.00)	(2.08,4.22,6.26)	(3.00,5.00,7.00)	(3.56,5.59,7.61)	(3.56,5.59,7.61)
A_3	(3.56,5.59,7.61)	(3.00,5.00,7.00)	(3.00,5.00,7.00)	(3.56,5.59,7.61)	(3.56,5.59,7.61)	(4.22,6.26,8.28)
A_4	(1.71,3.98,6.08)	(4.71,6.80,8.28)	(7.00,7.61,9.00)	(3.27,5.74,7.40)	(4.22,6.26,8.28)	(5.59,7.00,9.00)
A_5	(1.44,1.71,3.98)	(3.00,5.00,7.00)	(2.92,3.66,6.24)	(2.08,2.92,5.28)	(4.72,6.26,8.28)	(3.00,5.00,7.00)
A_6	(2.47,3.27,5.74)	(2.08,2.92,5.28)	(2.47,3.27,5.74)	(3.00,5.00,7.00)	(2.47,4.72,6.80)	(4.22,6.26,8.28)
A_7	(1.00,2.08,4.22)	(3.98,6.08,7.61)	(3.27,5.74,7.40)	(3.00,5.00,7.00)	(2.08,4.22,6.26)	(3.00,5.00,7.00)

Step 2. Determining the fuzzy weighting matrix.

The three experts assigned subjective weights to the six criteria according to their perceived importance. These weights were expressed based on linguistic variables, whose values are shown in *Table 2*. The weights assigned by the three experts (E_1, E_2, and E_3) are given in *Table 4*. The fuzzy weighting vector for each criterion is calculated using *Eq. (19)*, and normalized using *Eq. (11)* which are shown in *Table 4*.

Table 4. The fuzzy weighting matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	(0.19,0.32,0.62)	(0.25,0.51,0.76)	(0.11,0.23,0.47)	(0.27,0.55,0.82)	(0.21,0.48,0.73)	(0.26,0.41,1.00)
A_2	(0.32,0.62,0.89)	(0.36,0.60,0.85)	(0.23,0.47,0.70)	(0.39,0.66,0.92)	(0.43,0.68,0.92)	(0.19,0.26,0.41)
A_3	(0.47,0.73,1.00)	(0.36,0.60,0.85)	(0.33,0.56,0.78)	(0.47,0.73,1.00)	(0.43,0.68,0.92)	(0.17,0.23,0.34)
A_4	(0.22,0.52,0.80)	(0.57,0.82,1.00)	(0.78,0.85,1.00)	(0.43,0.75,0.97)	(0.51,0.76,1.00)	(0.16,0.21,0.26)
A_5	(0.19,0.22,0.52)	(0.36,0.60,0.85)	(0.32,0.41,0.69)	(0.27,0.38,0.69)	(0.57,0.76,1.00)	(0.21,0.29,0.48)
A_6	(0.32,0.43,0.75)	(0.25,0.35,0.64)	(0.27,0.36,0.64)	(0.39,0.66,0.92)	(0.30,0.57,0.82)	(0.17,0.23,0.34)
A_7	(0.13,0.27,0.55)	(0.48,0.73,0.92)	(0.36,0.64,0.82)	(0.39,0.66,0.92)	(0.25,0.51,0.76)	(0.21,0.29,0.48)

Table 5. The normalized fuzzy decision matrix.

	E_1	E_2	E_3	$\widetilde{w}_j$
C_1	VH	H	H	(0.62,0.85,1.00)
C_2	H	VH	M	(0.52,0.76,0.92)
C_3	VH	M	M	(0.44,0.68,0.85)
C_4	H	VH	M	(0.52,0.76,0.92)
C_5	M	H	M	(0.40,0.62,0.85)
C_6	VH	VH	M	(0.59,0.82,0.92)

Step 3. Normalizing the fuzzy decision matrix through linear normalization.

The normalized fuzzy decision matrix $\widetilde{X'}$, as shown in *Table 5*, is calculated based on *Eq. (11)*.

Step 4. Calculating the fuzzy performance matrix.

The fuzzy performance matrix *Y*, which is calculated from *Eq. (12)*, is shown in *Table 6*.

Table 6. The fuzzy performance matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
A_1	(0.12,0.27,0.62)	(0.13,0.39,0.70)	(0.05,0.16,0.40)	(0.14,0.42,0.76)	(0.08,0.30,0.62)	(0.15,0.33,0.92)
A_2	(0.20,0.52,0.89)	(0.19,0.46,0.78)	(0.10,0.32,0.59)	(0.21,0.50,0.85)	(0.17,0.42,0.78)	(0.11,0.21,0.37)
A_3	(0.29,0.62,1.00)	(0.19,0.46,0.78)	(0.15,0.38,0.66)	(0.24,0.56,0.92)	(0.17,0.42,0.78)	(0.10,0.19,0.31)
A_4	(0.14,0.44,0.80)	(0.30,0.62,0.92)	(0.34,0.57,0.85)	(0.23,0.57,0.89)	(0.20,0.47,0.85)	(0.09,0.17,0.24)
A_5	(0.12,0.19,0.52)	(0.19,0.46,0.78)	(0.14,0.27,0.59)	(0.14,0.29,0.64)	(0.23,0.47,0.85)	(0.12,0.24,0.44)
A_6	(0.20,0.36,0.75)	(0.13,0.27,0.59)	(0.12,0.25,0.54)	(0.21,0.50,0.85)	(0.12,0.35,0.70)	(0.10,0.19,0.31)
A_7	(0.08,0.23,0.55)	(0.25,0.56,0.85)	(0.16,0.43,0.70)	(0.21,0.50,0.85)	(0.10,0.32,0.64)	(0.12,0.24,0.44)

Step 5. Determining the fuzzy PIS and the fuzzy NIS.

The fuzzy PIS and the fuzzy NIS for each criterion are calculated based on *Eq. (13)* and are shown in *Table 7*.

Table 7. The fuzzy performance matrix.

	C_1	C_2	C_3	C_4	C_5	C_6
PIS	(0.29,0.62,1.00)	(0.30,0.62,0.92)	(0.34,0.57,0.85)	(0.24,0.57,0.92)	(0.23,0.47,0.85)	(0.15,0.33,0.92)
NIS	(0.08,0.19,0.52)	(0.13,0.27,0.59)	(0.05,0.16,0.40)	(0.14,0.29,0.64)	(0.08,0.30,0.62)	(0.09,0.17,0.24)

Step 6. Calculating the conflict index between the alternatives and PIS and NIS.

The conflict index between the alternatives and PIS and NIS, shown in *Table 8*, is calculated for lower, middle, and upper-performance matrixes separately based on *Eq. (14)*.

Table 8. The conflict index between the alternatives and the PIS and the NIS.

	Lower Performance Matrix		Middle Performance Matrix		Upper Performance Matrix	
	$\cos\theta^{+l}$	$\cos\theta^{-l}$	$\cos\theta^{+m}$	$\cos\theta^{-m}$	$\cos\theta^{+U}$	$\cos\theta^{-U}$
A_1	0.88	0.98	0.95	0.98	0.98	0.92
A_2	0.95	0.97	0.99	0.97	0.97	0.99
A_3	0.95	0.93	0.98	0.95	0.96	0.99
A_4	0.97	0.88	0.99	0.96	0.95	0.99
A_5	0.95	0.93	0.94	0.98	0.97	0.98
A_6	0.95	0.95	0.96	0.97	0.97	0.99
A_7	0.93	0.96	0.96	0.96	0.97	0.98

Step 7. Calculating the degree of similarity of the alternatives between each alternative and PIS and NIS.

The similarity degree is calculated for lower, middle, and upper-performance matrixes separately based on *Eq. (15)* and are shown in *Table 9*.

Table 9. The degree of similarity of the alternatives to PIS and NIS.

	Lower Performance Matrix		Middle Performance Matrix		Upper Performance Matrix	
	S^+	S^-	S^+	S^-	S^+	S^-
A_1	0.39	0.85	0.56	0.72	0.74	0.70
A_2	0.60	0.59	0.76	0.55	0.78	0.71
A_3	0.72	0.47	0.83	0.49	0.82	0.66
A_4	0.85	0.38	0.91	0.45	0.83	0.65
A_5	0.57	0.59	0.58	0.68	0.69	0.79
A_6	0.55	0.63	0.60	0.69	0.69	0.80
A_7	0.58	0.59	0.71	0.57	0.73	0.74

Step 8. Calculating the fuzzy overall performance index for each alternative according to all criteria in the fuzzy environment.

The fuzzy overall performance index is calculated through *Eq. (16)* and is shown in *Table 10*.

Table 10. The fuzzy overall performance index values.

	P_i
A_1	(0.27,0.44,0.60)
A_2	(0.40,0.58,0.66)
A_3	(0.48,0.63,0.69)
A_4	(0.58,0.67,0.67)
A_5	(0.39,0.46,0.60)
A_6	(0.37,0.46,0.58)
A_7	(0.39,0.56,0.63)

Step 9. Ranking alternatives in the descending order based on the fuzzy overall performance index value.

The fuzzy overall performance index values are ranked in descending order through *Eqs. (17)* and *(18)*. The minimum degree of possibility for each overall performance index is higher than the other five overall performance indices, and the ranking order of the six candidates is shown in *Table 11*. Results show that with regard to the experts' judgments, the fourth candidate is the best candidate for the international marketing department officer position.

Table 11. The overall performance indices and ranks.

Candidate	Rank based on Fuzzy Similarity	Rank based on Fuzzy TOPSIS	Rank based on Fuzzy GTMA	Rank based on Fuzzy EDAS
A_1	6	4	6	6
A_2	3	3	3	1
A_3	2	2	1	2
A_4	1	1	2	3
A_5	5	5	5	5
A_6	7	6	4	7
A_7	4	7	7	4

The decision matrix options were then compared with other ranking techniques such as Fuzzy TOPSIS, Fuzzy GTMA and Fuzzy EDAS. The results of this ranking are shown in *Table 12*.

Table 12. The results of the various options ranking using different techniques.

Candidate	Rank based on Fuzzy Similarity	Rank based on Fuzzy TOPSIS	Rank based on Fuzzy GTMA	Rank based on Fuzzy EDAS
A_1	6	4	6	6
A_2	3	3	3	1
A_3	2	2	1	2
A_4	1	1	2	3
A_5	5	5	5	5
A_6	7	6	4	7
A_7	4	7	7	4

As shown in *Fig. 3*, option A_5 had the same result in all four techniques. Options A_2, A_1, and A_3 had similar results in three techniques. Option A_4 has the same result in the two techniques fuzzy similarity and fuzzy TOPSIS.

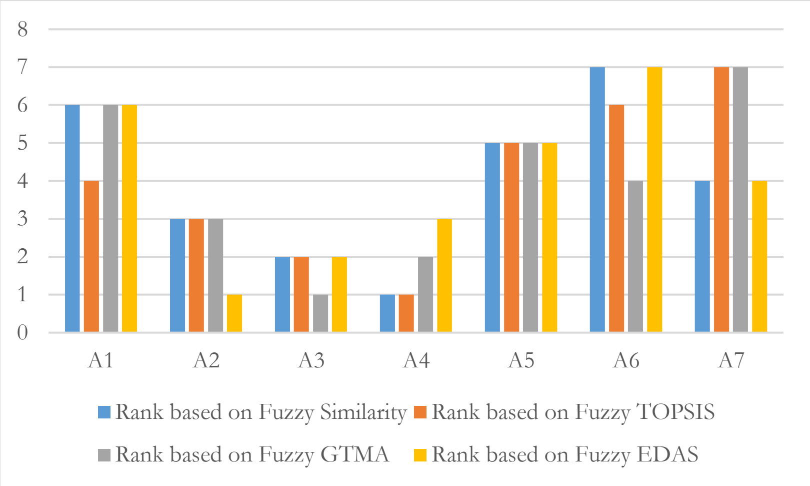

Fig. 3. Ranking results comparison.

4 | Conclusions

This paper presented a new MCDM method in a fuzzy environment. We showed that this technique could solve an important problem of the TOPSIS method based on the logic that the comparison of alternatives cannot be determined only by the distance from the PIS and NIS. Like TOPSIS, the similarity method compares the alternatives to PIS and NIS, but the comparison in similarity method is based on a broader concept. In the similarity method, the overall performance index of each alternative according to all criteria is determined based on the combination of the similarity degree to PIS and NIS using alternative gradient and magnitude. The proposed modified fuzzy similarity method is an extension of the method, which was introduced by Deng [10]. In fact, the proposed method has two significant contributions. First, it provides a solution for resolving the problem that exists in calculation of the similarity degree of the alternatives to NIS in Deng's technique [10]. The proposed method was applied in order to rank counties in terms of Human Development Index (HDI) and ranking countries based on CG measures by the authors but in the crisp format [54]. Second, the modified similarity method is extended to the fuzzy environment. The fuzzy similarity technique is also used to rank SOA [25] and risk analysis [23], but these two works have not considered the proposed modification of NIS shown in step 7. In this paper the modified similarity method was applied step by step. The results of this research show that simillarity is a good alternative to the TOPSIS method, but the innovation and distinguishing feature of the present paper is that it has expanded in fuzzy space and, secondly, has eliminated one of the shortcomings of the similiarity method mentioned earlier. Furthermore, a group of researches have already addressed the shortcomings of the TOPSIS method. Research using intuitionistic fuzzy numbers which is an extension of the soft set theory [55], [56] or by hesitant fuzzy set environment [57] or suggestion new techniques such as Interval-Valued Hesitant Pythagorean Fuzzy Sets (IVHPFSs) have attempted to solve this problem [58], are examples of this research. The present study in conventional fuzzy space has tried to address the shortcomings of similiarity, which is itself an alternative to TOPSIS.In order to demonstrate the feasibility and applicability of the proposed method, a numerical example was presented. The example was chosen from human resource management subjects (employee selection) to enlist the uncertainty that exists in this area. Since human judgments are very complex due to their subjective and intangible nature, this example helped in exhibiting a suitable application of this method. In addition, in the presented numerical example, in contrast to many other numerical examples in the field of employee selection, both the benefit and the cost criteria were used. In the human resource management field, most decisions are taken subjectively according to the non-quantative nature of this field. MCDM techniques in general and Modified Similarity teqnique in

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particular surely could help decision makers select accurately by quantifing the criteria. Also, the fuzzy solution, could help all other human management decisions such as performance appraisal or in assessment centers. The proposed method could be applied for other ranking purposes in many other fields such as risk analysis, corporate performance comparison, ranking and selecting strategies, and supplier selection purposes. It is recommended to compare the results of ranking alternatives through the modified similarity or modified fuzzy similarity method with other MCDM methods like TOPSIS, Superiority and Inferiority Ranking, Preference Ranking Organization Method for Enrichment Evaluations especially in the case of more alternatives. For future validation of the proposed fuzzy method, exploring more cases and conducting more empirical studies could prove to be useful. This study had also some limitations. First of all, we use a numerical example to show the applicability of the method. May be the actual and more data make the work more complex. Therefore, it is suggested that researchers apply the method for more related data. Second, we focus on the limitations of TOPSIS in general and Similarity method in patricular. Modifying these two methods can improve them but overally it is possible to find more accurate methods in the MCDM word. Thus, it is suggested that future research focus on comparing modified fuzzy similarity method and other MCDM techniques.

Conflict of Interest

The authors declare that they have no conflict of interest.

Funding

No funding was received.

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E-ISSN: 2676-6167 | P-ISSN: 2538-5100

Journal of Applied Research on Industrial Engineering

www.journal-aprie.com

J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 218–237.

Paper Type: Research Paper

A New Method to Predict the Quality of Umbilical Cord Blood Units based on Maternal and Neonatal Factors and Collection Techniques

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Citation:

Jamshidi, R., Rajabpour Sanati, S., & Zarrabi, M. (2023). A new method to predict the quality of umbilical cord blood units based on maternal and neonatal factors and collection techniques. *Journal of applied research on industrial engineering, 10*(2), 218-237.

Received: 14/05/2021 Reviewed: 15/06/2021 Revised: 11/08/2021 Accept: 20/09/2021

Abstract

The saving banks of "umbilical cord blood stem cells" are considered as strategic health-based institutions in most countries. Due to the limited capacity of cord blood sample storage tanks, the samples should be evaluated according to their quality. So these banks need a method to assess quality. In this paper, first, the effective factors on the quality index of the extracted cord blood from newborn infants are identified using the electronic records and database of Royan's umbilical cord blood bank. Then by machine learning and various statistical methods such as Multilayer Perceptron Neural Networks (MLPNNs), Radial Basis Function Neural Networks (RBFNNs), Logistic Regression (LR), and C4.5 Decision Tree (DT), the quality value of blood samples and their proper category (for discarding or freezing) are determined. Two different sets of data have been used to evaluate the proposed methods. The results show that the ensemble of RBFNN with k-means clustering model has the best accuracy compared to other methods, which categorizing the samples with 91.5% accuracy for the first data set and 81.6% accuracy for the second one. The results also show that using this method can save about 1 million dollars annually.

Keywords: Umbilical cord blood banking, Data mining, Neural network.

1 | Introduction

The stem cells are unique for their high proliferation ability and convertibility to other different cell types. The blood of umbilical cord is a precious resource of the stem cells, and it is a good alternative for bone marrow transplantation. Today, about 20 percent of stem cell transplantations are originated from the stem cells of the umbilical cord blood. Transplantation of the stem cells has various advantages such as facile collection and access, being safe and risk-free for mothers and newborns, lack of the need to total Human Leukocyte Antigen compatibility, reduction of the likelihood of transplant rejection, and Graft-Versus-Host Disease reaction. Despite these numerous advantages, using the umbilical cord blood has some limitations such as low volume, slow deployment process of the transplant in the host's body, and delays in the neutrophilic and platelet

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https://doi.org/10.22105/jarie.2021.286186.1326

cell retrieving recovery. Therefore, there is a vital need for transplantable stem cell detection in the umbilical cord blood and their safe storage [1]-[3].

Actually, storage of the umbilical cord blood cells provides an opportunity for a ready to use and always available resource of the stem cells, which is genetically compatible with the donor and it can be used to cure the possible future diseases of the individual or even his/her family members [3], [4].

Storage of the umbilical cord blood samples is carried out in three types of banks: public or national banks, private or family banks, and hybrid umbilical cord blood banks. The growth rate of these banks by 2011 based on their types is illustrated in *Table 1*. The growth rate of private banks has been significantly higher than the public ones.

Table 1. The worldwide growth rate of the umbilical cord blood banks.

Number	Year 2003	Year 2004	Year 2011	The Growth
Public banks	18	20	29	61%
Private banks	15	21	30	100%
Samples in the public banks	58650	76145	160000	2.7 times
Samples in private banks	179350	270991	1150000	6.4 times

If an accurate evaluative prediction of the future samples is provided at any stage before the conclusion of the contract (between the banks and families) or before conducting the qualitative tests, the umbilical cord blood banks can avoid possibly useless tests and cost. Also, due to the limited capacity of the storage tanks of the umbilical cord blood samples, the banks should prioritize their blood samples based on quality factors. If the samples are not ideal in terms of their quality level, they cannot be used at the time of transplantation. That is why the storage of high-quality samples has vital importance. Prioritization of samples should be based on parameters extracted from historical data by data mining and machine learning methods [5]-[7].

In this paper, the data mining techniques are used for the first time to predict the quality of the umbilical cord blood samples. Based on this prediction, sample quality is evaluated, and a decision is made about sample storage. Implementation of the proposed method reduces storage costs and also increases the likelihood of using these samples to treat diseases in the future.

The previous studies mainly focused on the factors affecting the quality of umbilical cord blood and proposed some methods for cell counting and samples selection, but in the proposed method, we predict the samples' quality to select the best samples for storage. To predict the sample quality, some heuristic methods such as Multilayer Perceptron Neural Networks (MLPNNs), Radial Basis Function Neural Networks (RBFNNs), Logistic Regression (LR), and C4.5 Decision Tree (DT) are used. Also, a case study is presented at Royan institute, which shows the efficiency of the proposed method.

2 | Literature Review

Many studies have been dedicated to evaluate the factors affecting the quality of blood samples extracted from the umbilical cord. Al-Sweedan et al. [8] determined the effective factors on the number of the hematopoietic stem cells collected from the umbilical cord blood. The data of 200 individuals which were eligible for blood-producing tests-such as Total Nucleated Cells (TNCs) and the number of CD 34+ cells, gathered for analysis. The results have been evaluated by single and multivariate analysis. In the single variable analysis, the factors with a positive correlation to TNC numbers were: maternal weight, preeclampsia, neonatal weight, neonatal platelet count, neonatal Rh, gestational age, and delivery type. Also, the positive factors related to the high number of CD34 + cells were: maternal weight, preeclampsia, maternal hypertension, neonatal weight, neonatal Rh type, and delivery type [8].

Lee et al. [9] analyzed the effective intrinsic factors on the hematopoietic variables of cord blood in Korea's newborns. The total number of nucleated cells, CD34+ cells, and the ratio of CD34+ cells to the whole nucleated cells in infants were compared regarding some factors such as sex, gestational age, birth weight, birth weight centile for gestational age, and blood type (ABO). The results provided that the TNC number was lower in males, but there was no difference in the CD34+ number. The increase in gestational age was positively correlated with whole nucleated cells, while it led to a decrease in the number of CD34 + cells and reduced the rate of CD34+ cells to the entire nucleated cells. The TNCs, CD34 + cells, and the ratio of CD34+ to TNCs increased when the neonatal weight increased. Abdul Wahid et al. [10] evaluated a comparison between the number of hematopoietic stem cells and CD34+ of the umbilical cord blood in preeclampsia, and those of the control sample and the factors affecting these observations. The cord blood volume, nucleated count, and CD34+ cell count in PE subjects were significantly lower than the non-PE subjects. Jan et al. [11] discussed whether maternal factors such as age, race, and ethnicity affect the laboratory parameters of hematopoietic content, such as CD34+ cells count, TNCs umbilical cord blood volume. The effect of neonatal factors, including the delivery type, gestational age, gender, and birth weight on those parameters was also studied as well. Ballen et al. [12] studied the effects of various factors such as race, age, and smoking habits on the potential laboratory parameters of hematology. Furthermore, the neonatal characteristics such as birth order, neonatal weight, gender, and gestational age on laboratory factors were analyzed. Surbek et al. [13] studied the effect of the extraction time of the umbilical cord blood. They argued that collecting the cord blood before or after the outgoing of the placenta may affect the volume of collected blood. Al-Deghaither [14] analyzed maternal and neonatal factors, including maternal age, neonatal weight, placental weight, neonatal gender, and the number of pregnancies. They showed that if the neonatal weight is more than 3.3 kg, the gestational age is lower, the size of placenta is larger, and the baby is delivered in the first or second pregnancy, TNC, CD34+, CD45+, NRBC, and viability will be higher. Nunes and Zandavalli [15] studied the effects of maternal and fetal factors on the qualitative characteristics of the umbilical cord blood in public blood banks. In this study, the factors of gestational age, mode of delivery, and neonatal weight of 458 samples were analyzed. The qualitative factors of blood samples, TNC, CD34+, and blood volume were considered. Manegold-Brauer et al. [16] investigated maternal factors such as maternal age, number of pregnancies, pre-gestational weight, as well as neonatal factors such as neonatal gender and birth weight. The focus was on the prediction of TNC index, which is just one of the various qualitative characteristics of the umbilical cord blood sample. Donaldson et al. [17] used the data of 500 umbilical cord blood samples to study the effects of factors such as maternal age, gestational age, neonatal weight, placental weight, duration of the first test, duration of the second test, total duration of the tests, duration of the collecting process of the placental blood, and duration of the collecting process of the venous blood of the umbilical cord on the qualitative indices such as volume and TNC.

Also, some researchers investigated the methods implemented for counting the cells in the blood unit. Jaime-Pérez et al. [18] analyzed the current standard method using the volume and TNC count to select cord blood units, cryopreservation, and further transplantation. The data consisted of 794 units of umbilical cord blood, which contained CD 34+ cells determined by flow cytometry. Wen et al. [19] investigated the relationship between the factors associated with the donor and the umbilical cord blood quality indices. The obstetric and neonatal clinical laboratory data of 1549 units of umbilical cord blood were gathered from the Buddhist Tzu Chi Stem Cells Center. A multivariate analysis method was used to analyze the data. The results showed that the neonatal birth weight has a significant positive correlation with any of the clinical features, i.e., the number of CD34+ cells, TNC count, unit volume, and placental weight. Cobellis et al. [20] examined the question of whether the storage of the umbilical cord blood using ultrasound and sonographic parameters at the time of pregnancy is predictable. For this purpose, the correlation of all sonographic parameters (head width, head circumference, abdominal circumference, femur length, estimation of fetal weight, rate index of the umbilical artery), which were extracted from the newborn's weight at birth and placental weight, were studied with the storage parameters of the umbilical cord blood samples (volume, CBU, TNC, and CD34+). After analyzing the 219 pregnant women, the results suggested that some factors such as abdominal circumference, femur length, estimation of fetal weight, neonatal weight at birth, and placental weight have a positive effect on the storage parameters such as CBU, CBU volume, TNC, and CD34+.

Optimizing cells selection to reduce the storage cost and the high likelihood for future use is one of the interesting issues. Mancinelli et al. [21] researched to optimize the selection process of the right donor. They evaluated the effects of factors such as neonatal weight, gender, Apgar score at minute 5, mode of delivery, type of blood sampling, maternal age, and number of deliveries, umbilical cord length, placental weight, and fecal presence in the infant on the qualitative indices such as blood volume, TNC, and CD34+. Solves et al. [22] wrote a paper on the selection process improvement. In this research, 1300 samples were studied and the effects of various factors such as maternal age, gestational age, number of pregnancies, delivery time, neonatal weight, placental weight, mode of delivery, neonatal gender, and type of blood sampling on the qualitative measures such as blood volume, TNC, HTC, CD34+, CFU, and viability were evaluated. Page et al. [23] examined the effects of maternal and neonatal factors as well as the type of blood sampling on the qualitative indices such as TNC, CD34+, and CFU. Manegold et al. [24] researched to reduce the sample rejection rate due to the low amount of cells in them. Wu et al. [25] analyzed the data of 4613 blood samples from Guangzhou's blood bank. In this study, they used statistical tools such as LR, chi-square test, and t-test to analyze the data

Although the previous studies mainly investigated the effective factors and tried to improve the cells selection for cord blood bank, there are no studies in which investigated the quality of the cells considering the effecting factors. In this paper, we predict the cell quality based on the effecting factors using Artificial Neural Networks (ANN) to select the best sample to store in the cord blood bank.

3 | Methodology

The classification prediction techniques are one of the most common methods in model learning. The classification is used to find a model to determine the class of objects according to their characteristics. In the classifier algorithms, the initial data set is divided into two sets of training data, and test data. The model is constructed, using the training data set, and the test data are used for validation. In this research, a two-stage method is developed to construct a hybrid intelligent model for the classification prediction of the blood samples.

The first stage is the pre-processing of data. In this stage, two transformation techniques are used. First, nominal and ordinal data are converted to continuous data. Then, all values in each attribute are mapped into the standard interval of [0, 1]. In the second stage, four methods, including MLPNNs, RBFNNs, LR, and C4.5 DT are used for prediction samples quality.

3.1 | Data Transformation

Using transformed data is more useful in most heuristic methods, especially when dealing with forecasting problems [26]. According to the structure of the existing attributes in the data sets, the data of qualitative attributes were converted to the data of new quantitative attributes [27]. In this case, a qualitative characteristic will be extended into several quantitative features in which the total of quantitative values will be an index of the qualitative feature. For example, the characteristic of being a man or woman is represented by (0, 1) or (1, 0).

3.2 | Data Normalization

Data normalization is used in different forecasting studies, for example, [28], [30]. There are different normalization algorithms, such as Min–Max normalization, Z-score normalization, and sigmoid normalization. In this paper, we use Min–Max normalization. The Min–Max normalization scales the numbers in a data set to improve the accuracy of the subsequent numeric computations. If X_{old}, X_{Max} and X_{Min} are the original, maximum and minimum values of the raw data respectively, and X^*_{Max}, X^*_{Min}

are the maximum and minimum of the normalized data. New normalized values can be obtained by the following transformation function:

$$X^*_{New} = \left(\frac{X_{old} - X_{Min}}{X_{Max} - X_{Min}}\right)(X^*_{Max} - X^*_{Min}) + X^*_{Min}. \quad (1)$$

3.3 | Artificial Neural Networks

ANNs are flexible computing frameworks for modeling linear and nonlinear problems [31]. One of the significant advantages of the neural network models is that they can be applied to different classification predictions with high accuracy. This advantage is the result of the power of parallel data processing. Also, no previous assumptions are needed to build the model. ANNs consist of an interconnection of some neurons. There are many varieties of connections under study and here, we discuss two types of network, which are called multilayer perceptron and Radial Basis Function (RBF).

3.4 | Multilayer Perceptron

We use a typical three-layer and four-layer feed forward model for the MLP method for classification. Hidden nodes with appropriate nonlinear transfer functions are used to process the information received by the input nodes. The symbolic structure of a MLPNN is shown in *Fig. 1*.

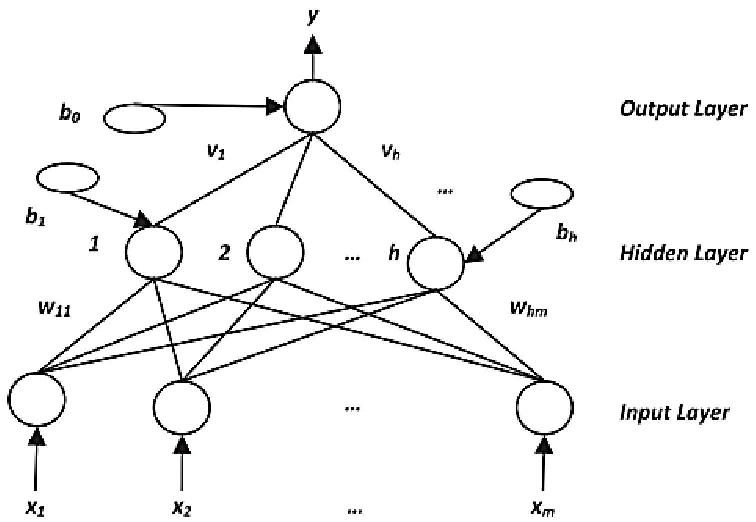

Fig. 1. MLP neural network model.

The training and learning process of this network is carried out through this algorithm:

Step 1. Initialize weights and thresholds to small random values.

Step 2. Choose an input-output pattern $(x^{(k)}, t^{(k)})$ from the training data.

Step 3. Compute the network's actual output $(o^{(k)} = f(\sum_{i=1}^{l} w_i x_i^{(k)} - \theta))$, (L is the size of input vector or the size of input neurons.)

Adjust the weight and bias according to the Levenberg-Marquart algorithm.

Step 4. If the whole epoch is complete, pass to the following step; otherwise, go to Step 2.

Step 5. If the weights and bias reach a steady state $\Delta w_i \approx 0$ through the whole epoch, stop the learning; else go through one more epoch.

The Levenberg Marquardt (LM) algorithm is the most widely used optimization algorithm. LM is similar to error back propagation in which it requires the calculation of the gradient vector, but in addition, LM also computes the Jacobian [32]. The gradient vector is represented as:

$$g = \begin{pmatrix} \frac{\partial E}{\partial W_1} \\ \frac{\partial E}{\partial W_2} \\ \vdots \\ \frac{\partial E}{\partial W_n} \end{pmatrix}, \tag{2}$$

where E is the error of the network for the pattern and W refers to the weights. The Jacobian is calculated as below:

$$J = \begin{bmatrix} \frac{\partial E_1}{\partial W_1} & \frac{\partial E_1}{\partial W_2} & \cdots & \frac{\partial E_1}{\partial W_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\partial E_2}{\partial W_1} & \frac{\partial E_2}{\partial W_2} & \cdots & \frac{\partial E_2}{\partial W_n} \\ \cdots & \cdots & \cdots & \cdots \\ \frac{\partial E_p}{\partial W_1} & \frac{\partial E_p}{\partial W_2} & \cdots & \frac{\partial E_p}{\partial W_n} \end{bmatrix}. \tag{3}$$

Once the Jacobian is calculated, the LM algorithm can be represented by the following:

$$W_{k+1} = W_k - (J_k^T J_k + \mu I)^{-1} J_k^T E. \tag{4}$$

Where E is the total error for all patterns, I is the identity matrix, and μ is a learning parameter. The learning parameter μ is then adjusted several times in each iteration and the result with the greatest reduction of error is selected. When the μ value is very large, the LM algorithm becomes steepest descent or BP, and when μ is equal to zero it is the Newton method. The entire process is then repeated until the error is reduced to the required value.

3.5 | Radial Basis Function

RBF uses a series of basic functions that are symmetric and centered at each sampling point. *Fig. 2* shows the structure of the RBF. The input neurons have no weight, thus the first hidden layer receives the same values as the first layer. The designed function in the hidden layer is the Radial Basis type. The transfer function for the neurons of the hidden layer is non-monotonic; then the output of these neurons is sent to the output layer by weights. The neurons of the output layers are actually, simple summations.

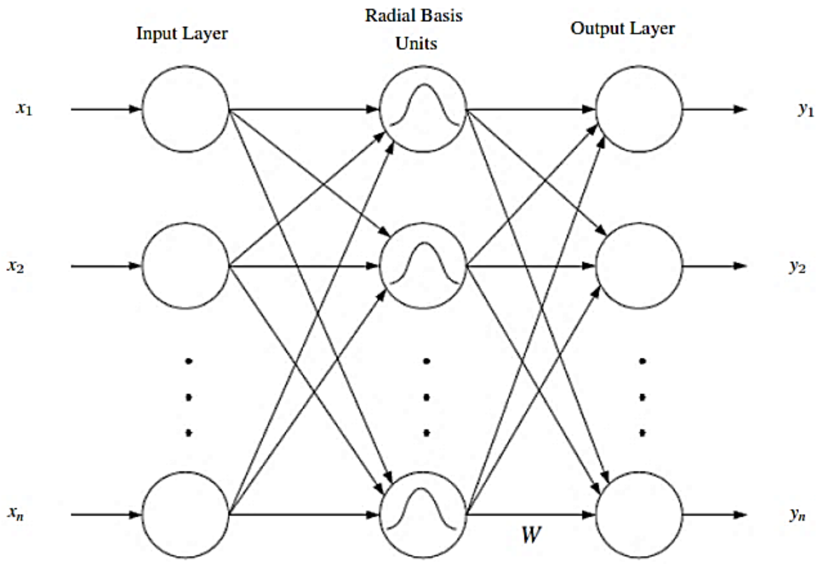

Fig. 2. Schematic diagram of RBF architecture.

Let us assume that there are H neurons in the hidden layer. The transfer function is like gaussian density functions. The gaussian function is introduced by the following equation:

$$a_{h,k} = \exp\left(-\frac{||\hat{x}_h - x_k||^2}{\sigma_h^2}\right), \quad (5)$$

where $a_{h,k}$ is the output of the hth neuron in the hidden layer. Also, x_h is the center of the radial function, and σ is the distance scaling parameter.

Finally, the weighted average of the outputs associated with the hidden layer determines the output. In other words, *Eq. (6)* shows the output value.

$$y_i = \sum_{i=1}^{n} w_i \times a_{h,i}, \quad (6)$$

where the w_i, is the weight assigned to the ith neuron in the hidden layer. Since this method is an observer learning method, the exact values for x_i and y_i are predetermined, thus to have the weights in the second layer, the pseudo-inverse method is used as bellow:

$$G = [g_{i,j}], \quad (7)$$

where

$$g_{i,j} = \exp\left(\frac{-\left\|x_i - v_j\right\|}{2\sigma_j^2}\right) \quad i = 1,2,\ldots,n; j = 1,2,\ldots,p, \quad (8)$$

And we have

$$D = GW, \quad (9)$$

where D is the desired output for the trained data. If G^{-1} exists, then we have

$$W = G^{-1}D. \quad (10)$$

If G is ill-conditioned (close to singularity) or is a non-square matrix, then:

$$W = G^{+}D, \quad (11)$$

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where

$$G^{+} = (G^{T}G)^{-1} \times G^{T}. \quad (12)$$

3.6 | C4.5

C4.5 is a well-known algorithm used to generate a DT. The C4.5 algorithm improves in DT learning (ID3) regard to the splitting rule and the calculation method [33]. The DTs generated by the C4.5 algorithm can be used for classification. Learned trees can also be represented as sets of if-then rules to improve human readability. C4.5 DT learning is a heuristic, one-step look ahead (hill climbing), non-backtracking search through the space of all possible DTs [34]. The algorithm of C4.5 is shown in the following steps. Training dataset and attributes are introduced as T, and S, respectively.

Algorithm 1. C4.5 algorithm.

```
If T is Null, then
    Return failure
End if
If S is Null, then
    Return Tree as a single node with most frequent class label in T
End if
If |S|=1 then
    Return Tree as a single node
End if
Tree={}
Set
For a ∈ S do
    Set Info (a,T)=0, and SplitInfo (a,T)=0
    Compute Entropy (a)
        For v ∈ values (a,T) do
            Set T_{a,v} as the subset of T with attribute a=v
Info (a,T) = Info (a,T)+ |T_{a,v}|/T_a Entropy (a_v)

Spil Info (a, T) = Split Info (a,T)- |T_{a,v}|/T_a log |T_{a,v}|/T_a

        Gain (a,T) = Entropy (a)-Info (a, T)

        Gain Ratio (a,T)= Gain (a,T) / SplitInfo (a,T)

        End for

Set a_best = argmax {Gain Ratio (a, T)}

Attach a_best into Tree
For v ∈ values (a_best, T) do
    Call C4.5 (T_{a,v})
End for
Return Tree.
```

Suppose C denotes the number of classes, and P(S,j) is the proportion of instances in S that are assigned to j[th] class. Hence, the entropy of attribute S is calculated as follows:

$$\text{Entropy}(S) = -\sum_{j=1}^{C} p(S,j) \times \log p(S,j). \quad (13)$$

Information gain by a training dataset T is defined as:

$$\text{Gain}(S,T) = \text{Entropy}(S) - \sum_{v \in \text{Values}(T_S)} \frac{|T_{S,v}|}{|T_S|} \text{Entropy}(S_v), \quad (14)$$

where Values (T_s) is the set of values for S in T, T_s is the subset of T induced by S and $T_{s,v}$ is the subset of T in which attributes S has a value of v.

Therefore, the information gain ratio of attributes S is defined as:

$$\text{Gain Ratio}(S,T) = \frac{\text{Gain}(S,T)}{\text{SplitInfo}(S,T)}, \tag{15}$$

where SplitInfo (S, T) is calculated as:

$$\text{Split Info}(S,T) = -\sum_{v \in \text{Values}(T_S)} \frac{|T_{S,v}|}{|T_S|} \times \log \frac{|T_{S,v}|}{|T_S|}. \tag{16}$$

3.7 | Logistic Regression

LR is used as a statistical algorithm for prediction and diagnosis in many disciplines. This model is very effective to solve relatively less complex problems [35]. LR is a regression method for predicting a dichotomous dependent variable. In producing the LR equation, the maximum-likelihood ratio was used to determine the variables' statistical significance [36]. In LR models, the dependent variable is always in categorical form and has two or more levels. Independent variables may be in the numerical or categorical form [37]. We consider the situation where we observe a binary outcome variable y and a vector $x = (1, x_1, x_{2,...,} x_k)$ of covariates for each N individuals. We code the two-class via a 0/1 response y_i, where y_i=1 for the first class and y_i=0 for the second one. Let P be the conditional probability associated with the first class. LR is a widely used statistical modeling technique in which the probability P of the dichotomous outcome event is related to a set of explanatory variables X in the bellow form:

$$\text{Logit}(p) = \ln\left(\frac{p}{1-p}\right) = f(X,\beta) = \beta^T X, \tag{17}$$

where $\beta = (\beta_0, \beta_1, \beta_2, ..., \beta_k)$ is the vector of the coefficients and β^T is the transpose vector. We refer to $p/(1-p)$ as odds-ratio and to the *Eq. (17)* as the log-odds or logit transformation.

Let $D = \{(xi, yi) \mid i = 1, 2, ..., n\}$ be the training data set, where the number of samples is n. Here, we assume that the training sample is a realization of a set of independent and identically distributed random variables. The unknown regression coefficients β_i, which should be estimated from the data, are directly interpretable as log-odds ratios or, in terms of exp(β_i), as odds ratios. That log-likelihood for n observations is:

$$l(\beta) = \sum_{i=1}^{n} \left[y_i \beta^T x_i - \log(1 + e^{\beta^T x_i}) \right]. \tag{18}$$

The log-likelihood function is used to estimate the regression coefficients β_i. The exponential value of regression coefficients (e^{β^T}) gives odds ratio, and this value reflects the effect of risk factor in the disease, and the interpreted values are odds ratios.

4 | Evaluation of the Classification Prediction Model

To select the appropriate model, we use three criteria of accuracy, sensitivity, and specificity. The accuracy of a classification prediction model on a given set is the percentage of test records that are correctly identified by the classifier. The accuracy can be calculated using the below formula:

$$\text{Accuracy} = \frac{TP + TN}{TP + TN + FP + FN}. \tag{19}$$

TP: True Positive, TN: True Negative, FP: False Positive, FN: False Negative.

Sensitivity is also considered as the actual positive rate, i.e., the proportion of positive records that are correctly identified. While specificity is the actual negative rate, that is, the ratio of negative records that are correctly identified. In other words:

$$\text{Sensitivity} = \frac{TP}{TP + FN}. \tag{20}$$

$$\text{Specificity} = \frac{TN}{TN + FP}. \tag{21}$$

4.1 | Cross Validation

In order to assess the accuracy of the classification models, a 5-fold cross-validation method has been utilized. In this method, the model is trained and tested five times. First, the data are divided into five sets. In the first step, the first four parts are used for training, and the fifth part is reserved for a test. Then for the second step, the data of parts one to three, and the last part are used for training and the fourth part is for the test. This process is repeated until the stage where the data of parts two to five are used for training, and the first part is used for the test. Finally, the obtained average value indicates the accuracy of the model.

4.2 | Data Compilation

The process of data collection was carried out by reviewing the literature. The collection of the important variables that are effective on the output can accelerate the model design, and improve the results. A summarized list of the input and output variables is shown in *Table 2*.

Table 2. Summary of the literature in the field of the umbilical cord blood sample quality.

Article	The Studied Factors	Qualitative Attributes	Sample Size
Solves et al. [22]	Maternal age, number of gravidities, gestational age, neonatal gender, neonatal weight, placental weight, delivery type, delivery duration	TNC	1300
Nakagawa et al. [38]	Neonatal weight, umbilical cord length, weight of placenta, neonatal gender, gestational age.	(TNC), CD34+ cell,	956
Jan et al. [11]	Maternity age, size of placenta, fetal weight, number of gravidities, neonatal gender	TNCs, CD34+, CD45+, NRBCs, and viability.	206
Urciuoli et al. [40]	Gestational age, neonatal weight, placental weight, gender, head diameter, head circumference, abdominal circumference, umbilical cord length, delivery type, blood white cells count	Blood volume, TNC, CD34+, Total CFU count, BFU-E count, CFU-GM count, CFU-GEMM count	365
Coldwll et al. [41]	Maternal age, neonatal gender, neonatal weight, placental weight, delivery type, meconium n the Amniotic fluid, gestational age, Apgar score, umbilical cord twist around the neck, umbilical cord length, multiparty delivery, maternal diabetes	Volume, TNC, CD34+, HPC recovery	49
Abdu Wahid et al. [10]	Gestational age, maternal age, neonatal gender, neonatal weight, placental weight, delivery type, Systolic blood pressure	Volume, TNC, CD34+, UCB pH	47
Wen et al. [19]	Maternal age, neonatal weight, placental weight, delivery type, umbilical cord length, number of gravidities, neonatal gender	Volume, TNC, CD34+	1549
Lee et al. [9]	Gestational age, maternal age, neonatal gender, neonatal weight, placental weight, delivery type, neonatal blood type	Volume, TNC, CD34+, Pre viability, Post viability	11098

Table 2. Continued.

Article	The Studied Factors	Qualitative Attributes	Sample Size
Al-Sweedan et al. [8]	Gestational age, neonatal weight, maternal weight, neonatal platelet cells count, delivery type, incidence of pre-eclampsia, maternal blood pressure, umbilical cord twist around the neck	TNC, CD34+	200
Cobellis et al. [20]	Gestational age, neonatal weight, placental weight, gender, head diameter, head circumference, abdominal circumference, umbilical cord length, delivery type	Blood volume, TNC, CD34+	219
Keersmaekers et al. [42]	Gestational age, neonatal ethnicity, neonatal gender, neonatal weight,	TNC	7839
Manegold-Brauer et al. [16]	Maternal age, number of gravidities, maternal height, maternal weight at the beginning and end of gestation, gestational age, neonatal gender, neonatal weight	TNC	758
Abdelrazik et al. [43]	Weight, gestational age, neonatal gender, delivery type, maternal weight	TNC, CD34+	200

To summarize, it can be said that the factors related to maternal conditions, neonatal, and delivery conditions are the ones that are considered to be effective on the quality of the umbilical cord blood samples in the past literature. In *Table 3*, some of the sample parameters for each category are given.

Table 3. Categorization of the effective factors, according to the past literature.

Maternal Factors	Neonatal Factors	Factors of Delivery Conditions
Maternal age	Birth weight	Delivery type (cesarean section / normal delivery)
Number of gravidities	Neonatal gender	Gestational age (weeks of pregnancy)
Maternal height	Placental weight	Intrauterine/ extrauterine (extravaginally) blood collection
Maternal weight at the beginning and end of pregnancy	Umbilical cord length	
Blood pressure	Head diameter	
Maternal white blood cells count	Head circumference	
Blood type	Thigh bone length	

The data used in this study were collected from the Electronic Health Record of Royan's umbilical cord blood bank. For the evaluation and quality prediction, the previously used samples in the database are studied. These data were collected from 2012-09-24 to 2013-03-26 and 2015-09-28 to 2016-04-06. According to the available data types, two types of data sets are used. The collected value types are compiled in *Table 4*. The number of data in the first dataset was 71, and the second set contained 618 records. The basic information about these two sets is shown in *Tables 5* and *6*. Both data sets follow the same structure regarding the batch features. *Table 7* shows a list of the batch attributes in each category.

Table 4. The value types used for the data.

Row	Factors	Type of Values	Type of Variable	Row	Factors	Type of Values	Type of Variable
1	Maternal age	Discrete	Independent	12	Uterine problems	Nominal	Independent
2	Number of gravidities	Discrete	Independent	13	Type of delivery	Nominal	Independent
3	Duration of pregnancy	Discrete	Independent	14	Mother's active disease	Nominal	Independent
4	Delivery type	Nominal	Independent	15	Blood collecting method	Nominal	Independent
5	Placental exit state	Nominal	Independent	16	Punch	Ordinal	Independent
6	Placental clamp state	Nominal	Independent	17	Apgar in 1 minute	Discrete	Independent
7	Neonatal gender	Nominal	Independent	18	Placental weight	Discrete	Independent
8	Apgar in 5 minutes	Discrete	Independent	19	Number of arteries and veins	Nominal	Independent
9	Connecting position of the umbilical cord	Nominal	Independent	20	Umbilical cord length	Discrete	Independent
10	Birth weight	Discrete	Independent	21	Discard or freeze	Nominal	Dependent
11	Number of pregnancies	Discrete	Independent				

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Table 5. Basic information about set 1.

Factors	Average	Variance	Standard Deviation	Maximum	Minimum
Maternal age	30.88	14.57	3.81	41	22
Umbilical cord length	43.55	198.28	14.08	77	15
Number of gravidity	1.07	0.067	0.25	2	1
Duration of pregnancy (weeks)	39.12	116.45	10.79	41	35
Apgar in 5 minutes	9.85	0.12	0.35	10	9
Birth weight	3212.39	167885.3	409.73	4600	2000
Number of pregnancies	1.44	0.45	0.673	3	1
Apgar in 1 minute	9.05	0.16	0.41	10	8
Placental weight	527.77	13132.67	114.59	839	240

Table 6. Basic information about set 2.

Factors	Average	Variance	Standard Deviation	Maximum	Minimum
Maternal age	31.14	16.91	4.11	43	19
Umbilical cord length	46.07	183.91	13.56	90	10
Number of gravidity	1.1	0.11	0.33	3	1
Duration of pregnancy (weeks)	39.13	1.46	1.21	42	28
Apgar in 5 minutes	9.85	0.14	0.37	10	7
Birth weight	3141.49	120559.6	347.21	4250	2000
Number of pregnancies	1.56	0.69	0.83	6	1
Apgar in 1 minute	9	0.27	0.52	10	3
Placental weight	519.08	17431.62	132.02	1000	250

Table 7. Basic information about the categorical features of the data.

Factors	Number of Categories	Description
Uterine problems	2	Has / Doesn't have
Type of delivery	2	Normal /Cesarean section
Condition of delivery	2	Emergency / Expected
Mother's active disease	2	Healthy / Ill
Placental exit state	3	With elongation /No intervention /Twisted placenta
Blood collection method	3	Intrauterine /Ectopic / Both
Placental clamp state	2	Close to fetus /Close to placenta
Punch count	3	Once /Twice /More than twice
Gender	2	Female / Male
Connecting position of the umbilical cord	4	Curtain /Marginal /Central /Out of center
Number of arteries and veins	2	One and two / Two and one
Discard or freeze	2	Discard/ Freeze

5 | Result and Discussion

In this section, the results of the proposed classification methods are presented. To assess the appropriate prediction method, the three criteria of specificity, sensitivity, and accuracy have been considered. All results are expressed separately for sets 1 and 2.

Set No. 1: The methods used for this database are discussed in the methodology section. The results of LR and DTs are shown in *Table 8*.

Table 8. The results of the DT and LR.

Method	Specificity	Sensitivity	Accuracy
LR	26.66%	96.66%	86%
DT	16.6%	81.2%	71.46%

Also the DT extracted for fold 2 is shown in *Fig. 3*.

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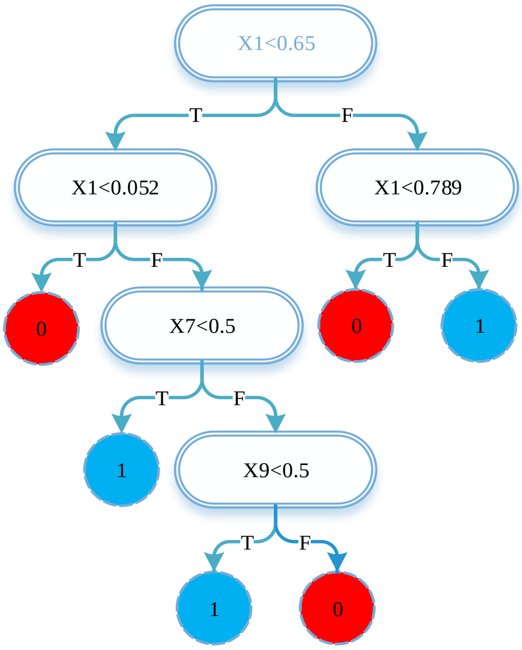

Fig. 3. The tree schema of generated rules for fold 2 prediction of database 1.

Different designs were proposed to use the RBFNNs. In order to adjust the input parameters such as the center and radius, the k-means clustering method is issued. 16 different designs are considered for the RBF neural network. *Table 9* shows the results of RBFNNs. It can be seen that the highest accuracy in these methods was achieved using 40 clusters, which is about 91.5%. In terms of the sensitivity criteria, several different designs have managed to reach as high as 95 percent. In design No. 10, using 20 neurons in the hidden layer, the highest value of specificity was achieved compared with other designs. Ultimately, design No. 14 has the best performance with 40 neurons in the hidden layer.

Table 9. The results of the radial basis neural network method.

Design NO.	Number of Clusters (Neurons)	Activation Function	Specificity	Sensitivity	Accuracy
1	3	Gaussian	60%	85%	81.9%
2	4	Gaussian	50%	91.7%	86.1%
3	5	Gaussian	56.7%	95%	88.9%
4	6	Gaussian	80%	90%	88.9%
5	7	Gaussian	63.3%	91.7%	87.4%
6	8	Gaussian	53.3%	93.3%	87.4%
7	9	Gaussian	66.7%	91.7%	87.5%
8	10	Gaussian	60%	95%	90.1%
9	15	Gaussian	53.3%	95%	88.8%
10	20	Gaussian	90%	86.7%	87.3%
11	25	Gaussian	73.3%	90%	87.3%
12	30	Gaussian	63.3%	95%	90.2%
13	35	Gaussian	73.3%	93.3%	90.2%
14	40	Gaussian	73.3%	95%	91.5%
15	45	Gaussian	63.3%	95%	90.2%
16	50	Gaussian	73.3%	91.7%	88.8%

Table 10 shows the results of the MLPNNs method. In the construction of these networks, one or two hidden layers with two different activation functions were used. The number of neurons in each hidden layer is shown in *Table 10*. 66 different designs of the MLPNN were constructed and evaluated.

Table 10. The results of the MLPNNs method.

Design NO.	Number of Hidden Layers	Neurons in each Hidden Layer	Activation Function	Specificity	Sensitivity	Accuracy
1	1	2	Sigmoid	26.6%	76.2%	69.6%
2	1	3	Sigmoid	60%	76.7%	73.1%
3	1	4	Sigmoid	30%	78.3%	70.4%
4	1	5	Sigmoid	26.6%	85%	76.1%
5	1	6	Sigmoid	30%	80%	71.8%
6	1	7	Sigmoid	36.7%	78.3%	71.7%
7	1	8	Sigmoid	20%	81.7%	71.9%
8	1	9	Sigmoid	46.7%	83.3%	77.4%
9	1	2	Tanh	40%	63.3%	58.9%
10	1	3	Tanh	30%	61.7%	56.3%
11	1	4	Tanh	50%	59.3%	54.9%
12	1	5	Tanh	46.7%	51.7%	51%
13	1	6	Tanh	36.7%	61.7%	60%
14	1	7	Tanh	30%	78.3%	70.4%
15	1	8	Tanh	16.7%	75%	66.2%
16	1	9	Tanh	6.7%	73.3%	63.2%
17	2	(1:2,2:2)	Sigmoid	46.7%	75%	70.3%
18	2	(1:2,2:3)	Sigmoid	20%	88.4%	77.8%
19	2	(1:2,2:4)	Sigmoid	26.7%	70%	63.1%
20	2	(1:2,2:5)	Sigmoid	36.7%	75%	69.2%
21	2	(1:2,2:6)	Sigmoid	36.7%	67.2%	59%
22	2	(1:3,2:2)	Sigmoid	20%	80%	70.5%
23	2	(1:3,2:3)	Sigmoid	20%	78.3%	69.1%
24	2	(1:3,2:4)	Sigmoid	36.7%	78.3%	71.6%
25	2	(1:3,2:5)	Sigmoid	26.7%	81.7%	73.2%
26	2	(1:3,2:6)	Sigmoid	26.7%	76.7%	68.8%
27	2	(1:4,2:2)	Sigmoid	10%	80%	68.9%
28	2	(1:4,2:3)	Sigmoid	26.7%	80%	71.8%
29	2	(1:4,2:4)	Sigmoid	36.7%	83.3%	75.9%
30	2	(1:4,2:5)	Sigmoid	30%	71.6%	64.6%
31	2	(1:4,2:6)	Sigmoid	10%	83.3%	71.8%
32	2	(1:5,2:2)	Sigmoid	30%	85%	76%
33	2	(1:5,2:3)	Sigmoid	26.7%	85%	76%
34	2	(1:5,2:4)	Sigmoid	36.7%	88.3%	80.3%
35	2	(1:5,2:5)	Sigmoid	20%	81.7%	71.7%
36	2	(1:5,2:6)	Sigmoid	26.7%	83.3%	74.5%
37	2	(1:6,2:2)	Sigmoid	40%	83.3%	76%
38	2	(1:6,2:3)	Sigmoid	30%	81.7%	73.2%
39	2	(1:6,2:4)	Sigmoid	30%	85%	76%
40	2	(1:6,2:5)	Sigmoid	26.7%	75%	67.1%
41	2	(1:6,2:6)	Sigmoid	36.7%	73.3%	67.5%
42	2	(1:2,2:2)	Tanh	43.3%	65%	62%
43	2	(1:2,2:3)	Tanh	10%	73.3%	63.2%
44	2	(1:2,2:4)	Tanh	46.7%	71.7%	67.8%
45	2	(1:2,2:5)	Tanh	56.7%	58.3%	57.9%
46	2	(1:2,2:6)	Tanh	26.7%	75%	67.7%
47	2	(1:3,2:2)	Tanh	20%	83.3%	73.3%
48	2	(1:3,2:3)	Tanh	50%	71.7%	67.7%
49	2	(1:3,2:4)	Tanh	33.3%	73.3%	67.7%
50	2	(1:3,2:5)	Tanh	16.7%	70%	61.9%
51	2	(1:3,2:6)	Tanh	56.7%	70%	67.8%
52	2	(1:4,2:2)	Tanh	63.3%	61.7%	62%
53	2	(1:4,2:3)	Tanh	10%	85%	73.2%
54	2	(1:4,2:4)	Tanh	36.7%	78.3%	71.6%
55	2	(1:4,2:5)	Tanh	56.7%	61.7%	60.7%
56	2	(1:4,2:6)	Tanh	36.7%	63.3%	59.1%
57	2	(1:5,2:2)	Tanh	36.7%	61.7%	57.8%
58	2	(1:5,2:3)	Tanh	30%	71.7%	64.8%
59	2	(1:5,2:4)	Tanh	10%	81.7%	70.5%

Table 10. Continued.

Design NO.	Number of Hidden Layers	Neurons in each Hidden Layer	Activation Function	Specificity	Sensitivity	Accuracy
60	2	(1:5,2:5)	Tanh	10%	75%	64.7%
61	2	(1:5,2:6)	Tanh	33.3%	71.7%	66%
62	2	(1:6,2:2)	Tanh	16.7%	88.3%	77.4%
63	2	(1:6,2:3)	Tanh	16.7%	78.3%	68.9%
64	2	(1:6,2:4)	Tanh	33.3%	73.3%	67.3%
65	2	(1:6,2:5)	Tanh	53.3%	76.6%	73.3%
66	2	(1:6,2:6)	Tanh	26.7%	86.7%	77.5%

The best results in specificity, sensitivity, and accuracy were achieved for designs No. 52, 18, and 34, respectively. In order to predict the discarding or freezing of samples, four methods of LR, C4.5 DT, RBFNNs (hybrid with the k-means method), and MLPNNs were used. The maximum value of sensitivity was achieved using the LR method, but regarding the two criteria of specificity and accuracy, RBFNN method has the highest scores.

Set No. 2: The results of LR and decision trees are shown in *Table 11*.

Table 11. The results of the DT and LR.

Data Set	Method	Specificity	Sensitivity	Accuracy
2	LR	35.27%	83.94%	73.62%
2	DT	36.2%	86.8%	77.6%

Also, the DT extracted for fold 2 is shown in *Fig. 4*.

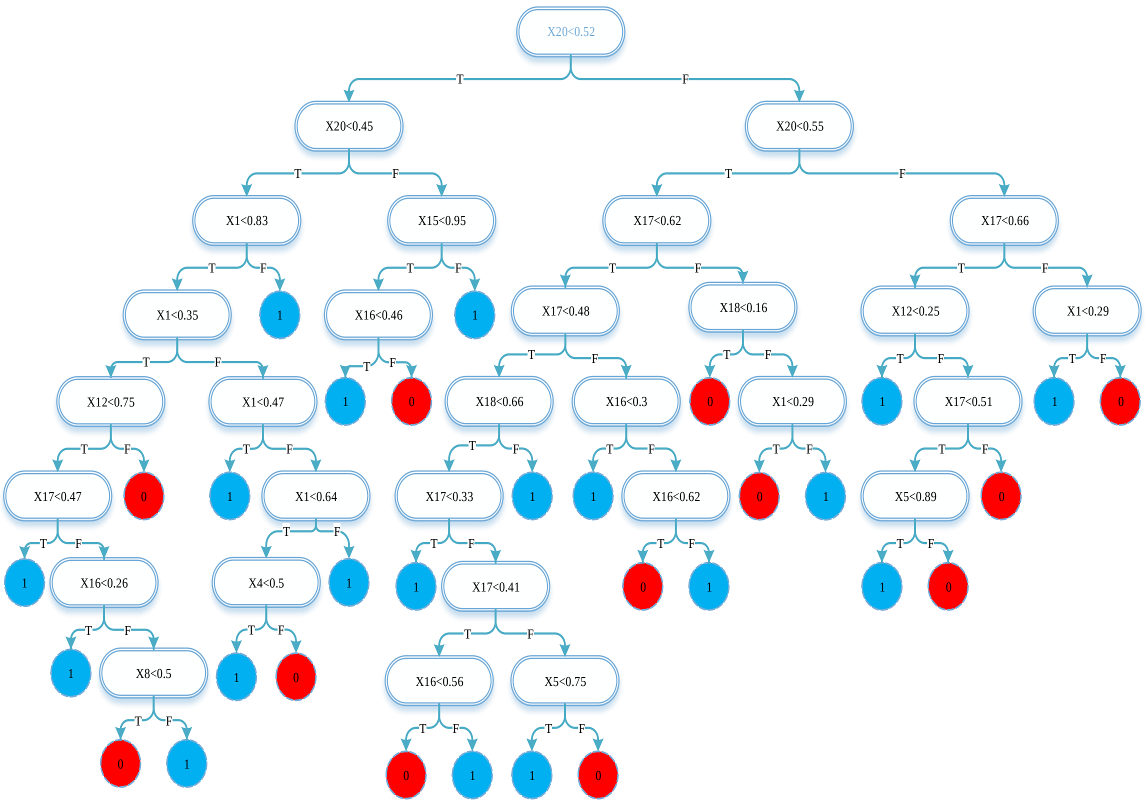

Fig. 4. Tree schema of generated rules for fold 2 prediction, using the DT method.

Different designs were proposed to use the RBFNNs. In order to adjust the input parameters such as the center and radius, the k-means clustering method is issued. 16 different designs are considered for the RBF neural network. *Table 12* shows the results of RBFNNs. It can be seen that the highest accuracy in these methods was achieved in design 3, using 5 clusters which are about 81.6%. In terms of the sensitivity criteria, the 5th design with 7 neurons in the hidden layer has managed to reach as high as 98.8

percent. In design no. 9, using 15 neurons in the hidden layer, the highest value of specificity was achieved compared with other designs.

Table 12. The results of the radial basis neural network method.

Design NO	Number of Clusters	Activation Function	Specificity	Sensitivity	Accuracy
1	3	Gaussian	11.7%	95.8%	80.4%
2	4	Gaussian	9.2%	95.8%	79.8%
3	5	Gaussian	10.5%	97.8%	81.6%
4	6	Gaussian	9.8%	96.9%	80.5%
5	7	Gaussian	3.7%	98.8%	81.3%
6	8	Gaussian	12.1%	93.7%	78.2%
7	9	Gaussian	9.9%	97.1%	80.7%
8	10	Gaussian	8.2%	96.6%	80.5%
9	15	Gaussian	25.1%	93.6%	81.3%
10	20	Gaussian	11%	96.5%	80.5%
11	25	Gaussian	12.2%	96.2%	80.5%
12	30	Gaussian	7.7%	97.6%	81%
13	35	Gaussian	5.9%	98%	81%
14	40	Gaussian	8.1%	95.8%	79.7%
15	45	Gaussian	11%	96.6%	80.5%
16	50	Gaussian	9.8%	96.4%	80.3%

Table 13 shows the results of the MLPNNs method. In the construction of these networks, one or two hidden layers with two different activation functions were used. The number of neurons in each hidden layer is shown in *Table 13*. 66 different designs of MLPNN were constructed and evaluated. The best results in terms of specificity, sensitivity, and accuracy were achieved for design numbers 65 and 9, respectively.

Table 13. The results of the MLPNNs method.

Design NO.	Number of Hidden Layers	Neurons in each Hidden Layer	Activation Function	Specificity	Sensitivity	Accuracy
1	1	2	Sigmoid	26.6%	76.2%	68.4%
2	1	3	Sigmoid	28.6%	85.6%	75.1%
3	1	4	Sigmoid	24.3%	80.7%	70.3%
4	1	5	Sigmoid	23.6%	84.7%	73.3%
5	1	6	Sigmoid	19.2%	79.3%	68.6%
6	1	7	Sigmoid	24.5%	79.3%	69.3%
7	1	8	Sigmoid	33.2%	77%	68.5%
8	1	9	Sigmoid	18.8%	78.7%	67.7%
9	1	2	Tanh	4.5%	99.2%	81.6%
10	1	3	Tanh	16.4%	88.9%	75.6%
11	1	4	Tanh	14.3%	81.2%	73.6%
12	1	5	Tanh	18.9%	80.4%	69.4%
13	1	6	Tanh	28.1%	71%	63.2%
14	1	7	Tanh	35.7%	79%	71%
15	1	8	Tanh	32.3%	73%	65.1%
16	1	9	Tanh	28.1%	78.1%	68.6%
17	2	(1:2,2:2)	Sigmoid	14.9%	89.2%	75.4%
18	2	(1:2,2:3)	Sigmoid	15.7%	87.2%	73.8%
19	2	(1:2,2:4)	Sigmoid	10.8%	89.7%	75.4%
20	2	(1:2,2:5)	Sigmoid	6.1%	92.8%	77%
21	2	(1:2,2:6)	Sigmoid	22.5%	86.4%	74.6%
22	2	(1:3,2:2)	Sigmoid	13.5%	91.7%	76.9%
23	2	(1:3,2:3)	Sigmoid	23.1%	84.4%	73%
24	2	(1:3,2:4)	Sigmoid	15.5%	86.7%	73.6%
25	2	(1:3,2:5)	Sigmoid	21.5%	85.4%	73.6%
26	2	(1:3,2:6)	Sigmoid	27.5%	79.9%	70.7%
27	2	(1:4,2:2)	Sigmoid	25.5%	79.5%	69.7%
28	2	(1:4,2:3)	Sigmoid	27.9%	81.7%	71.6%
29	2	(1:4,2:4)	Sigmoid	19.6%	78.4%	67.9%
30	2	(1:4,2:5)	Sigmoid	20.3%	81.2%	69.9%
31	2	(1:4,2:6)	Sigmoid	25.4%	82.9%	72.3%

Table 13. Continued.

Design NO.	Number of Hidden Layers	Neurons in each Hidden Layer	Activation Function	Specificity	Sensitivity	Accuracy
32	2	(1:5,2:2)	Sigmoid	30.2%	80.9%	71.3%
33	2	(1:5,2:3)	Sigmoid	29.5%	78.3%	68.7%
34	2	(1:5,2:4)	Sigmoid	30.7%	77.4%	68.7%
35	2	(1:5,2:5)	Sigmoid	33%	75.7%	67.8%
36	2	(1:5,2:6)	Sigmoid	21.6%	81%	69.7%
37	2	(1:6,2:2)	Sigmoid	25.7%	81.3%	71.8%
38	2	(1:6,2:3)	Sigmoid	30.9%	75.6%	67.2%
39	2	(1:6,2:4)	Sigmoid	34.8%	81%	72.5%
40	2	(1:6,2:5)	Sigmoid	30.5%	76.2%	67.6%
41	2	(1:6,2:6)	Sigmoid	27%	76.3%	67.2%
42	2	(1:2,2:2)	Tanh	9.7%	93.5%	79%
43	2	(1:2,2:3)	Tanh	8.9%	90%	75%
44	2	(1:2,2:4)	Tanh	16%	91.5%	77.4%
45	2	(1:2,2:5)	Tanh	14.5%	88.8%	75.1%
46	2	(1:2,2:6)	Tanh	16.2%	81.5%	69.7%
47	2	(1:3,2:2)	Tanh	3.2%	94.9%	77.8%
48	2	(1:3,2:3)	Tanh	21%	78.2%	67.6%
49	2	(1:3,2:4)	Tanh	12.5%	89%	75%
50	2	(1:3,2:5)	Tanh	25.5%	83.1%	72.5%
51	2	(1:3,2:6)	Tanh	19.6%	81.4%	70%
52	2	(1:4,2:2)	Tanh	26.5%	79.4%	69.7%
53	2	(1:4,2:3)	Tanh	22%	81.3%	70.3%
54	2	(1:4,2:4)	Tanh	20.9%	80.3%	69.3%
55	2	(1:4,2:5)	Tanh	30.9%	76.7%	68.4%
56	2	(1:4,2:6)	Tanh	27%	79.8%	70%
57	2	(1:5,2:2)	Tanh	30.5%	74.5%	66.3%
58	2	(1:5,2:3)	Tanh	27.4%	76%	66.9%
59	2	(1:5,2:4)	Tanh	25.5%	79.2%	69%
60	2	(1:5,2:5)	Tanh	21.1%	78.4%	67.7%
61	2	(1:5,2:6)	Tanh	17.9%	77.7%	66.9%
62	2	(1:6,2:2)	Tanh	30.4%	72.8%	64.2%
63	2	(1:6,2:3)	Tanh	34.9%	77.2%	69.2%
64	2	(1:6,2:4)	Tanh	28%	77.9%	69%
65	2	(1:6,2:5)	Tanh	36.4%	74.5%	67.5%
66	2	(1:6,2:6)	Tanh	33%	75.3%	67%

In order to predict the discarding or freezing of samples, four methods of LR, C4.5 DT, RBFNNs (hybrid with the k-means method), and MLPNNs were used. The highest values for the sensitivity and specificity criteria were obtained using the MLPNN method. But regarding the accuracy criterion, both methods of MLPNN and RBFNN (hybrid with the k-means method) earned the highest scores.

According to the presented results in the previous section, based on the prediction model of the RBFNN method, the reduced costs of discard and lost opportunity of the collected samples in Royan's umbilical cord blood bank during the past year can be calculated by the following procedure.

The cost of each contract is 22,000,000 Rials, in case of cancellation, 80% of the contract cost will be returned to the referring person. The cost imposed on the company will be different based on the fact that at what stage of the tests, the discard is determined. Hence the average cost of collecting the samples and related tests is estimated to be about 6,000,000 Rials.

The total number of contracts in the umbilical cord blood bank was 11,750 in 2015.

The percentage of contract discard was about 14% in 2015.

Considering the above data, the total reduction cost for sets 1 and 2 are shown in *Table 14*.

Table 14. The total reduction in the contract discard costs (Rials).

Set 1	Set 2
$11750*0.14*0.915*(0.8*22000000+6000000)$ $=35522130000$	$11750*0.14*0.816*(0.8*22000000+6000000)$ $=31678752000$

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This cost reduction for the company is estimated without considering the lost opportunity costs for discarded contracts, if it's taken into account, the amount of total cost reduction will be more than the above value.

6 | Conclusion

Choosing the best umbilical cord blood stem cells for storage, is one of the important issues that needs a proper pre-determined method. In the absence of this method, high costs are imposed on companies, and the optimal use possibility of the stored cells is reduced. In this paper, we proposed a proper classification prediction method (hybrid of radial basis neural network with k-means clustering) for freezing or discarding of umbilical cord blood stem cells, since some frozen records are useless when we need to use them for transplantation. Using the proposed method reduced storage costs and increased the likelihood of cells effectiveness. We implemented the proposed model in Royan institute and saved 1 million dollars for the first year and the provided result showed the method's effectiveness.

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E-ISSN: 2676-6167 | P-ISSN: 2538-5100

Journal of Applied Research on Industrial Engineering

www.journal-aprie.com

J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 238–255.

Paper Type: Research Paper

Evaluation of the Influential Factors in Human Resource Development in State-Owned Enterprises Using a Mixed Method

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Citation:

Heravi, A., Zamani Moghadam, A., Hashemi, S. A., Vakil Alroaia, Y., & Sajadi Jagharg, A. (2023). Evaluation of the influential factors in human resource development in state-owned enterprises using a mixed method. *Journal of applied research on industrial engineering, 10*(2), 238-255.

Received: 04/05/2021 Reviewed: 06/06/2021 Revised: 12/08/2021 Accepted: 21/10/2021

Abstract

Given the increased competition and turbulence in business environments, the proper management of human resources and employee growth is a significant challenge faced by organizations to achieve competitive advantage. The present study aimed to analyze the influential factors in Human Resource Development (HRD) in State-Owned Enterprises (SOEs). This was an applied research in terms of objective and a mixed (qualitative-quantitative), exploratory study in terms of design. In the qualitative-quantitative section of the study, content analysis and descriptive-exploratory techniques were applied. Data were collected via semi-structured interviews and by using questionnaires in the qualitative and quantitative sections, respectively. The research population included human resource experts, managers, and experts in the field of human resource planning and SOE management. In total, 22 individuals were selected via purposeful sampling. In the qualitative section, data analysis was carried out using open, axial, and selective coding for the classification of the identified factors into four categories of organizational, occupational, behavioral, and empowerment factors. In addition, screening was performed using the Fuzzy Delphi method, and the correlations between the identified factors and sub-factors were determined using the Fuzzy DEMATEL method. According to the results, empowerment factors were the most significant determinants of HRD, which could be improved by considering the associated influential factors and prioritization of organizational factors. On the other hand, the factor weighting findings based on the Fuzzy Analytic Network Process (FANP) indicated that among the identified factors and sub-factors of knowledge management, empowerment factors had the most significant impact on HRD.

Keywords: Human resource development, Industrial companies, Fuzzy DEMATEL, Fuzzy analytic network process.

1 | Introduction

Today, fundamental changes have been made in the world economy due to excessive competition. Researchers believe that competition changes rapidly within a short period, and such environmental changes are rather difficult to predict for companies. Human resource quality plays a pivotal role in achieving competition mainly because human resources could improve competitiveness through their capabilities and skills [1]. Human resources are the capital for the growth and development of a country. Skilled manpower increases productivity and directly contributes to economic growth. On a national scale, human resource policies and educational programs are considered essential to the workforce productivity growth within a country [2], [3]. Human development methods are classified as the organizational activities that could lay the foundation for the comprehensive enhancement and

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https://doi.org/10.22105/jarie.2021.284052.1322

education of all employees, which result in the improvement of their knowledge and skill-seeking behaviors [4].

Human development is a key issue in the field of organizational human resources as the empowerment of human resources to guarantee an organization's survival is a major challenge in various companies [5]. Human Resource Development (HRD) plays a pivotal role in the development of human expertise and implementation of systematic changes in organizations. Through organizational and educational development and enhancing the main areas of HRD, HRD strategies and methods could increasingly contribute to long-term human development and organizational performance [6]. Today, several high-tech companies have heavily invested in employee development [4]. However, it is crucial to plan human resources in order to eliminate irregularities and lay the foundation for the operational planning of an organization [7].

According to the literature, the higher quality of human resources is associated with the higher competitiveness of the workforce [1]. HRD supports the efficacy and long-term stability of an organization [6]. As such, organized and efficient HRD programs encompassing the necessary support infrastructures largely contribute to retaining experienced and skilled staff [9]. Human resources and skills development are major organizational challenges in every country, especially developing countries [8]. Therefore, continuous changes in the cultural, economic, and technological environment of organizations may give rise to challenges concerning proper human resource management and the improvement of their performance [10], which highlights the importance of long-term HRD programs [8]. By creating a beneficial work environment, HRD could increase employees' knowledge, honesty, trust, and involvement in performance improvement programs [11]. Performance improvement at an organizational level requires the establishment of a culture revolving around continuous staff training within an organization [12].

The State-Owned Enterprise (SOE) system is one of the foundations of the country's economic development since it could provide the economic cycle of the society and generate jobs. Since SOEs are the engines of the national economic production sector, they are expected to excel in HRD. Given the constant development of the world's industrial sector and the key role of SOEs in this area, SOEs must have a better understanding of the correlation between HRD and production quality. Therefore, HRD has become a necessity in such organizations. In the city of Mashhad, there are 24 SOE that face several issues of development in the field of human resources that must be addressed in order for state-owned industrial companies to expand their presence domestically and internationally.

SOEs deal with various issues regarding HRD, which must be resolved in order to increase the presence of SOEs at national and international levels. Notably, HRD in these companies is so important that weaknesses in HRD and staff knowledge improvement have become a critical issue in the management of different challenges such as work-related problem-solving incapability, diminished value of the knowledge of experiences, poor competence, and inadequate knowledge of staff, which could weaken human resource performance, diminish the overall efficiency of the organization, and intensify issues in the future. One of the main goals of private companies is to reduce costs, earn profits and increase productivity, while state-owned companies have not been successful in reducing costs, increasing profits and productivity hence, what distinguishes this study from other studies is that this study was conducted on SOEs in which there are no previous studies. Given the importance of HRD in SOEs, the following questions have been addressed in the present study:

- *What are the factors, sub-factors, and indicators affecting the HRD of SOEs?*
- *What are the correlations between the factors and sub-factors affecting the HRD of SOEs?*
- *What is the relative importance of the factors and sub-factors affecting the HRD of SOEs?*

2 | Theoretical Framework

The industrial revolution is recognized as a driving force in the evolution of HRD. By the mid-1930s, the formal concept of Organizational Development (OD) had emerged. The theories of OD development have created an opportunity for the education and development of flourishing staff [13]. On the other hand, neglecting HRD and its impact on organizational success may have detrimental effects on organizational performance [14]. HRD establishes purposeful measures that guide staff toward certain behaviors and physical/mental inclinations [15]. According to Burma's theory, HRD mainly focuses on learning with the aim of achieving individual and organizational goals. In this respect, development occurs over time and through emphasizing learning, education, and development opportunities to improve the individual, a team, and organizational performance [7]. Sablok et al. [16] define HRD as the integrated use of education, development, organizational enhancement, and career advancement to improve the individual, a group, and organizational efficiency. In general, HRD is defined from two perspectives; first, HRD is defined as a learning model, which is recognized as learning and performance outcome enhancement based on Chalofsky's theory. The other model has been presented by Ju [17], who emphasized that HRD could improve performance through learning. HRD is an interdisciplinary profession, which is focused on systematic training and development, professional development, and OD to improve organizational processes and enhance the learning and performance of individuals, organizations, and communities [18]. Researchers have evaluated HRD based on individual development, training/development, career advancement, team development, and OD [19]. OD and strategic HRD are often employed to improve individuals, a team, and organizational performance [17]. In a research conducted by Dixit and Sinha [9], education and development were reported to be the main components of HRD [9]. According to Ju [17], the most important components of HRD include the individual, a team, and OD.

In numerous countries, terms such as productivity, professional education, equity/diversity, and health/safety are considered the inherent elements of HRD [11]. Moreover, the production and improvement of competitive advantage occur through workforce productivity and innovation [3]. While long-term sustainable HRD programs are of paramount importance, they cannot be designed without a solid basis, and adequate preparation for efficient human resource management is essential to expertise development. To retain workforce, workforce planning should: 1) assess the current workforce and the extent to which it is used to exploit industries, 2) establish a regular structure for evaluating various types of HRD plans and improvements, 3) identify the competency gaps between the current and future manpower, 4) develop long-term competency-based recruitment strategies, and 5) ensure careers, incentives, and reward packages [8]. On the same note, Shin et al. [20] confirmed that the coordination among the three factors of industry, HRD, and research is essential to economic development.

Employment could be strengthened in agencies through improving skills and promoting innovation by taking effective HRD measures, such as job training, on-the-job learning, and specialized training development [21]. In this regard, Otoo and Mishra [40] claimed that HRD measures are the plans that strategically contribute to the organizational process of HRD, thereby leading to the overall success of the organization. HRD measures should be designed and implemented by organizations to enable the staff to work efficiently through enhancing their individual competencies and meeting performance expectations. In addition, HRD measures should enhance employees' abilities in terms of their occupation, efficiency, and productivity and increase the quality of products and services [40].

As mentioned earlier, HRD measures are absolutely essential, and researchers have previously proposed some of these measures. According to the literature, career development efforts could enhance employee competencies [40]. Career development encompasses organized, official, and planned efforts to strike a balance between the occupational needs of an individual and the workforce needs of an organization, which increases the motivation of employees and enhances the company's performance [40]. Evidence suggests that organizations use education and development to improve the work-related knowledge and technical skills of their employees [16]. Education and development are attained through training,

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occupational learning, coaching, and other nurturing approaches [22]. Educational quality has a significant impact on the economic development of Asian countries [3].

Researchers have widely discussed performance assessment and its role in HRD. The evaluation of individual performance could increase efficiency. Meanwhile, performance management strategies play a key role in the commitment and attitudes of the workforce [40]. On the other hand, it has been proposed that using technology in HRD methods could improve learning, occupational performance, and organizational decision-making, thereby providing a great opportunity for increasing the efficiency of HRD measures [23]. Technology saves time, money, and human resources in HRD techniques over time [24]. Moreover, strategic human resource management affects HRD. In fact, strategic human resource management explicitly links human resource management measures with the organization's strategic management processes, emphasizing the coordination of various human resource management measures, including education and development. Therefore, strategic human resource management could influence HRD activities [16], while the lack of strategic plans regarding the knowledge of management in an organization leads to the failure of human resources in innovation and strategic performance [25].

Several studies have discussed the role of leadership development in HRD [19]. Leadership is an operational tool for the effective change of HRD and helping the staff to have a better performance [26]. A leader must be able to teach and foster a suitable culture to prevent misunderstandings, errors/failures in a project, and personal/professional dissatisfaction [27]. In the theoretical literature, researchers have proposed various HRD measures with economic, cultural, and psychological viewpoints (*Table 1*).

Table 1. HRD measures extracted from the theoretical literature.

HRD Measures	Reference
Strategic planning	[16]
Management development	[16]
Occupational planning	[16], [22], [40]
Technology	[41], [42]
Budget	[41]
Management support	[42]
Organizational structure	[42], [43]
Organizational structure	[22], [43], [44]
Human resource management	[43]
State policies	[43], [45]
Knowledge management	[28]
Performance evaluation	[40]
Information technology	[46]
Leadership	[19]

3 | Literature Review

In this section, we have presented a summary of previous domestic and foreign findings regarding HRD models and measures in various areas. In a research, Hajilo et al. [28] evaluated an HRD ethical model in government organizations, focusing on three dimensions of empowerment, talent management, and knowledge management, in order to achieve an optimal combination. Fallah [30] stated that knowledge management plays a pivotal role in the empowerment of employees through increasing the synergy of cultural and capacity-building factors. Furthermore, Pakdel et al. [31] assessed a national HRD model using a dynamic system approach, reporting that the national HRD system had the key infrastructures for the training of human resources and their introduction to the market.

In another study, Masoudi Alavi [5] identified and ranked the influential factors in HRD in educational organizations. In the mentioned study, the main HRD dimensions were determined to be individual, organizational, and environmental. According to the obtained results, the individual dimension had the most significant effect in this regard. Askari Masouleh [32] proposed an integrated HRD model in the organizations of the Islamic Republic of Iran based on the Islamic-Iranian model of progress. In the

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mentioned study, the key factors of the development model were managerial, national/extra-organizational, individual, service compensation, performance appraisal system, employee commitment, career advancement path, employee planning/guidance, employees' independence in performing tasks, hardware/software conditions of the work environment, training/knowledge management in the organization, employee empowerment, culture/values/organizational behavior, religious orientation, organizational justice, perfectionism, and content/indigenous factors. In another study, Namee [29] presented an HRD model based on the knowledge management process and knowledge transfer model. According to the findings, the knowledge transfer model, knowledge management process, and organizational factors directly affected HRD. On the same note, Ahmadvand and Yavari Bafghi [33] designed an HRD model in the Islamic Republic of Iran Police (NAJA). According to the obtained results, the evaluation and level of human resources, ordering education, continuous education, job rotation, and individual opinion most significantly affected the HRD of NAJA, respectively.

As for foreign studies, Mahmood et al. [11] confirmed the effect of emotional intelligence on HRD. Nguyen and Hadikusumo [19] investigated the impact of HRD on the success of engineering projects, reporting the main HRD components to be individual, education and development, occupational development, teaching development, and OD. In another study, Ensour et al. [34] evaluated the effects of different factors on the HRD strategic position in the universities in Jordan, observing that all the identified factors (i.e., performance, organizational, and individual factors) played a key role in the prediction of the dependent variable. Sparkman [35] evaluated the national HRD conditions and influential factors in Brazil, stating that political, economic, social, and educational factors had the most significant impact of HRD.

Kazakovs [36] analyzed the influential factors in finding a solution for HRD. In the mentioned study, 12 influential factors were identified, including the need for development, efficiency of developmental solutions, time, development methods, identification style, and place of residence, price, travel costs, indirect costs, situation development priorities, and skill development priorities. Furthermore, Kumpikaite and Sakalas [37] proposed an HRD system assessment model encompassing variables such as the organizational approach to HRD, career organization, training, professional development, adaptation, and evaluation, developmental needs, and rewards.

4 | Research Methodology

The present study aimed to evaluate the influential factors in the HRD of SOEs. This was an applied research in terms of objective since it developed applicable knowledge in the field of HRD in SOEs. In addition, it was a mixed research (qualitative-quantitative) in terms of the type of data. In terms of design and methodology, this was an exploratory study. Data were collected using the library method, and field data collection was performed via interviews and by using questionnaires. The study was carried out in two qualitative and quantitative sections. The study population includes experts, managers and employees of SOEs in the city of Mashhad. *Table 2* shows the statistical population and sample size.

The qualitative section involved a directed content analysis, using the theoretical background proposed by experts, and interviewing these experts. The research population included experts, managers, and specialists in the field of human resources management and SOE planning in Mashhad, Iran. The inclusion criteria of the study were ahigh academic levelminimum work experience of 15 years in the related fields a previous human resource management position in SOEs thorough knowledge of the research subject and sufficient motivation. The participants were selected via purposeful sampling, and a total of 22 individuals completed the questionnaires. The researcher attempted to select the participants who had an adequate knowledge of the research subjects.

Table 2. SOEs in the city of Mashhad and sample size.

Company Name	Activity	Number of Staff	Sample Size
Foolad Yar Novin Factory Industrial Complex	Nonmetallic mineral	128	18
Lahour Ahan-e Shargh	Basic metals	113	16
Production of Khorasan Gas Power Plants	Power generation	65	9
Part navard-e lahour	Basic metals	79	11
Gas Refining of Shahid Hasheminejad	Oil, gas and petrochemicals	68	10
East Asian Cavian Steel	Basic metals	256	36
Khorasan Steel	Basic metals	385	54
Arna Petro Gas	Oil, gas and petrochemicals	79	11
State Mining Company	Basic metals	202	29
Production of minerals in East Khorasan Steel	Basic metals	257	36
Iran Khodro Khorasan Company Shir	Car	318	45
Pegah Khorasan Company Mashhad	nutritive	112	16
Cement Company	Nonmetallic mineral	253	36
Mashhad Packaging Industries	Nonmetallic mineral	45	6
Carton of Mashhad	Nonmetallic mineral	62	9
Mashhad ring making	Car	82	12
Shargh Electric Car Company	Car	108	15
Tavanir Company	Power generation	126	18
Total		2738	360

In the quantitative section, data were collected via semi-structured, in-depth interviews, and data analysis was performed by coding. This section of the research was descriptive-exploratory, and the sample population included experts such as human resources managers. In total, 22 individuals were selected for model development and screening the factors using the Fuzzy Delphi method and fuzzy DEMATEL method to determine the correlations between the identified factors, and data were collected using a questionnaire. For screening by the Fuzzy Delphi method, the items of the questionnaire were scored based on a five-point Likert scale, and the questionnaire of fuzzy DEMATEL method was also applied for paired comparisons. Data analysis was carried out using the Fuzzy Delphi method to screen the identified factors and the fuzzy DEMATEL method to determine their correlations. In addition, the significance of the identified factors was determined through the Fuzzy Analytic Network Process (FANP).

Content validity was evaluated based on the opinions of the experts in the field. In the present study, we applied measurement tools and Lawshe method to assess the research variables. To this end, a questionnaire was provided to the experts to determine the appropriateness of each item related to each variable by selecting one of the options of 'necessary', 'Beneficial but not necessary', and 'Unnecessary'. In the next stage, the Lawshe coefficient of 22 experts was calculated and compared to the Lawshe table for the minimum values of the content validity ratio. In this respect, the Lawshe coefficient of 0.40 was estimated for 22 experts as an acceptable value.

The fuzzy DEMATEL-based FANP was used for data analysis in the quantitative section of the present study. DEMATEL is an approved method for the assessment of complex structures and the correlations between the identified influential factors in HRD. Moreover, this approach shows the visual structural model as a cause-and-effect graph. In addition to examining the correlations between the levels of various criteria, cause-and-effects are also classified and displayed in a diagram in this method [47]. The FANP also weighs factors and is more accurate for the factors that are correlated [38]. To implement the fuzzy DEMATEL-based FANP:

I. We asked a panel of experts to determine the effect of each factor on the other factors based on the information provided in *Table 2* using a paired comparison questionnaire. Afterwards, a fuzzy direct relation matrix was prepared by calculating the arithmetic mean.

Table 3. Linguistic scales for pairwise comparison.

Linguistic Words for Pairwise Comparisons		Fuzzy Numbers
Extremely high effect	$\tilde{4}$	(0.75, 1, 1)
High effect	$\tilde{3}$	(0.5, 0.75, 1)
Low effect	$\tilde{2}$	(0.25, 0.5, 0.75)
Extremely low effect	$\tilde{1}$	(0, 0.25, 0.5)
No effect	0	(0, 0, 0.25)

II. After forming the fuzzy direct relation matrix, the matrix was normalized using *Eqs. (1)* and *(2)*.

$$X= K.\widetilde{A}. \tag{1}$$

$$k = \min\left[\frac{1}{\max_{1\le i\le n}\sum_{j=1}^{n}\widetilde{A}_{ij}},\frac{1}{\max_{1\le i\le n}\sum_{i=1}^{n}\widetilde{A}_{ij}}\right],\quad i, j= 1, 2\ldots n. \tag{2}$$

In these equations, K is the least value obtained by dividing 1 by the sum of the values of the rows and columns. Afterwards, the fuzzy direct relation matrix was multiplied into K value and normalized matrix was obtained.

In Stage 3, the general relationship matrix was obtained through *Eq. (3)*.

$$T = [X(I - X)]^{-1}. \tag{3}$$

In these equations, K is the lowest value obtained by dividing one by the sum of the values of the rows and columns. At the next stage, the fuzzy direct relation matrix was multiplied into the K value, and a normalized matrix was obtained.

III. In Stage 3, general relation matrix was obtained using *Eq. (3)*.

$$T=X(I-X)^{-1}. \tag{4}$$

In the equation above, $\widetilde{T}$ shows the general relation matrix, and X is the normalized matrix. To calculate the T matrix, the normalized matrix was subtracted from the identity matrix and reversed. Ultimately, the obtained value was multiplied into the normalized matrix, and the general relation matrix was obtained.

IV. Based on the general fuzzy relation matrix, $(\widetilde{D})$ effectiveness values were obtained from the sum of the columns of the general relation matrix, and $(\acute{R})$ effectiveness values were calculated from the sum of the rows of the general relation matrix. These relations are presented in *Eqs. (5)-(7)*.

$$T=\left[t_{ij}\right]n\times n,\quad i, j= 1, 2\ldots n. \tag{5}$$

$$\widetilde{D}=\left[\sum_{j=1}^{n} t_{ij}\right] =[t_i]\ n\times 1. \tag{6}$$

$$R=\left[\sum_{i=1}^{n} t_{ij}\right] =[t_j]1\times n. \tag{7}$$

V. At the final stage, the status of each factor was determined by calculating the sum of the effective and impressionable values $(\widetilde{D+R})$ and subtracting the respective values from the effective values $(\widetilde{D}\text{-}\acute{R})$.

Correspondingly, the cursor and state of a factor were plotted on the axis of the coordinates, and the map of the relations of effects was obtained, which demonstrated the interactions of cause

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(effectiveness) and effect (impressibility). Various hypotheses were used to determine the correlation among the identified factors, which have been discussed below:

I. The factor is considered impressionable if it is below zero $(\widetilde{D}\text{-}R)<0$ and $(\widetilde{D}+\acute{R})=\alpha$.

II. The factor is considered effective if it is above zero $(\widetilde{D}\text{-}R)>0$ and $(\widetilde{D}+R)=\alpha$.

At the next stage, the fuzzy DEMATEL general relation matrix was exploited to solve the FANP. Notably, the accuracy of the method has been previously confirmed [38]. Initially, we normalized the fuzzy DEMATEL general relation matrix using *Eq. (7)* to achieve a balanced matrix for solving the FANP.

$$T_C^{nor_{11}} = \begin{bmatrix} t_{C_{11}}^{11}/d_1^{11} & \cdots & t_{C_{1j}}^{11}/d_1^{11} & \cdots & t_{C_{1m_1}}^{11}/d_1^{11} \\ \vdots & & \vdots & & \vdots \\ t_{C_{i1}}^{11}/d_i^{11} & \cdots & t_{C_{ij}}^{11}/d_i^{11} & \cdots & t_{C_{im_1}}^{11}/d_i^{11} \\ \vdots & & \vdots & & \vdots \\ t_{C_{m_1 1}}^{11}/d_{m_1}^{11} & \cdots & t_{C_{m_1 j}}^{11}/d_{m_1}^{11} & \cdots & t_{C_{m_1 m_1}}^{11}/d_{m_1}^{11} \end{bmatrix}. \quad (8)$$

The exponentiation of the obtained balanced supermatrix was performed until all the elements were integrated based on $\lim_{h\to\infty}(W^w)^h$ equation and the weight of each element was calculated.

5 | Empirical Results

In the qualitative section, data analysis was carried out in three main steps. The first step involved presenting the qualitative data and coding, the second step was extracting concepts from the qualitative data through axial coding, and the third step was extracting the categories of the related concepts through selective coding. To this end, the main concepts obtained from the interviews were initially shown in a free coding form, and the overview of the research was presented to the readers. In addition, the key points in the interviews were converted into open codes, and the codes were converted into concepts related to the research subjects.

In the second step of axial coding, the codes that were distinguished in the previous step were combined based on their correlation with the other codes, which resulted in the formation of the related concepts. In the final stage (i.e., selective coding), the related concepts were classified based on their correlation with similar subjects, thereby forming categories with a high conceptual power since they were able to accumulate concepts on the axis. The categories were labeled by the researcher based on a research literature and attempted to have the highest communication and harmony with their representative data. *Table 4* shows the concepts extracted from the open codes and their conversion into different categories.

Table 4. Open codes, concepts and extracted categories.

Main Category	Concepts	Open Codes
Organizational factors	Strategic planning	Human Resource Strategic Planning - futurism and a clear vision- policy and developing programs - strategic coordination of programs.
	Budgeting	All codes were eliminated by the Lawshe coefficient.
	Organizational structure	Flexibility- decentralized control - horizontal structure.
	Information technology	All codes were eliminated by the Lawshe coefficient.
	Communications	Participation and cooperation with other units - communication and cooperation between people - communication facilities.
Occupational factors	Human resource management	Retention of specialists - design and analysis of occupations – performance-based compensation - health and safety - timely salaries and facilities.
	Job rotation	Skill diversity – identification of potential skills.
	Job enrichment	Emphasizing knowledge and expertise in decision making - job identity - increased employee authority and decision making - career feedback.

Table 4. Continued.

Main Category	Concepts	Open Codes
Empowerment factors	Career path planning	All codes were eliminated by the Lawshe coefficient.
	Career advancement path management	Designing career development paths - recognizing employees' career goals and aspirations -career policy and goals.
	Education	Staff training planning - continuity in training - applied and specialized training - training needs assessment – coaching.
	Knowledge management	Information sharing - establishment of knowledge management system based on culture and structure - training and culture of knowledge promotion - knowledge development.
	Talent management	All codes were eliminated by the Lawshe coefficient.
Behavioral factors	Performance assessment	Designing a performance evaluation system based on the appropriate method - performance evaluation and monitoring.
	Management and leadership	Senior manager support - incentive and motivational systems – proper leadership style - employee identification.
	Arousal	Individual motivation - sense of belonging - employee satisfaction.
	Organizational culture	Valueism - participatory culture - performance improvement culture - work culture formation - change management culture.
	Creativity and innovation	Attention to creativity and innovation - attention to employees' opinions - individual innovation.

Initially, the key points and concepts (sub-factors) were extracted from the interviews with the experts. Following that, the concepts were collected in larger categories of the main concepts (factors) based on the theoretical literature in this regard. According to the obtained results, the four main HRD categories included organizational, occupational, empowerment, and behavioral factors.

At the next stage, the Lawshe coefficient was applied to assess the indices, followed by the fuzzy Delphi method, to evaluate the sub-factors. In addition, the Lawshe coefficient of each questionnaire item was calculated based on the opinions of 22 experts. The Lawshe coefficient of all the items was compared to the coefficient value of 0.40, and the validity of the items was assessed. Following that, the fuzzy Delphi method was exploited to determine and select the sub-factors. To this end, the opinions of 22 experts about the significance of 21 sub-factors were obtained for solving the fuzzy Delphi in three stages based on a five-point Likert scale. To terminate the fuzzy Delphi, the experts considered the threshold of the difference of opinions to be 0.2 based on the Pareto front (80-20 rule). The sub-factors for which a lack of consensus was less than 0.2 in various stages and the mean fuzzy points were above eight were selected as the final sub-factors.

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Table 5. Fuzzy Delphi results based on experts' opinions.

Factors	Column	Linguistic Value	Extremely High	High	Moderate	Low	Extremely Low	Non-Fuzzy Mean of Expert Opinion	Differences in Questionnaire Means	Results
		Numerical value	9	7	5	3	2			
		Sub-factors – fuzzy value	(10, 9, 7)	(9, 7, 5)	(7, 5, 3)	(5, 3, 1)	(3, 1, 0)			
Organizational factors	1	communications	14	6	2	0	0	8.78	0.10	Confirmation of the second stage
	1	Organizational structure	14	5	2	0	0	8.43	0.15	Confirmation of the second stage
	3	Budgeting	0	10	9	3	0	6.20	0.01	Rejected
	4	Information technology	0	5	9	7	1	5.11	0.01	Rejected
	5	Strategic planning	17	3	2	0	0	9.06	0.09	Confirmation of the second stage
Occupational factors	6	Job rotation	10	9	2	0	0	8.07	0.15	Confirmation of the third stage
	7	Career path planning	1	8	5	8	0	5.69	0.18	Rejected
	8	Human resource management	15	7	0	0	0	9.08	0.10	Confirmation of the third stage
	9	Job enrichment	14	4	3	1	0	8.48	0.10	Confirmation of the second stage
	10	Career path management	12	9	1	0	0	8.70	0.15	Confirmation of the third stage
Empowerment factors	11	Talent management	6	11	1	4	0	7.35	0.10	Rejected
	12	Education	13	7	2	0	0	8.69	0.10	Confirmation of the third stage
	13	Knowledge management	15	5	2	0	0	8.88	0.18	Confirmation of the second stage
	14	Performance evaluation	11	6	4	1	0	8.11	0.10	Confirmation of the second stage
Behavioral factors	15	Arousal	15	3	4	0	0	8.68	0.10	Confirmation of the second stage
	16	Organizational culture	13	9	0	0	0	8.89	0.19	Confirmation of the second stage
	17	Creativity and innovation	16	4	2	0	0	8.97	0.10	Confirmation of the second stage
	18	Management and leadership	15	4	3	0	0	8.78	0.10	Confirmation of the second stage

Four out of 18 sub-factors were eliminated from the conceptual model of the research over the three stages of the survey, and the final model consisted of 14 sub-factors (*Fig. 1*), forming a model with the network structure of the research.

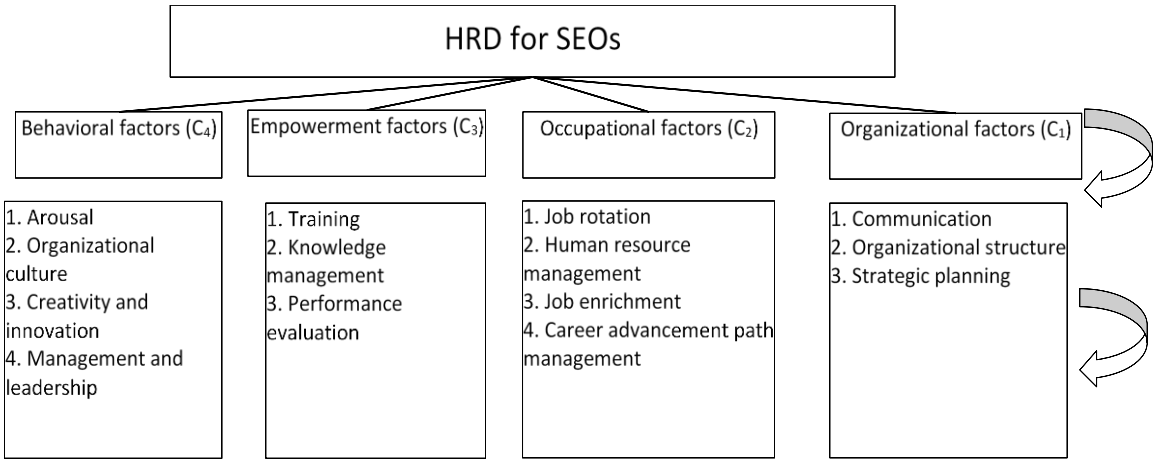

Fig. 1. The research model with an HRD network structure for SEOs.

Table 6. Fuzzy direct matrix among factors affecting HRD.

	Organizational Factors			Occupational Factors			Empowerment Factors			Behavioral Factors		
	Low	Middel	High	Low	Middel	High	Low	Middel	High	Low	Middel	High
Organizational factors	0	0	0	0.75	0.5	0.25	0.85	0.6	0.35	0.75	0.5	0.25
Occupational factors	0.55	0.3	0.05	0	0	0	1	0.9	0.65	0.9	0.7	0.45
Empowerment factors	0.5	0.25	0.05	0.55	0.3	0.1	0	0	0	0.9	0.7	0.45
Behavioral factors	0.4	0.15	0	0.65	0.4	0.15	1	0.9	0.65	0	0	0

In this section, the fuzzy DEMATEL method was applied to address the second research question. To this end, a paired comparison questionnaire was designed and provided to 22 experts to be completed. Afterwards, the responses were collected and analyzed by fuzzy DEMATEL coding in the Excel software. In addition, the significance of the impact of the identified factors and sub-factors on each other was determined, and the fuzzy direct relation matrix was obtained based on the primary DEMATEL step (see, *Tables 5* and *6*).

Afterwards, the fuzzy direct relation matrix was normalized using *Eq. (2)*, and the general relation matrix was obtained based on *Eq. (3)*. Following that, we obtained the sum of the rows and columns of the fuzzy general relation matrix using *Eqs. (4)* and *(5)*. The interactions between the influential factors and sub-factors were determined by summing up the values of effectiveness and impressibility ($\widetilde{D}_i+R_i$) and based on their correlations by subtracting the impressibility factors from the effectiveness factors ($\widetilde{D}_i-R_i$) (*Table 7*).

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Table 7. Fuzzy direct matrix among the sub-factors affecting HRD.

	C_{11}			C_{12}			$C_{...}$	C_{43}			C_{44}		
C11	0	0	0	0.75	0.55	0.3	...	0.75	0.5	0.25	0.6	0.35	0.1
C12	0.85	0.65	0.4	0	0	0	...	0.8	0.55	0.3	0.7	0.5	0.25
C13	0.8	0.55	0.3	0.85	0.6	0.35	...	0.8	0.55	0.3	0.75	0.5	0.25
C21	0.6	0.35	0.1	0.65	0.4	0.15	...	0.65	0.4	0.15	0.75	0.5	0.25
C22	0.75	0.5	0.25	0.9	0.7	0.45	...	0.7	0.45	0.2	0.65	0.4	0.15
C23	0.55	0.3	0.1	0.5	0.25	0	...	0.7	0.45	0.2	0.6	0.35	0.1
C24	0.7	0.45	0.2	0.8	0.55	0.3	...	0.6	0.35	0.15	0.6	0.35	0.15
C31	0.95	0.7	0.45	0.9	0.65	0.4	...	0.75	0.5	0.25	0.8	0.55	0.3
C32	0.85	0.65	0.4	0.65	0.4	0.15	...	0.75	0.5	0.25	0.9	0.65	0.4
C33	0.85	0.6	0.35	0.9	0.65	0.4	...	0.65	0.4	0.15	0.65	0.4	0.15
C41	0.85	0.65	0.4	0.75	0.55	0.3		0.8	0.55	0.3	0.55	0.3	0.05
C42	0.8	0.55	0.3	0.8	0.6	0.35		0.7	0.45	0.2	0.7	0.45	0.2
C43	0.9	0.65	0.4	0.75	0.5	0.25		0	0	0	0.6	0.35	0.15
C44	0.65	0.45	0.2	0.55	0.3	0.05		0.9	0.75	0.5	0	0	0

Table 8. Effective and impressible factors and the interaction between factors and subfactors affecting HRD.

Factors/Subfactors	Total Rows	Total Columns	Interaction Severity	Effectiveness/Impressibility Severity	Results
Organizational factors	1.424	0.762	2.186	0.662	The most effective
Communications	0.82	0.859	1.679	-0.0395	Impressible
Organizational structure	0.879	0.827	1.706	0.0517	Effective
Strategic planning	0.841	0.854	1.695	-0.0123	Impressible
Occupational factors	1.57	1.116	2.686	0.454	Effective
Job rotation	0.964	1.104	2.068	-0.14	Impressible
Human resource management	1.037	0.889	1.925	0.1479	Effective
Job enrichment	1.019	1.055	2.073	-0.0356	Impressible
Career advancement path management	1.1	1.072	2.172	0.0277	Effective
Empowerment factors	1.163	1.913	3.076	-0.75	The most impressible
Education	0.871	0.85	1.721	0.0207	Effective
Knowledge management	0.835	0.9	1.735	-0.0651	Impressible
Performance evaluation	0.865	0.82	1.685	0.0445	Effective
Behavioral factors	1.27	1.637	2.907	-0.366	Impressible
Arousal	0.907	0.978	1.885	-0.0704	Impressible
Organizational culture	1.057	1.113	2.17	-0.0563	Impressible
Creativity and innovation	1.05	1.009	2.059	0.0403	Effective
Management and leadership	0.987	0.901	1.888	0.0863	Effective

According to the information in *Table 7*, the organizational and occupational dimensions had positive $\widetilde{D}$-R and affected the other factors. On the other hand, the behavioral and empowerment factors had negative $\widetilde{D}$-R and were affected by the other factors. *Fig. 2* depicts the level of significance, effectiveness, and impressibility of the identified factors and sub-factors. In this figure, the horizontal axis of the diagram indicates the significance of the factors ($\widetilde{D}_i$+R_i), while the vertical axis shows the effectiveness or impressibility of the factors ($\widetilde{D}_i$-R_i). Based on the correlations between the factors shown in *Fig. 2*, the organizational factors affected the occupational, behavioral, and empowerment factors and were affected by none of the factors. On the other hand, the empowerment factors were affected by the other factors and impacted none of the other factors.

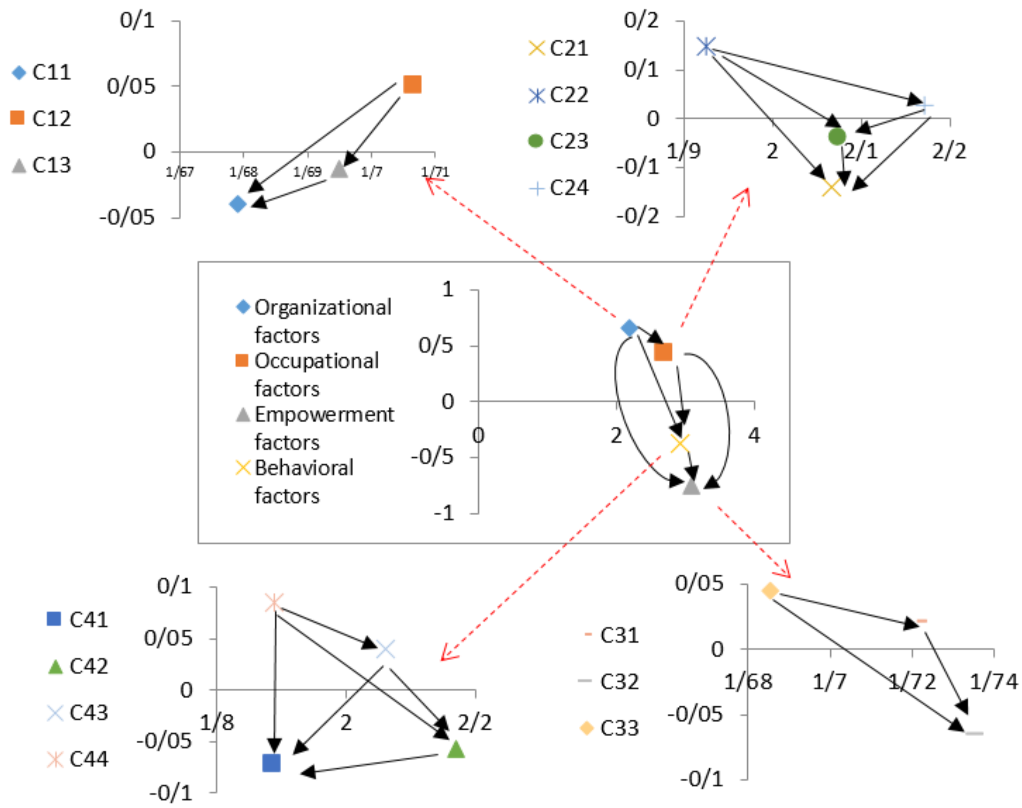

Fig. 2. Cause-effect diagram and network map of relations between factors and subfactors affecting HRD.

At this stage, the FANP was applied to determine the weight and significance of the HRD factors and sub-factors to address the third research question. To solve the FANP, we used the output of the fuzzy DEMATEL method and the general relation matrix results. The general relation matrix was normalized by *Eq. (5)*, followed by obtaining a fuzzy weighted supermatrix. Afterwards, the weighted supermatrix was integrated at exponentiation seven through the equation $\lim_{K\to\infty} W^{a})^{K}$, which led to the formation of a bounded supermatrix, where the weight of all the factors and sub-factors was repeated in exponentiation 7, and calculations were terminated. Accordingly, the number of the bounded supermatrix was identified as the final weight of the sub-factors. *Table 8* shows the weight of the HRD factors and sub-factors.

Table 9. List of Arc lengths.

Weight and Importance of Factors		Sub-Factors	Final Weight of Sub-Factors	Final Importance of Factors
Organizational factors C1	0.119 (4)	Communications	0.041	(11)
		Organizational structure	0.039	(14)
		Strategic planning	0.039	(13)
Occupational factors C2	0.194 (3)	Job rotation	0.053	(8)
		Human resource management	0.04	(12)
		Job enrichment	0.05	(10)
		Career advancement path management	0.051	(9)

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Table 9. Continued.

Weight and Importance of Factors		Sub-Factors	Final Weight of Sub-Factors	Final Importance of Factors
Empowerment factors C3	0.361 (1)	Education	0.117	(2)
		Knowledge management	0.132	(1)
		Performance evaluation	0.112	(3)
		Arousal	0.073	(6)
Behavioral factors C5	0.326 (2)	Organizational culture	0.103	(4)
		Creativity and innovation	0.076	(5)
		Management and leadership	0.073	(7)

According to the information in *Table 8*, the largest weight belonged to the empowerment factors (0.361), indicating that these factors had the foremost significance. As for the sub-factors, knowledge management had the most significant weight (0.132) and the foremost significance, followed by the education sub-factor (0.117).

6 | Discussion and Conclusion

The present study aimed to evaluate the influential factors in the HRD of SEOs by using a mixed method, including qualitative (content analysis) and quantitative approaches (fuzzy DEMATEL-based FANP). According to the obtained results, the organizational, behavioral, occupational, and empowerment factors affected OD. In addition, attempts were made to determine the correlations, effectiveness, and impressibility of the factors in the fuzzy DEMATEL method, and the findings indicated that the organizational factors had the most significant effect on the other factors (net effect = 0.662), as well as the first priority in terms of influence on HRD. Therefore, success in HRD begins with this factor and extends to other factors.

In SEOs, achieving HRD requires managers' attention to organizational communication, organizational structure, and strategic planning. In our country, communications in SEOs are extremely unilateral and top-down, which cannot be beneficial for HRD. Therefore, today's organizational structures are expected to be flat and horizontal to further exploit and develop human resources and have the necessary flexibility in achieving competitive advantage. In other words, organizational goals could be achieved through strategic planning since it properly determines policy and strategic coordination.

According to the results of the present study, the empowerment factors had the highest impact on HRD (net effect = -0.75), which requires urgent improvement. The impressibility of these factors has become a challenge in HRD, and the success or failure of HRD in SOEs largely depends on the features of human resource empowerment factors. Our findings were indicative of the dependence of HRD from human resource empowerment. Education, knowledge management, and proper performance evaluation were the identified sub-factors of the empowerment factors in the current research. Human resource education could improve job-related skills, which results in the better management of occupations and achieving the necessary productivity. Furthermore, knowledge management in organizations allows individuals to confidently share their knowledge, so that organizational jobs could be fulfilled more efficiently. Proper performance evaluation allows the abilities of individuals to be meticulously monitored and assessed to plan for improvement.

According to the FANP results, the knowledge management sub-factor was most significant in the HRD of SEOs. Therefore, attaining HRD requires the management of knowledge in organizational sectors since knowledge plays a pivotal role in the competitiveness of economic organizations. Therefore, it could be concluded that knowledge management is an essential tool for HRD. To improve this sub-factor, it is recommended that a knowledge management system be established based on the culture and structure of companies. SEOs often have a vertical structure, which must be changed towards a horizontal structure in order to properly implement knowledge management. Moreover, knowledge promotion should be

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culturalized; for instance, knowledge sharing should be supported and motivated in every organization. On the same note, knowledgeable employees should be supported, and synergistic social networks, committees, and specialized associations of employees should be encouraged, so that they could effectively interact and share their knowledge and experiences in companies.

In the present study, the sub-factor of education had the second priority in HRD. Accordingly, education could increase employees' abilities in improving the overall organizational performance. In addition, investment in education increases the productivity of organizations, and employees' skills could be enhanced through education, so that the learned knowledge, attitude, and skills could be incorporated into daily activities for the higher efficiency of the employees' job. In order to enhance this sub-factor, it is suggested that: 1) needs assessment of education be carried out with proper planning. It is essential to focus on environmental changes and organizational needs in this regard, 2) employee education should be planned by paying attention to the hours required for education, educational areas, educational place, and transfer of educational contents through physical or electronic presence.

In the current research, the sub-factor of performance evaluation had the third priority. Accordingly, performance management could significantly affect employees' performance by assessing behaviors, rewarding favorable behaviors and performance, and providing the necessary training. A performance evaluation system is designed and implemented using proper techniques. In order to improve performance evaluation for HRD, it is recommended that: 1) behaviors and performance of employees be assessed based on appropriate criteria. In other words, an appropriate performance evaluation system should define and identify the most appropriate criteria in this regard, 2) performance should be constantly monitored and evaluated based on proper indices, and 3) feedback should be provided within the system to identify and plan for the strengths and weaknesses of each employee separately.

To the best of our knowledge, no prior research has assessed, identified, and prioritized the influential factors in HRD, and our findings cannot be compared in this regard. Nevertheless, similar studies have been focused on the identification of the influential factors in HRD. For instance, Hajilo et al. [28] evaluated HRD in three dimensions of empowerment, talent management, and knowledge management, which is consistent with our findings. In another study, Masoudi Alavi [5] identified individual, organizational, and environmental dimensions as the main influential factors in HRD in educational organizations. In the current research, the experts referred to organizational factors as the most significant HRD determinants, which is relatively congruent with the results of the mentioned study. Moreover, Mohammadi et al. [39] reported organizational, individual, and underlying factors as the main factors affecting the HRD of an armed force organization. In the present study, organizational factors were also observed to be significant influential factors in the research model, which is consistent with the results obtained by Mohammadi et al. [39].

In a research conducted by Dixit and Sinha [9], education and development were identified as the main factors affecting HRD. In the current research, the sub-factor of education had the highest significant and second priority, which is in line with the results of the mentioned study. In another research, Epstein and Harding [27] stated that managers must gain the necessary skills to ensure that their responsibilities are fulfilled efficiently. In the present study, the sub-factor of management and leadership affected HRD and had higher significance, which is in line with the results of the mentioned research.

Bunton [24] evaluated the emerging processes of using advanced technologies in HRD. In the current research, information technology was recognized as an important factor affecting HRD, while it was not a priority in the screening section from the perspective of the experts. This is inconsistent with the results obtained by Bunton [24] in this regard. In the research performed by Otto and Mishra [40], HRD measures such as job development, education, enhancement, and compensation were reported to influence employees' performance. In the current research, the occupational factors and performance evaluation affected HRD, which is consistent with the results obtained by Otto and Mishra [40]. The functional, organizational, and personal factors played a pivotal role in predicting the strategic position of HRD. In our research, the identified organizational factors were the most significant influential factors in HRD, which is congruent with the results of the mentioned study.

The present study had some executive and scientific limitations. The research findings could be generalized to the SEOs in Mashhad, while generalization to other organizations with a similar structure should be with caution. Moreover, the factors were identified by content analysis and based on the experts' opinions, which may differ in various organizations, especially non-state or service organizations.

Given the structural, technical, communication, organizational, and human resource differences between industrial, service-providing, public, and private organizations, it is essential to identify and analyze the influential factors in HRD in other industries in order to reach a consensus in this regard. Since SEOs are often affected by the environment (e.g., political, social, market, and sanction philosophies), it is recommended that the environmental factors affecting HRD be assessed in further investigations.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

Funding Source

Abbas Heravi performed conceptualization, methodology, software, and literature review and manuscript preparation. Afsaneh Zamani Moghadam, Seyed Ahmad Hashemi, Younos Vakil Alroaia and Abddulah Sajadi Jagharg performed data correction, writing original draft preparation, writing reviewing and editing references.

Conflicts of Interest

I am submitting a manuscript for consideration of publication in JARIE. The manuscript is entitled "Designing and Explaining a Model for Creation and Development of Knowledge-Based Cooperative Companies with a Mixed Qualitative-Quantitative Approach". It has not been published elsewhere and that it has not been submitted simultaneously for publication elsewhere.

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E-ISSN: 2676-6167 | P-ISSN: 2538-5100

Journal of Applied Research on Industrial Engineering

JARIE

www.journal-aprie.com

J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 256–272.

Paper Type: Research Paper

A Reliable and Sustainable Design of Supply Chain in Healthcare under Uncertainty Regarding Environmental Impacts

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Citation:

Eslamipoor, R., & Nobari, A. (2023). A reliable and sustainable design of supply chain in healthcare under uncertainty regarding environmental impacts. *Journal of applied research on industrial engineering, 10*(2), 256-272.

Received: 27/03/2022 Reviewed: 01/05/2022 Revised: 09/06/2022 Accepted: 11/07/2022

Abstract

Nowadays, designing a reliable network for blood supply chains by which most blood demands can be supplied is an important problem in the health care systems. In this paper, a multi-objective model is provided to create a sustainable blood supply chain, which contains multiple donors, collection centers, distribution centers, and hospitals at different echelons. Regarding the potential of a blood shortage occurring, the suggested model considers the supply chain's capacity to meet hospitals' blood demands as dependable and a means of achieving the societal purpose. In addition, limiting the overall cost and environmental effect of designing a supply network and blood transportation are considered economical and environmental objectives. To solve the proposed multi-objective model, an improved ε-constraint approach is first employed to construct a single-objective model. Additionally, an Imperialist Competitive Algorithm (ICA) is developed to solve the single-objective model. Several test cases are analysed to determine the technique's effectiveness. CPLEX is then used to compare the results.

Keywords: Supply chain, Sustainability, Reliability, Blood supply chain, Environment, Imperialist competitive algorithm.

1 | Introduction

SCN Design (SCND) has a substantial effect on network components, including the quantity and placement of facilities, their capabilities, and the allocation of information and material flows. Changes to the network infrastructure are not possible in the near future because of the costs and time required. The SCND factor significantly impacts on supply chain management choices, both strategic and operational [1]-[4]. Environmental, social, and regulatory concerns drive firms to investigate the environmental and the social consequences of designing a sustainable supply chain [5], [6]. In this regard, Corporate Social Responsibility (CSR) refers to the impact of a company's activities on a wide range of persons. Since human blood supply is a finite and valuable resource, no other product or chemical technique can be utilized in its place at this time, and human blood is the only source available [7]. Only a small fraction of donated blood units is helpful, and there is a necessary interval between the donor's contribution and the next round of blood collection.

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https://doi.org/10.22105/jarie.2022.335389.1461

Consequently, the body can restore depleted blood if given sufficient time. Platelets are the most quickly degraded of several blood components, lasting just five days until they are no longer viable. Therefore, platelets play a critical role in healing. Even though they are only utilized in rare circumstances, the number of units that must be transfused at once might be staggering when they are employed. Consequently, platelet needs vary greatly [8]. Many components of supply networks are not well defined, and this has a substantial impact on the chain of supply. It is thus essential to include uncertainty in supply chain architecture and optimization [9]. A catastrophe happens in a supply chain when several links in the supply chain are broken, causing considerable delays in the movement of products and services [10]. Below is a breakdown of the rest of the essay: Section 2 reviews the literature on supply chain networks and blood supply chains in a concise manner. Section 3 of this paper details the issue and its mathematical formulation. Section 4 explains how the suggested approach would work. For the proposed model's implementation and evaluation, see Section 5. Finally, in Section 6, the model's outcomes and possible research prospects.

2 | Literature Review

This section focuses on blood supply networks. Researchers have looked at the problem of blood supply chains from several perspectives. The model established by Haijema et al. [11] functioned successfully at a regional blood centre since it took into account seasonal characteristics, such as the holiday season, when it is almost challenging to collect donations. Nagurney et al. [12] employed bi-objective linear programming to identify a blood centre. Duan and Liao [13] created a quantitative inventory model for the Red Blood Cell (RBC) supply chain that considers various blood types and the possibility of replenishment. In this inquiry, simulation-optimization used to get a nearly optimal solution.

Jokar and Hossein-Motlagh [14] used a Mixed-Integer Linear Programming (MILP) model to reduce the emergency costs of the whole blood supply chain. The platelet collection appointment and collection schedule system proposed by Mobasher et al. [15] takes into account real-time limitations on platelet production. To enhance platelet formation, the MILP model was used. Blood unit age was taken into consideration in the creation of Gunpinar and Centeno's [16] platelet inventory model for hospitals. Yousefi Nejad Attari et al. [17] analysed a two-tier blood supply chain using a constrained bi-objective mathematical model to reduce the hospital's blood supply shortage and waste. They also lowered the disparity between the hospital's demand for blood transfusion services and the available blood supply. For disasters, Fahimnia et al. [18] developed an emergency supply network for blood supplies. With the use of Lagrangian relaxation, they came up with an innovative solution to the epsilon constraint problem. From a blood bank standpoint, RBC inventory management was introduced by Puranam et al. [19]. Many independent merchants were taken into consideration in this strategy. Rajendran and Ravindran [20] employed a stochastic programming technique to deal with the platelet's inventory management challenge. A set of four heuristic rules was devised to deal with the problem of platelets that had a varying shelf life in a medical supply system. Using a priority matching rule, an improved platelet supply chain has been suggested by Hosseinifard and Abbasi [21]. Lowalekar and Ravichandran [22] worked on a blood bank's integrated age-stock ordering model. For improved inventory management, this model considers the remaining shelf life of blood products as well as the current stock levels.

An attempt was made by Baş et al. [23] to balance blood supply chain production by looking at the appointment scheduling issue in more detail. Both pre-booked donors and unreserved donors would be taken into account in the proposed reservation system. Bashiri and Ghasemi [24] presented a two-stage stochastic programming approach to a blood supply inventory-routing challenge that can only be solved selectively. ÖZener and Ekici [25] addressed vehicle routing issues in the blood supply. To optimise the amount of blood that could be utilised for platelet formation, the model was designed. The model also included the possibility of platelet donation at random. Using a new transshipment policy that centred the hospital's inventory, Hosseinifard and Abbasi [21] attempted to improve the blood supply chain performance. Some hospitals believe they can meet their blood supply needs by relying on nearby blood banks. The model improves the system's average age and the pace at which it is obsolete. When it comes to RBC inventory routing, Jafarkhan and Yaghoubi [26] developed a comprehensive model to consider unforeseen events. The model incorporates transshipment and replacement flexibility to appropriately remedy the gap. Hamdan and Diabat [27] analysed the RBC supply chain using a stochastic programming framework considering production, inventory, and location. This strategy simultaneously reduces the quantity of wasted blood, system expenditures, and delivery time. The organisation has developed three-tier blood supply networks [28]. Quality factories were identified according to product storage conditions, taking into account blood storage equipment. According to Larimi et al. [29] the itemized-platelet supply chain may be modelled stochastically. Under uncertainty, Rajendran and Ravindran [30] proposed a supply chain inventory management approach for platelets. Stochastic genetic algorithms were updated to tackle the issue. The blood supply system was explored within the context of motivational efforts [31]. Uncertainty about product disruption in collecting facilities was handled in this approach. It was solved with the help of CPLEX, a computer algorithm. Khalilpourazari et al. [32] created a model for a disaster blood supply chain that incorporated helicopters and ambulances, as well as other modes of delivery. Hosseini-Motlagh et al. [31] emphasised for the first time the significance of motivational programmes in the blood supply chain networks. Haeri et al. [33] studied the durability of a blood supply network. They employed a data envelopment analysis approach to choose data collection facilities. Hosseini-Motlagh et al. [34] created a plasma supply chain architecture. The plasma supply chain has several distinctive aspects, including a freezing time interval and a need in both the medical and pharmaceutical industries. The longer the plasma had been frozen, the better the quality. Finally, a study of the blood supply system takes into consideration operational and failure risks [35]. This model was created to assist in the planning of the blood supply chain in an emergency. Lagrangin relaxation was used by Hamdan and Diabat [36] to overcome an issue with a disaster zone's blood supply system. They took into account the system's course and the distribution of facilities. TQM concepts, such as quality control systems, preventive maintenance and inspections, were utilised by Moslemi and Pasandideh [37] to highlight the quality flaws in blood supply chain. They found that the network's performance may be significantly affected by having the correct transit conditions. Asadpour et al. [38] employed multi-objective modelling to investigate the impact of wastes on the long-term sustainability of the blood supply chain. Blood transshipment between hospitals is the subject of a mathematical model created by Arani et al. [39]. In this model, there are a lot of variables and several goals. Models for economic, social, and environmental sustainability were devised. They came up with a workaround based on a modified version of the multi-choice goal programming approach. Soltani et al. [40] utilised the hub location idea to investigate a blood supply chain network under crisis scenarios. Particle swarm and DE optimization were used to tackle the problem at hand. Dehghani et al. [41] studied the blood supply chain inventory concerns. The goal was to optimise hospital ordering and transshipment choices via the use of a two-stage stochastic programming approach. In this work, we employ a mathematical model based on reliability concept that integrates the idea of shortages to better understand why the demand is not being satisfied. In this study, a multi-objective mathematical model for network design of a multi-level blood supply chain was developed. Many layers of the supply chain were evaluated, such as blood donors as suppliers, blood facilities as collection sites, blood centres as distribution hubs, and hospitals as demand places for blood products. The supply chain was analysed. The entire cost of the network was considered an objective function alongside environmental and social goals in the design of the network for sustainability. To ensure social responsibility, the supply chain's ability to meet hospital blood demand was examined considering anticipated shortages.

3 | Problem Definition

This study examines the challenge of network design for a multi-echelon blood supply network including multiple donors, blood facilities, blood centres, and hospitals. The donors play the supplier role and visit blood facilities which work as collection centers in this supply chain to donate blood. First, following registration, all blood donors are examined for blood-transfusion-related disorders. Additionally, the blood samples are analyzed for a variety of blood disorders. Moreover, the compatibility test is performed before a blood transfusion to avoid any negative outcomes due to incompatibility. On the other side, the blood centers (as distribution points in the supply chain) with specific capacity, receive

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the demand from the hospitals (demand points). Accordingly, these centers get the donated blood types from the collection centers and supply the blood demands. This supply chain assumes that the platelet apheresis method is used to get blood platelets. It is possible to extract platelets and their components from a donor's blood using a specialized apparatus known as platelet apheresis, an advanced platelet collection and preparation technique. Once the remaining blood components have been restored to the patient's body, the patient will be discharged. In this manner, a greater number of platelets may be produced from a single donor than would otherwise be possible. The configuration of the model is shown in *Fig. 1*, in which the red colored notations indicate decision variables for each echelon.

Locating the collection and distribution centers in this network are decision variables which are determined for potential locations. Also, the blood centers' capacity must be defined. Moreover, allocation of the facilities between different echelons and the blood flow through the network are other decision variables. According to the capability of open blood centers in supplying the blood demand and the possibility of shortage occurrence in satisfying the demand, the reliability concept is determined in the network. These characteristics should be identified in a manner that will lead to the creation of a network for a sustainable blood supply chain. As a matter of social duty, the objective of the network design challenge is to maximise the network's dependability in meeting blood demand. Moreover, minimization of the total cost and environmental impacts are considered as economical and environmental goals, respectively.

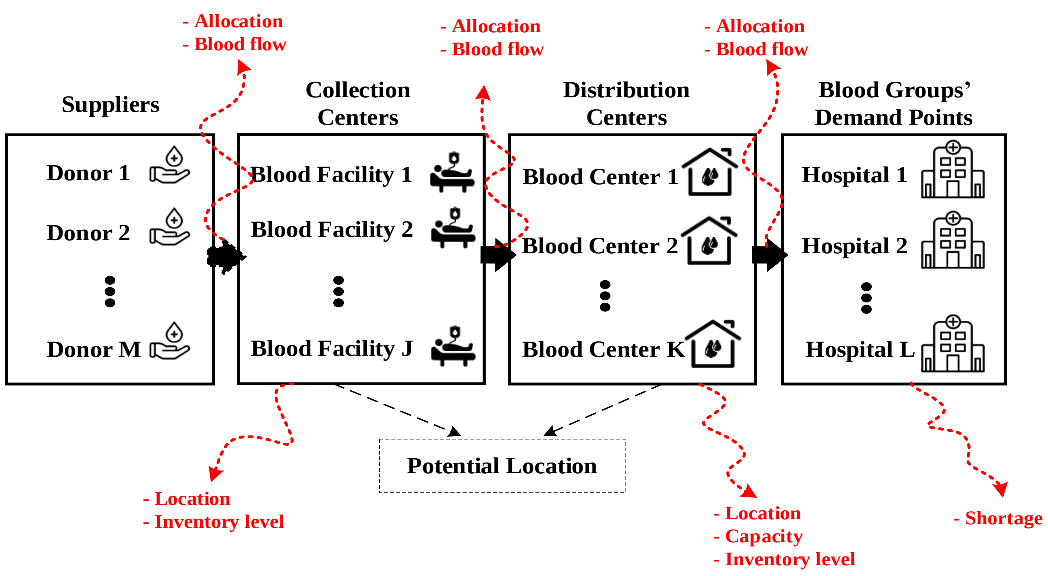

Fig. 1. Problem configuration.

3.1 | Assumptions

There are some assumptions for our model, which have been gathered as follows:

I. Platelets have a five-day life expectancy, plus two days required for testing.
II. When a hospital places an order for blood products, there is no delay in delivery.
III. A wide range of vehicles are available, each with a distinct carrying capacity.
IV. A single vehicle is limited to one visit per period to any given hospital or open blood facility.
V. Each route can only have one vehicle allocated to it.
VI. Each day is equal to one period.
VII. A blood facility, blood center, or hospital can only provide a limited amount of blood.
VIII. There must be an open blood center at the beginning and conclusion of every journey.
IX. Platelet ages are known for each unit of blood. If a platelet is less than three days old, it is referred to as "young".
X. The sites of hospitals and donor groups are predetermined; thus, there is no room for error.

XI. Wastes generated by blood-related illnesses, blood expired in blood center or healthcare center, and unused blood during tests.
XII. In the absence of sufficient supplies, the price of not being able to meet demand is allowed to rise.
XIII. Supplying demand, procuring, collecting, producing, testing, and distributing blood all contribute to the total cost of manufacturing.

The study of Pishvaee et al. [42] outlines certain sustainability concepts. The suggested model seeks to estimate the locations and sizes of the blood facilities and blood centres, the volume of shipping, and the most reliable vehicle routes such that the following sustainable objectives may be realised simultaneously:

I. Economic goal: minimizing the total cost including transportation costs, holding costs, dispatching costs, centers and facilities' establishing costs, operating and production costs and blood disposal costs.
II. Environmental goal: minimizing the environmental impacts due to establishing and shipping blood through the supply chain network.
III. Social goal: maximizing the reliability of blood supply in the supply chain network.

3.2 | Notations

The notations used in the mathematical model are as follows:

3.2.1 | Sets

M: Areas designated for blood donors, $m \epsilon M$.

J: List of potential locations for blood collection facilities, $j, j_1 \epsilon J$.

K: Set of prospective locations for blood clinics, $k, k_1 \epsilon K$.

L: Set of hospitals as demand centers, $l, l_1 \epsilon L$.

D: Set of blood centers' capacity, $d \epsilon D$.

S: Set of blood age, $s \epsilon S$.

U: Set of distinct planning horizons, $u \epsilon U$.

G: Consolidated groups of hospitals and potential blood supply locations, i.e., $L\ V\ K$ and $g, g_1 \epsilon G$.

B: Set of the age range for blood, $b \epsilon B$.

3.2.2 | Parameters

Db_{jk}: Fixed transportation costs from the blood facility j to blood center k.

Db_{gg_1}: Fixed transportation costs between location g to location g_1.

UF_{jm}: Donors' transportation costs from their location j to m.

PD_{ku}: The cost of operating a blood facility for one unit of blood center k in time span u.

DD_{ju}: Operational costs associated with collecting blood units at a particular location j in time span u.

PDH_{lu}: Cost of operating a single unit of blood at hospital l in time span u.

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TD_d: Each blood center's maximum storage capacity is determined by its size d.

DG: The capacity of fixed blood facility.

DU: The capacity of temporary blood facility.

DH: The upper level of capacity for every hospital.

ND_{jj_1u}: Transferring the costs associated with each temporary blood facility from its current location j_1 to location j in the planning period t.

GC_{kd}: Expenses associated with the establishment of a blood facility at a prospective site k with size d.

Gq_j: Expenses related to the establishment of a permanent blood facility at a prospective site j.

HC_{ku}: The cost of storing a blood unit at a blood facility k at time span u.

HH_{lu}: The expense of storing each unit of blood at a hospital l at time span u.

V_m: The upper level for blood supply for the permitted donor group m.

π_s^0: Costs associated with utilizing old blood for patients requiring young blood during the planning phase s.

π_s^1: Costs associated with the use of young blood for patients with any blood need during the planned period s.

EG_j: Environmental consequences of building a permanent blood collection facility at a particular site j.

EC_{kd}: Consequences of blood donation on the environment center k with size d.

ES_{jk}: The environmental burden of transporting each collection of blood from site j to location k.

ES'_{gg_1}: The environmental burden of transporting each collection of blood from site g to the location g1.

E'_{blu}: Demand for blood group b at the hospital l in planning period u.

ED: Cost of waste blood disposal and transportation on a unit basis.

ρ: Cost of penalties associated with the environmental impact of waste blood.

γ: Blood loss rate during the manufacturing process.

η_1: Rate of blood lost during examination after blood center receipt.

η_2: Blood loss rate during hospital inspections after blood receipt.

ω: Estimated proportion of blood in inventory which is five years old.

C: Number of hospitals in total.

M: A big number.

3.2.3 | Variables

Y_{jku}: Blood transported from blood facility j to blood center k during the planning period u.

Z_{slwu}: Blood age s heading to the hospital l by car w during the planning time u.

C_{sku}: The blood age s shortage for the blood center k at the end of time span u.

C'_{blu}: The blood group b shortage at hospital l at the end of time span u.

Rel_u: Indicates reliability of supplying blood during time period u.

M_{jku}: A binary variable equal to 1 if the blood facility in location j transferred to blood center in location k during the planning period u; otherwise, 0.

J'_{blu}: The inventory level of blood groups at the hospital l by the end of the planned period u.

J_{sku}: The number of s days remaining on the blood inventory at blood center k at the end of the time span t.

IQ_u: Total volume of waste blood produced during time span u.

F_{jmu}: A binary variable equal to 1 if the blood center at the location j assigned to donor group m during time span u; otherwise, 0.

x_j : A binary variable equals 1 if a permanent facility at site j is opened; 0, otherwise.

P_{kd}: A binary variable equals 1 if a blood center of size d is established at location k; 0, otherwise.

H_{jj_1u}: A binary variable that equals 1 if a temporary facility is positioned at location j_1 during period u-1 and then relocates to location j during planning period u.

W_{klu}: A binary variable equal 1 if the hospital at location l is allocated to the blood center at location k during the planning period u; 0, otherwise.

3.3 | Model Formulation

In this subsection, the objective functions and constraints are described.

3.3.1 | The objective functions

$$\begin{aligned}\text{Min } Z_1 = {} & \sum_j^J \sum_k^K \sum_u^U M_{jku} Db_{jk} + \sum_g^G \sum_{g_1}^G \sum_w^W \sum_u^U S_{gg_1wu} Db'_{gg_1} + \\ & \sum_j^J \sum_{j_1}^J \sum_u^U M_{d_{jj_1u}} H_{jj_1u} + \sum_j^J \sum_m^M \sum_u^U TF_{jm} F_{jmu} + \sum_s^S \sum_k^K \sum_u^U HC_{kt} J_{sku} + \\ & \sum_b^B \sum_l^L \sum_u^U HH_{lu} J'_{blu} + \sum_l^L \sum_u^U \pi_u^0 \delta_{lu}^0 + \sum_l^L \sum_u^U \pi_u^1 \delta_{lu}^1 + \sum_d^D \sum_k^K GC_{kd} P_{kd} + \\ & \sum_j^J Gq_j x_j + \sum_j^J \sum_k^K \sum_u^U PD_{ku} Y_{jk} + \sum_s^S \sum_l^L \sum_w^W \sum_u^U PDH_{lu} y_{slwu} + \\ & \sum_j^J \sum_k^K \sum_u^U DD_{jt} y_{jkt} \left(\frac{1}{1-\gamma}\right) + \sum_u^U EDHq_u + \sum_w^W \sum_u^T WH_{wu} DW_w. \end{aligned} \tag{1}$$

$$\begin{aligned}\text{Min } Z_2 = {} & \sum_k^K \sum_d^D EC_{kd} P_{kd} + \sum_j^J EG_j x_j + \sum_j^J \sum_k^K \sum_u^U ES_{jk} M_{jku} + \\ & \sum_g^G \sum_{g_1}^G \sum_w^W \sum_u^U ES'_{gg_1} S_{gg_1wu} + \sum_u^U \rho IQ_u. \end{aligned} \tag{2}$$

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The third objective function relates to social responsibility and attempts to maximize the reliability of supplying blood demands in the network. The reliability in each period depends on the total shortages in satisfying different blood groups' demand. Indeed, $Rel_u = 1 - \underset{b\in B, l\in L}{Average}(\frac{C'_{blu}}{E'_{blu}})$.

3.3.2 | Constraints

$$MaxZ_3 = \min_u Rel_u, \tag{3}$$

$$\sum_{s\geq 2}^{S} J_{sku} \leq \sum_{d}^{CD} TD_d P_{kd}, \ u = 2,3, \dots, U \ \text{ for all k}, \tag{4}$$

$$J'_{1lu} + J'_{0lu} \leq DH, \quad u = 2,3, \dots, U \ \text{ for all l}, \tag{5}$$

$$\sum_{k}^{K} y_{jku} \leq x_j DG + \sum_{j_1}^{J} G_{jj_1t} DU, \quad u = 2,3, \dots, T \quad \text{for all j}, \tag{6}$$

$$Y_{jku} \leq M.M_{jku}, \quad u = 2,3, \dots, U \ \text{ for all j, k}, \tag{7}$$

$$x_j + \sum_{j_1}^{J} G_{jj_1u} \leq 1, \quad u = 2,3, \dots, U \ \text{ for all j}, \tag{8}$$

$$\sum_{j_1}^{J} G_{jj_1u} \leq \sum_{j_1}^{J} G_{jj_{1,u-1}}, \quad u = 2,3, \dots, U \ \text{ for all j}, \tag{9}$$

$$\sum_{d}^{D} P_{kd} \leq 1 \quad \text{for all k}, \tag{10}$$

$$\sum_{l}^{l} \sum_{b}^{B} E'_{blu} W_{klt} \leq \sum_{d}^{D} TD_d P_{kd}, \quad u = 3, \dots, T \ \text{ for all k, l}, \tag{11}$$

$$\sum_{k}^{K} W_{klu} \leq 1, \quad u = 3, \dots, T \ \text{ for all l}, \tag{12}$$

$$\sum_{k}^{K} M_{jku} \leq x_j + \sum_{j_1}^{J} G_{jj_1u} \quad \text{for all j, u}, \tag{13}$$

$$M_{jku} \leq \sum_{d}^{D} P_{kd}, \quad u = 2, \dots, T \ \text{ for all j, k}, \tag{14}$$

$$\sum_{j}^{J} E_{jmu} \leq 1 \quad \text{for all j, u}, \tag{15}$$

$$E_{jmu} \leq x_j + \sum_{j_1}^{J} G_{jj_1u} \quad \text{for all j, m, u}, \tag{16}$$

$$\sum_{j}^{J} \frac{z_{jku}}{(1-\gamma)} \leq \sum_{m}^{M} V_m E_{jmu} \quad \text{for all j, u}, \tag{17}$$

$$\sum_{s\geq 3}^{S} z_{slwu} \leq WD_w \sum_{g}^{G} S_{glwu}, \ u = 3, \dots, U \ \text{ for all l, w}, \tag{18}$$

$$\sum_{l}^{L} \sum_{w}^{W} z_{4lwu} = 0, \quad u = 1,2,3, \tag{19}$$

$$\sum_{l}^{L}\sum_{w}^{W} z_{5lwu} = 0, \quad u = 1,2,3, \tag{20}$$

$$J'_{0lu} = 1 - \eta_2) \sum_{w}^{W} Z_{3lwu} + \delta_{0lu} - \delta_{1lu} - E'_{10u} + c'_{0lu}, \qquad u = 3, \dots, U \ \text{ for all } \ l, \tag{21}$$

$$\delta_{olu} = 0, \quad u = 3 \ \text{ for all } \ l, \tag{22}$$

$$1 - \eta_2) \sum_{w}^{W} Z_{3lwu} - \delta_{1lu} - E'_{lou} \geq 0, \quad u = 3, \dots, U \ \text{ for all } l, \tag{23}$$

$$J'_{1lu} = J'_{0l,u-1} + \ 1 - \eta_2) \textstyle\sum_{s\geq 4}^{S} Z_{slwu} + \delta_{1lu} - \delta_{0lu} - E'_{l1u} + c'_{1lu}, \ u = 3, \dots, U \text{ for all } l, \tag{24}$$

$$c'_{0lu} J'_{0lu} = 0, \quad u = 3, \dots, U \ \text{ for all } \ l, \tag{25}$$

$$c'_{1lu} J'_{1lu} = 0, \quad u = 3, \dots, U \ \text{ for all } \ l, \tag{26}$$

$$J'_{0,l,u-1} + \ 1 - \eta_2) \sum_{w}^{w} \sum_{s\geq 4}^{S} Z_{slwu} - \delta_{olu} - E'_{l1u} \geq 0, \quad u = 3, \dots, U \ \text{ for all } \ k, \tag{27}$$

$$IQ_u = \omega \sum_{l}^{L} J'_{1lu} + \sum_{j}^{J}\sum_{k}^{K} \left(\frac{\gamma}{1-\gamma}\right) Y_{jku} + \sum_{j}^{J}\sum_{k}^{K} \eta_1 Y_{jku} + \sum_{k}^{K} J_{5ku} \quad \text{for all } \ k, u, \tag{28}$$

$$J_{sku} = J_{(s-1)k(u-1)} - \sum_{l}^{L}\sum_{w}^{W} W_{klt} Z_{slwu} + c_{sku}, \quad u = 3, \dots, U, \quad s = 3, \dots, S \ \text{ for all } k, \tag{29}$$

$$J_{2ku} = \sum_{j}^{J} 1 - \eta_1) Y_{jk\ u-1)}, \quad u = 2, \dots, U \ \text{ for all } \ k, \tag{30}$$

$$J_{sku} \cdot c_{sku} = 0, \quad u = 2, \dots, U \quad \text{for all } \ k, \tag{31}$$

$$y_{jku}, y_{slwu}, c'_{plu}, c'_{1lu} J'_{plu}, J'_{1lu}, J_{sku}, c_{sku} \ \epsilon Z^{+} \quad \text{for all } \ j, k, s, h, w, u, \tag{32}$$

$$W_{klu}, WH_{wu}, M_{jku}, X_j, P_{kd}, K_{jj_1u}, S_{gg_1wu} \in \{0,1\} \quad \text{for all } \ j, j_1, k, l, w, u, g, g_1, d, \tag{33}$$

$$M_{lwu}, IQ_u \geq 0 \ \text{ for all } \ l, w, u. \tag{34}$$

The constraints of proposed model are as follows:

To ensure that the blood supply stays within the facility's capacity, *Constraints (4)* and *(5)* must be followed. This restriction limits the amount of blood each blood centre may donate to the system. Blood cannot be transferred to the blood centre from any facility that is not designated to one by *Constraint (7)*, *(8)* restricts the number of facilities that may be opened at a given location to a maximum of one per place. One short-term blood facility may be located at a particular location due to *Constraint (9)* of the design. According to *Constraint (10)*, there can only be one blood centre of a specified size. Using existing blood centres, *Constraint (11)* keeps the capacity constraint in place. *Constraint (12)* mandates that no hospital be allocated to more than one blood centre. For those who live in location I and have access to a blood bank, every single blood facility may be assigned to a single blood centre because of *Constraint (13)*. *Constraint (14)* states that when a blood centre shuts, no new blood facility will be assigned to it. One blood centre may only be assigned to a single donor group, as stipulated by *Constraint (15)*. All blood donors must be sent to existing donation centres as a result of *Constraint (16)*. There is a restriction on the amount of blood that may be taken from each blood centre in order to meet the maximum supply l authorised for the donor group of choice according to *Constraint (17)*. When it comes to blood deliveries to hospitals, there is a limit, as seen in *Constraint (18)*. As a result of these constraints, the time it takes to prepare blood for delivery at particular hospitals is taken into consideration in the calculations. Because of *Constraint (21)* every institution must keep a record of the young people who have given their blood to the institution. This shows that there is no such thing as "ancient" blood in the event of mismatched blood *Constraint (22)*. There is no shortage of "young" blood types, as shown by *Constraint (23)*. It is necessary for each institution to maintain a proper balance of old blood to comply with *Constraint (24)* one variable can only be positive at a time, as shown by *Constraints (25)* and *(26)*. *Constraint*

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(27) shows that patients' usage of Kind 1 blood does not lead to a shortage of "old" blood kinds. *Constraint (28)* affects how much blood is wasted or lost in the supply chain. The end-of-term blood inventory levels at blood centres are tied into *Constraints (29)* and *(30)*. Only one of the variables in *Eq. (31)* may be positive. *Constraint (32)* describe the variables used to make decisions in *Eq. (34)*.

The proposed model is a MINLP model because of *Eq. (3)* and *Constraints (25)*, *(26)*, *(29)* and *(31)*. To have a MILP model, the following changes are needed:

Objective *Function (3)* can be simply linearized using replacing *Eq. (3)* with *Eq. (35)*. Furthermore, *Eq. (36)* should be considered as a new constraint in the proposed model.

$$\text{Max } Z_3 = \text{Rel}'. \tag{35}$$

$$\text{Rel}' \geq \text{Rel}_u \quad \text{for all } u. \tag{36}$$

To linearize the *Constraint (29)*, in which integer and binary variables are multiplied, term $W_{klt}Z_{slwu}$ should be replaced by Q_{sklwt} and *Constraints (37)-(40)* should be added to the model.

$$Q_{sklwt} \leq Z_{slwu}, \quad u = 3, \dots, U, \quad s = 3, \dots, S \quad \text{for all } k, l, w. \tag{37}$$

$$Q_{sklwt} \leq MW_{klu-1}, \quad u = 3, \dots, U, \quad s = 3, \dots, S \quad \text{for all } k, l, w. \tag{38}$$

$$Q_{sklwt} \geq M\ W_{klu-1} - 1) + Z_{slwu}, \quad u = 3, \dots, U \quad s = 3, \dots, S \ \text{ for all } k, l, w. \tag{39}$$

$$Q_{sklwt} \in Z^+. \tag{40}$$

Finally, to linearize *Constraints (25)*, *(26)* and *(31)* in which two integer variables (X.Y) are multiplied, *Constraints (41)-(44)* should be considered in the model.

$$Y \leq M.K'. \tag{41}$$

$$X \leq M.K''. \tag{42}$$

$$K' + K'' \leq 1. \tag{43}$$

$$K', K'' \in \{0,1\}. \tag{44}$$

4 | Solution Approach

To solve the proposed multi-objective MILP model, first, it is converted to a single-objective model. Then, an Imperialist Competitive Algorithm (ICA) is used as a metaheuristic approach to solve this single-objective model, approximately. *Fig. 2* indicates the overall parts of developed solution approach.

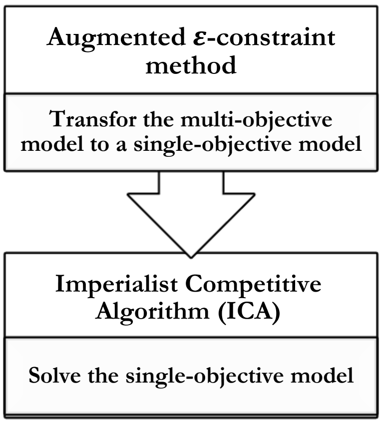

Fig. 2. General part of solution approach.

4.1 | Single-Objective Model

To simplify the multi-objective model, ε-constraints are used. As a result, this technique prioritises the most critical goal function and regards all other goals as constraints. A single-objective framework has been implemented to focus on the most critical objective function [43]. This method generates more non-dominant answers, which decision-makers like. *Eq. (1)* shows how the suggested model is reworked using the enhanced e-constraint technique in *Eq. (45).*

$$\begin{aligned} &\text{Optimize } (\text{OF1}, \text{OF2}, \text{OF3}) \rightarrow \\ &\quad \text{s.t.} \quad \text{Constraint} \\ &\text{Optimize } \text{FO}_{\text{e-constraint}} = \left(\text{OF1} + \delta\left(\frac{\text{sl}_2}{\text{Range}_2} + \frac{\text{sl}_3}{\text{Range}_3}\right)\right), \\ &\qquad \text{s.t.} \quad \text{Constraints} \\ &\qquad\quad \text{OF2} + \text{sl}_2 = \text{e}_2, \\ &\qquad\quad \text{OF3} - \text{sl}_3 = \text{e}_3, \end{aligned} \tag{45}$$

where e_i is the epsilon value for objective functions considered as new constraints, sl_i is slack or surplus variables, determined based on minimization or maximization objective functions and $Range_i$ indicate range of variations for each objective functions. This single-objective model is solved for different values of e_i.

4.2 | Approximate Solution Approach

The ICA is used as an approximation solution method to solve the single-objective model proposed in this paper. A population-based evolutionary algorithm developed by Atashpaz-Gargari and Lucas [44] is known as a population-based evolutionary algorithm. Based on of the phenomena of imperialism and the fight amongst imperialists to extend their empire and conquer weaker nations, the ICA operates [45]. *Fig. 3* depicts the suggested algorithm's stages. It all begins with establishment of empires, complete with imperialists and the territories they control. Secondly, the colonies migrate toward their imperialist. The third phase is to ensure that the imperialists are not replaced by stronger colonies. After then, empires battle for control of the weaker empires' colonies in order to increase their overall dominance. It's at this point when empires without colonies are eliminated, and the algorithm's execution is stopped.

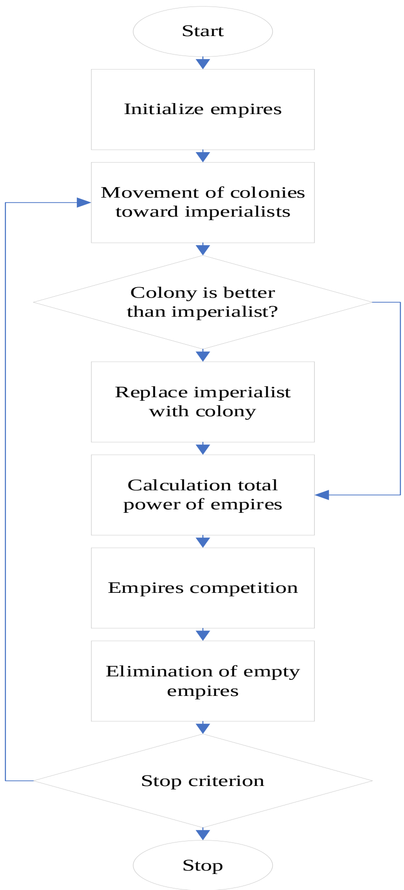

Fig. 3. ICA flowchart.

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4.2.1 | Solution representation

The solution representation of the proposed model consists of three parts, as shown in *Fig. 4*. In order to determine the activate facilities including blood facilities and blood centers, a $1 \times n$ vector is generated randomly based on uniform distribution U 0,1), in which n is determined based on potential existing locations. The second part determine the capacity level in each blood center. In this part, a $1 \times m$ vector is generated randomly based on uniform distribution U 0,1) in which m is defined with regard to the number of blood centers. Random numbers are multiplied by the number of capacity levels, and the results are rounded to calculate the capacity of the blood centre. As a reminder, the capacity level should only be established for the blood centres that were opened in the earlier section of this article. The third portion results in the movement of facilities, shortages, and inventory levels between one another. In this regard, a $x \times y$ matrix is generated, randomly based on uniform distribution $U(0,1)$, in which x and y are defined based on opened facilities, determined in previous parts. Then, for each column (as destination point), the generated numbers are normalized by which share of each sender in supplying demand is specified. The other variables are determined randomly or according to specified variables.

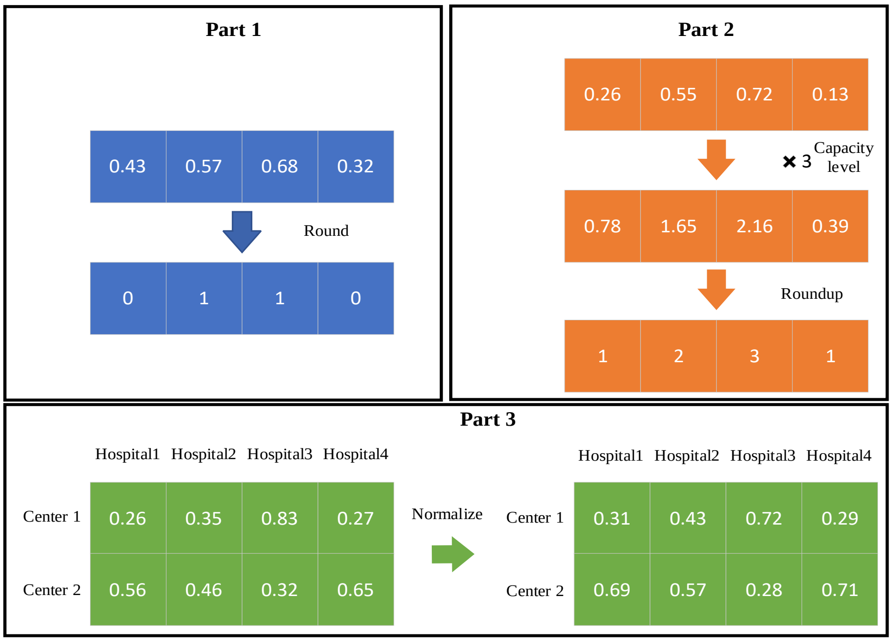

Fig. 4. Solution representation.

4.2.2 | Parameters adjustment

Adjusting the parameter of ICA using the Taguchi approach is done in order to minimise the noise impact in relation to establishing the best level for signal factors [46]. *Table 1* shows different levels of ICA factors, with the corrected values, estimated based on L27 design, being underlined.

Table 1. ICA parameter ranges.

ICA Parameter	Parameter Level		
	Low	Middle	High
Number of population	20	30	40
Number of imperialists	5	10	15
A random variable in movement toward imperialist	1	2	3
Deviation from original direction	0.5	0.6	0.7
Influence coefficient of colonies	0.05	0.1	0.2
Maximum generation	50	100	150

5 | The Numerical Study

To evaluate the efficiency of presented solution approach in solving the proposed model, several numerical examples are studied. *Table 2* indicates the size of numerical examples. Furthermore, the parameters of numerical examples are generated randomly based on *Table 3*.

Table 2. Size of numerical examples.

Problem No.	Blood Donors	Blood Facilities	Blood Centers	Hospitals	Period
1	2	2	2	2	2
2	3	3	2	2	2
3	4	3	3	3	3
4	5	3	3	3	3
5	7	5	4	4	4
6	8	6	5	4	5
7	10	8	6	5	6
8	12	10	8	6	9
9	12	10	8	7	9
10	15	12	10	8	12

It is necessary to structure all test problems as single-objective models in accordance with the enhanced electronic constraint approach (Section 4.1) and to answer them using an ICA that was built (Section 4.2). It is important to highlight that MATLAB R2013 is utilised to solve the ICA test cases. Additionally, the CPLEX 10.0 solver in GAMS on a 2 GHz machine with 8 GB RAM is utilised to solve the test problems in order to assess the effectiveness of the proposed approach. *Fig. 5* indicates the convergence of ICA in solving test problem 4.

Table 3. The values of parameters in the test problems.

Parameter	Distribution	Parameter	Distribution
η_1	U[0.002, 0.005]	FT'_{gg_1}	U [1, 50]
ρ	U [500, 1000]	KP_{kd}	U [1, 10]
v_m	U [200, 2000]	KP'_j	U [2, 20]
E'_{olt}	U [5, 200]	γ	U [0.01, 0.05]
E'_{1lt}	U [5, 200]	WD_w	U [5000, 50000]
ED	U [1000, 2000]	PD_{kt}	U [50, 50]
η_2	U [0.002, 0.005]	MD_{jj_1t}	U [1000,4000]
s_{jm}	U [1, 100]	DG	U [50000, 100000]
Parameter	**Distribution**	**Parameter**	**Distribution**
Db'_{gg_1}	U [30, 200]	GC_{kd}	U [100,50000]
PDH_{lt}	U [10, 150]	Gq_j	U [0,200]
EG_j	U [20, 200]	TD_d	U [20000,100000]
EC_{kd}	U [1, 5]	π_{kt}	U [10000,500000]
ES_{jk}	U [1, 5]	π'_{lt}	U [10000,500000]
Db_{jk}	U [5, 20]	HC_{kt}	U [1000, 5000]
DW_w	U [100, 20000]	π_t^1	U [10, 100]
DD_{jt}	U [2,20]	DG	U [50000,100000]

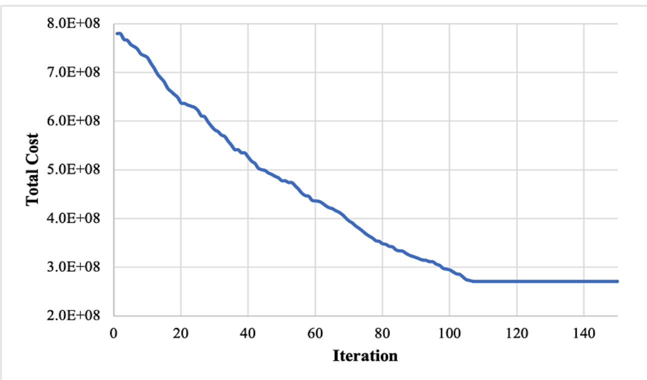

Fig. 5. Convergence of ICA in test problem.

Moreover, the results of solving test problems using CPLEX and developed ICA are indicated in *Table 4*.

Table 4. The values of parameters in the test problems.

Problem No.	OF_1		OF_2		OF_3	
	CPLEX	ICA	CPLEX	ICA	CPLEX	ICA
1	9.33×10^{6}	9.91×10^{6}	900	950	0.83	0.82
2	3.98×10^{7}	4.08×10^{7}	950	1025	0.87	0.81
3	9.37×10^{7}	9.86×10^{7}	1050	1125	0.77	0.74
4	2.51×10^{8}	2.71×10^{8}	1275	1350	0.72	0.68
5	9.54×10^{10}	1.09×10^{11}	1725	1800	0.73	0.71
6	2.19×10^{11}	2.34×10^{11}	1850	1950	0.76	0.72
7	4.83×10^{12}	5.23×10^{12}	2200	2275	0.77	0.72
8	9.84×10^{12}	1.24×10^{13}	2475	2550	0.7	0.65
9	NA	3.12×10^{13}	NA	3100	NA	0.64
10	NA	2.26×10^{14}	NA	3300	NA	0.58

As shown in *Table 4*, the CPLEX solver in gams during 15000 seconds lead to no result for test problems 9 and 10. In contrast, ICA resulted in solutions for these large-scale problems. Moreover, a comparison of the results achieved by each solution approach indicates no significant difference between the results and ICA is capable of achieving near optimum solutions. The last column of *Table 4*, indicates CPU time, spent to achieve the final solution using ICA.

Finally, *Table 5* indicates the gap between results that came from each developed metaheuristic algorithm and CPLEX.

According to *Table 5*, it can be concluded that the ICA algorithm can reach near optimum solution in a more reasonable time. Moreover, it is more useful to solve large-scale problems, in contrast with CPLEX which is not enable to reach near optimum solution for this type of problems.

Table 5. The gap between results of solving test problems via CPLEX and ICA.

Problem No.	OF_1	OF_2	OF_3
1	0.06	0.06	0.01
2	0.03	0.08	0.07
3	0.05	0.07	0.04
4	0.08	0.06	0.06
5	0.06	0.04	0.03
6	0.07	0.05	0.05
7	0.08	0.03	0.06
8	0.04	0.03	0.07
9	NA	NA	NA
10	NA	NA	NA

5 | Conclusion

Mathematical models for the design of a multi-echelon blood supply system are described in this paper. The examined supply chain network included many tiers, such as donors as suppliers, blood facilities as collecting locations, blood centres as distribution points, and hospitals as demand points. For the sake of sustainability in designing the network, minimizing the total cost as an economic concern was considered as an objective function besides environmental and social goals. To consider the social responsibility in the proposed model, the reliability of sustainable blood supply chain in supplying hospitals' blood demand was regarded for shortages in meeting the demands. Moreover, the environmental raised from establishing facilities and their operations was considered as an environmental objective function. To solve the described mixed-integer linear model, the augmented ε-constraint approach is first utilised to reduce the multi-objective model to a single-objective one. An ICA, a population-based metaheuristic devised to solve the single-objective model, was also created. Additionally, numerical examples are utilised to assess the suggested solution approach's efficiency, and the results are compared to the results produced by CPLEX. A blood supply chain's capability to fulfil demand is critical, and this research attempted to build a blood supply chain where network dependability is regarded as a social objective alongside well-known economic and environmental goals in meeting blood needs.

However, considering the uncertainty of numerous model components, such as demand, might broaden the scope of this research. In this way, the reliability concept in the proposed model can be developed about the probability of shortage occurrence in supplying the demand. Furthermore, for the sake of simplicity, single-objective optimization is considered, while using multi-objective optimization results in more reliable options for decision-makers. Hence, using multi-objective algorithms by which multiple objective functions are optimized simultaneously is recommended as another future research direction.

Acknowledgments

We thank the anonymous reviewers for their careful reading of our manuscript and their many insightful comments and suggestions.

Funding

No funding declared by the authors.

Conflicts of Interest

All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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E-ISSN: 2676-6167 | P-ISSN: 2538-5100

Journal of Applied Research on Industrial Engineering

RJARIE

www.journal-aprie.com

J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 273–285.

Paper Type: Research Paper

Robust Optimization Model to Improve Supply Chain Network Productivity under Uncertainty

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Citation:

Mousavi, S. F., Apornak, A., & Pourhassan, M. R. (2023). Robust optimization model to improve supply chain network productivity under uncertainty. *Journal of applied research on industrial engineering, 10*(2), 273-285.

Received: 22/11/2021 Reviewed: 22/12/2021 Revised: 11/01/2022 Accepted: 08/02/2022

Abstract

Although the importance of supply chain agility considering the necessity of speed of action, response to customers, progressive changes in the market, consumers' needs, etc. in many industries is clear both scientifically and experimentally, today organizations have found that the benefit from this cooperation is greater than cases performed without collaboration with relevant organizations. Meanwhile, supply chain management refers to integration of all processes and activities in the supply chain through improving the relations and implementing the organizational processes in order to achieve competitive advantages. On the other hand, uncertainty in the supply chain results in non-optimality of decisions that are made with assumption of certainty. Accordingly, the main aim of this research is to provide a model for supply chain in an agile and flexible state based on uncertainty variables. The method of research has been based on a mathematical model, whose stages of implementation are investigated by breaking down this model step-by-step. For this purpose, in the first stage and after getting familiar with the intended modeling industry, solution and simulation were done. Eventually the results were compared indicating that through reducing the risk-taking (increasing the protection levels), the objective function which was of minimization type worsened. This study also showed that model robustification is very important in order to reduce the risk of decision-making.

Keywords: Supply chain, Robust optimization, Uncertainty, Productivity.

1 | Introduction

In order to remain in a competitive environment, it is essential to design a flexible-responsive manufacturing system with automatic material handling systems [1]. Over the first two decades of 21st-century, organizations and people have been experiencing new events and phenomena, whose roots may have been growing from many years ago. Introduction of the information technology element in any area, the necessity of speed of action in response to customers as well as the progressive change of market and needs of consumers, and the need to have flexibility in organizations and production all entail moving towards the concept of productivity in organizations [2]. This concept which arises from the needs of organizations is indeed creating a network in physical and virtual areas as well as eliminating losses in the organization including the most important transformations and novel approaches in management [3].

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https://doi.org/10.22105/jarie.2022.316357.1402

One of the concepts and paradigms propounded within the last two decades is the concept of Productivity, which arises from the needs of the organizations following development of previous approaches such as manual production, mass production, and lean production [4]. Meanwhile, over the last two decades, supply chain management has been propounded as one of the key factors of competition and success of organizations, and has attracted attention of various researchers as well as scholars of production and operations management [5]. Dealing with productivity in supply chain as a hybrid concept has also become very popular these days, and researchers are trying to provide new angles of this newly emerging concept [6].

Although within the last decade, many individuals have dealt with providing the elements and indicators of assessing the supply chain Productivity, generally a group of researchers have centralized the main stages of supply chain including procurement, production, and distribution and propounded productivity indicators [7]. On the other hand, another group has focused on the elements affecting productivity including stimuli, competences, and empowers, and has been trying to provide an indicator for these elements in the supply chain [8]. The present research tries to provide the elements and indicators of supply chain productivity assessment comprehensively. In other words, the assessment indicators of each of the productivity indicators in every major step of the supply chain have been determined and validated [9].

The important point is that the indicators and criteria for flexibility assessment, with the most important ones mentioned in the previous section, are usually very general and have mostly measured the Productivity competences rather than all of its dimensions [10]. The present research tries to present the criteria and indicators of supply chain productivity assessment comprehensively and based on all of its dimensions [11]. In classic examples of mathematical programming, the input data of the model (parameters) are considered certain (definite) and equivalent to nominal values [12]. This attitude neglects the effect of uncertainty on the quality and justification of the model. Indeed, the data that adopt different values from their nominal values may cause some limitations to be violated. Also, the optimal solution in the long run may not remain optimal or even its justification may be lost. This conveys the fact that solution methods (models) should be designed that creates immunity and protection against data uncertainty [13]. These solution methods are called "robust". The first step in this regard was in the form of a linear programming model for generating solutions that would be justified for all data belonging to a convex set. The mentioned model offers solutions that are very conservative with regards to optimality of the nominal problem in order to ensure robustness. Indeed, this problem is one of the first problems of robust optimization [14]. Thereafter, other important steps were taken independently to develop the robust optimization theory including Ben-Tal and Nemirovski [34], and Bertsimas and Sim [5]. Since optimization of this research is of mixed integer number type, the model robustification is in line with the approach of "Bertsimas and Sim [5]" model [15]. A compelling, productive and strong supply chain may be an economical competitive advantage for countries and firms and makes a difference them to manage with increasing environmental turbulences and more seriously competitive weights [16]. A supply chain could be a organize of provider, generation, conveyance centers and channels between them organized to obtain crude materials, change over them to wrapped up products, and disseminate last items in an effective way to clients [17]. Supply chain arranges plan is one of the foremost critical key choices in supply chain administration. In common, organize plan choices incorporate deciding the numbers, areas and capacities of offices and the amount of stream between them [18].

In the present research, in addition to a brief review on the literature about supply chain productivity and its assessment indicators, expert opinion has been investigated, operational indicators of supply chain productivity assessment have been provided, and a model has been developed to enhance productivity as well as flexibility in the form of a case study. This research attempts to present a model that fits the real-world setting using uncertainty variables and applying verbal variables. The important point is that the indicators and criteria for flexibility assessment, the most important of which were mentioned in the previous section, are typically very general and have mostly measured productivity competences rather than all of its dimensions. The present research tries to provide criteria and indicators for assessing the supply chain productivity comprehensively and based on all of its dimensions.

This paper is structured as follows: Section 2 presents a literature survey. In Section 3, the proposed method is provided generally. Section 4 illustrated the simulation method that is used in this paper, in Section 5 discussed results and discussion on a selected case study. Finally, in Section 6 the conclusion, future research and managerial implementation delivered.

2 | Literature Review

The theoretical basis and research background associated with the subject of the present research are discussed further. The most important condition for survival in today's competitive world is uniqueness and eliminating losses, delivering suitable products, with proper price at the proper time. It is very important for customers to receive their desired product as they wish with a reasonable price as soon as possible. Nevertheless, it should be noted that today and considering the rapid changes in the world, the interests, needs, and demands of customers are also changing equally fast, and considering the uncertainties in the competitive market and in the decision-making system, these issues can no longer be solely relied upon for success and to expend the whole energy for that. Market has shown that even if we provide the product with a very high quality and reasonable price, there are many competitors who would replace us rapidly in the market if our product is not available or not according to the customers' needs. Thus, in this competitive market, productivity is a major and undeniable principle. Accordingly, companies should have productivity in their production and establish integrity with their suppliers and customers. This helps them maintain their position in the competitive world and take effective steps for progress by creating an integrated supply chain [19].

Similar studies have mostly been conducted by foreign researchers. Here, the most important research studies on indicators of supply chain productivity assessment are reviewed. However, delivery flexibility is able to manage a flexible demand per a specific and constant value. Typically, these two cases are used in the supply chain, which go forward based on strategic decisions.

Vahdani and Mohammadi [20] displayed a bi-objective optimization demonstrate for planning a closed circle supply chain organize beneath vulnerability in which the overall costs and the greatest holding up times within the line of items are considered to play down. A common multi-priority and multi-server lining framework for parallel preparing execution is proposed. Too an unused cross breed arrangement approach is presented based on interim programming, stochastic programming, vigorous optimization approach, and fluffy multi-objective programming. Moreover, a meta-heuristic algorithm called self-adaptive colonialist competitive calculation is put forward for the given issue. At that point, in arrange to assess the quality of the arrangements gotten by this calculation; a lower bound method is examined. At last, different computational tests are carried out to survey the proposed demonstrate and arrangement approaches.

Ning and You [21] proposed a novel data-driven versatile strong optimization system that leverages huge information in prepare businesses is proposed. This machine-learning demonstrate is consistently coordinates with versatile vigorous optimization approach through a novel four-level optimization system. This system expressly accounts for the relationship, asymmetry and multimode of instability information, so it produces less traditionalist arrangements. Moreover, the proposed system is vigorous not as it were to parameter varieties, but moreover to bizarre estimations. Two mechanical applications on group handle planning and on prepare organize arranging are displayed to illustrate the preferences of the proposed modeling system and adequacy of the arrangement calculation.

Shang and You [22] proposed a viable distributional vigorous optimization system for arranging and planning beneath request instabilities. A novel data-driven approach is proposed to develop equivocalness sets based on foremost component investigation and first-order deviation capacities, which offer assistance uncovering exact and valuable data from vulnerability information. Additionally, it leads to mixed-integer direct reformulations of arranging and planning issues. To account for the multi-stage successive decision-making structure in prepare operations, they created multi-stage distributional strong optimization models and embrace relative choice rules to address the computational issue. Applications in industrial-scale handle organize arranging and group prepare planning illustrate that, the proposed distributional vigorous optimization approach can viably use vulnerability information data, way better fence against distributional uncertainty, and abdicate more benefits.

Zhao and You [23] investigated resilient supply chain design and operations with decision-dependent uncertainty using a data-driven robust optimization approach. The decision-dependent vulnerability set guarantees that the dubious parameters (e.g., the remaining generation capacities of offices after disturbances) are subordinate on first-stage choices, counting office area choices and generation capacity choices. A data-driven strategy is utilized to build the vulnerability set to completely extricate data from chronicled information. Additionally, the proposed show takes the time delay between disturbances and recuperation into thought. To handle the computational challenge of fathoming the coming about multilevel optimization issue, two arrangement procedures are proposed. The appropriateness of the proposed approach is outlined through applications on a location-transportation issue and on a spatially-explicit biofuel supply chain optimization issue.

Hosseini-Motlagh et al. [24] investigated blood supply chain management by robust optimization, disruption risk, and blood group compatibility in a real-life case, the aim of this paper was contribution blood supply chains under uncertainty. In this respect, this paper developed a bi-objective two-stage stochastic programming model for managing a red blood cells supply chain that observes above-mentioned issues. This model determines the optimum location-allocation and inventory management decisions and aims to minimize the total cost of the supply chain includes fixed costs, operating costs, inventory holding costs, wastage costs, and transportation costs along with minimizing the substitution levels to provide safer blood transfusion services. To handle the uncertainty of the blood supply chain environment, a robust optimization approach is devised to tackle the uncertainty of parameters, then, a real case study of Mashhad city in Iran, is implemented to demonstrate the model practicality as well as its solution approaches, and finally, the computational results are presented and discussed. Further, the impacts of the different parameters on the results are analyzed which help the decision makers to select the value of the parameters more accurately.

Violi et al. [25] proposed an energetic and stochastic approach for a stock directing issue in which items with a tall perishability must be conveyed from a provider to a set of clients. In arrange to viably oversee all these highlights, a rolling skyline approach based on a multistage stochastic direct program is proposed. Computational tests over medium-size occurrences outlined on the premise of the genuine information given by an agri-food company working in Southern Italy appeared the viability of the proposed approach.

Tordecilla et al. [26] checked on the papers in arrange to simulation-optimization strategies for planning and surveying strong supply chain systems beneath vulnerability scenarios. The plan of supply chain systems points at deciding the number, area, and capacity of generation offices, as well as the allotment of markets (clients) and providers to one or more of these offices. This paper reviewed the existing literature on the use of simulation-optimization methods in the design of resilient supply chain networks under uncertainty scenarios. From this review, we classify some of the many works in the topic according to factors such as their methodology, the approach they use to deal with uncertainty and risk, etc. The paper also identifies several research opportunities, such as the inclusion of multiple criteria amid the design-optimization prepare and the comfort of considering half breed approaches combining metaheuristic calculations, reenactment, and machine learning strategies to account for vulnerability and energetic conditions, individually.

Goli et al. [27] investigated the prediction of dairy product demand. The main contribution of this research is to provide an integrated framework based on statistical tests, time-series neural networks with novel meta-heuristic algorithms in order to obtain the best prediction the results confirmed that the proposed hybrid methods have the ability to improve the prediction of the demand for various products.

Tirkolaee et al. [28] proposed a novel two-echelon multi-product Location-Allocation-Routing problem. The aim of this study is to minimize the total cost, which involves costs related to the establishment, shipment processes, environmental pollution, travelling, vehicle usage, and fuel consumption, in a way to cover the total demand of retailers.

Chouhan et al. [29] proposed the sugarcane industry is technologically pioneering in the area of food production. The algorithms' performance is probed using the Taguchi experiments, and the best combinations of parameters are identified. The obtained results suggest that simulation can be optimized the supply chain network by using metaheuristic method.

Tirkolaee et al. [30] simultaneously minimized the total cost, total environmental emission, maximize citizenship satisfaction and minimize the workload deviation. A hybrid multi-objective optimization algorithm, namely, MOSA-MOIWOA is designed based on Multi-Objective Simulated Annealing Algorithm (MOSA) and Multi-Objective Invasive Weed Optimization Algorithm (MOIWOA). To increase the algorithm performance, the Taguchi design technique is employed to set the parameters optimally. The results illustrated the high efficiency of the suggested model and algorithm to solve the problem.

Based on the investigations performed on the mathematical models provided for flexible supply chain and productivity of the chain network, we found that a method based on uncertainty variables is missing. In this research, we intended to combine robust optimization model using uncertainty variables to enhance flexibility and productivity of supply chain network in order to achieve productivity and flexibility in all four areas of purchase, order, production, and transportation. This research attempted to resolve weak points and strengthen the strong points of past research based on identifying their pros and cons.

3 | Theoretical Framework

In recent years, extensive research has been conducted on capturing data uncertainty in mathematical models. These studies have led to development of robust optimization methods. Uncertainty can affect the optimality and justification of problems; typically, the best data estimation is used for mathematical modeling, which is known as nominal data. The first model of robust optimization was presented by Soyster. This model dealt with creating viable solutions for a convex set. The solutions of the Soyster models were very conservative, such that optimality would be neglected against ensuring robustness of the solution. In the next step, to develop robust optimization, Ben-Tal and Nemirovski model [34] was presented. Their models had two problems: 1) it increased the computational complexity of the problem, and 2) it did not provide any probable guarantee on problem viability. The operational framework of the Ben-Tal and Nemirovski model [34] was nonlinear. Bertsimas and Sim [5] presented an approach in which there was an interaction between optimality and robustness. Their model was linear which dealt with modifying the level of conservativeness of robust solution. The features of Bertsimas and Sim [5] models included linearity, the ability of controlling the conservativeness of robust solutions through a parameter known as robustness cost, and usability in integer number problems.

According to the explanations given in the previous section regarding the modeling of objective functions and constraints, the model in its ideal form is:

$$\text{MinZ} = \sum_{r=1}^{r} w_r(d_r^+, d_r^-) = w_1 d_1^+ + w_2 d_2^+ + w_3 d_3^+ + w_4 d_4^+ + w_5 d_5^-, \tag{1}$$

s.t.

$$\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} STOP_{mn} S_{mnt} + d_1^- - d_1^+ = G_1, \tag{2}$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} PPM_{mn} S_{mnt} + d_3^- - d_3^+ = G_3, \tag{3}$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} DP_{mn} S_{mnt} + d_4^- - d_4^+ = G_4, \tag{4}$$

$$\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T} CS_{mn} S_{mntj} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T} \tilde{C}t_{mnj} S_{mntj} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T} Ch_{mn} IS_{mntj} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T} PP_{mnjt} + Z \times \Gamma_1 - d_5^+ \le G_5, \tag{5}$$

$$S_{mtj} = \sum_{n=1}^{n} S_{mntj} = \sum_{i=1}^{i} VC_{im} P_{ijt} - \sum_{n=1}^{n} IS_{mnjt-1} + \sum_{n=1}^{i} IS_{mnjt} \quad \text{for all } j, m, t, \tag{6}$$

$$\sum_{i=1}^{n} IS_{mtj} \ge VC_{im} \times X_{ijt} \times \alpha \times LT_m \quad \text{for all } j, m, t, \tag{7}$$

$$\sum_{i=1}^{n} IS_{mtj} \le VC_{im} \times X_{ijt} \times (1+\alpha) \times LT_m \quad \text{for all } j, m, t, \tag{8}$$

$$\sum_{j=1}^{J} S_{mntj} + ZZ_{mnt}\Gamma_2 + ppp_{mnt} \le \tilde{C}_{mn} \quad \text{for all } m, n, t, \tag{9}$$

$$\sum_{j=1}^{J} S_{mnjt} \ge \beta \times \sum_{n=1}^{n}\sum_{j=1}^{J} S_{mnjt} \quad \text{for all } m, n, t, \tag{10}$$

$$PP_{mnjt} + ZZ \ge \hat{C}t \;\; S_{mntj} \quad \text{for all } m, n, j, t, \tag{11}$$

$$PP_{mnjt} + ZZ \ge \hat{C}t \;\; S_{mntj} \quad \text{for all } m, n, j, t, \tag{12}$$

$$ZZ_{mnt} + ppp_{mnt} \ge \hat{C}_{mn} \quad \text{for all } m, n, t, \tag{13}$$

$$S_{mnjt}, IS_{mtj} \ge 0, \text{integer} \quad \text{for all } m, n, j, t. \tag{14}$$

Due to the fact that in the model designed in the previous section, there are integer variables, to convert the model to a stable counterpart, the "Bertsims and Wire" model was used. Therefore we have this model in *Eqs. (15)-(27)*:

$$\text{MinZ} = \sum_{r=1}^{r} w_r(d_r^+, d_r^-) = w_1 d_1^+ + w_2 d_2^+ + w_3 d_3^+ + w_4 d_4^+ + w_5 d_5^-, \tag{15}$$

s.t.

$$\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} STOP_{mn} S_{mnt} + d_1^- - d_1^+ = G_1, \tag{16}$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} PPM_{mn} S_{mnt} + d_3^- - d_3^+ = G_3, \tag{17}$$

$$\sum_{i=1}^{I}\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{t=1}^{T} DP_{mn} S_{mnt} + d_4^- - d_4^+ = G_4, \tag{18}$$

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$$\sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T} CS_{mn} S_{mntj} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T} \tilde{C}t_{mnj} S_{mntj} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T} Ch_{mn} IS_{mntj} + \sum_{m=1}^{M}\sum_{n=1}^{N}\sum_{j=1}^{J}\sum_{t=1}^{T} PP_{mnjt} + Z \times \Gamma_1 - d_5^{+} \le G_5, \tag{19}$$

$$S_{mtj} = \sum_{n=1}^{n} S_{mntj} = \sum_{i=1}^{i} VC_{im} P_{ijt} - \sum_{n=1}^{n} IS_{mnjt-1} + \sum_{n=1}^{i} IS_{mnjt} \ \forall j,m,t, \tag{20}$$

$$\sum_{i=1}^{n} IS_{mtj} \ge VC_{im} \times X_{ijt} \times \alpha \times LT_m \ \forall j,m,t, \tag{21}$$

$$\sum_{i=1}^{n} IS_{mtj} \ge VC_{im} \times X_{ijt} \times (1+\alpha) \times LT_m \ \forall j,m,t, \tag{22}$$

$$\sum_{j=1}^{J} S_{mntj} + ZZ_{mnt} \Gamma_2 + ppp_{mnt} \le \tilde{C}_{mn} \ \forall m,n,t, \tag{23}$$

$$\sum_{j=1}^{J} S_{mnjt} \ge \beta \times \sum_{n=1}^{n}\sum_{j=1}^{J} S_{mnjt} \ \forall m,n,t, \tag{24}$$

$$PP_{mnjt} + ZZ \ge \hat{C}t \ S_{mntj} \ \forall m,n,j,t, \tag{25}$$

$$ZZ_{mnt} + ppp_{mnt} \ge \hat{C}_{mn} \ \forall m,n,t, \tag{26}$$

$$S_{mnjt}, IS_{mtj} \ge 0, \text{integer} \ \forall m,n,j,t. \tag{27}$$

4 | Theoretical Framework

Simulation technique is one of the most important and applicable tool for complexity of manufacturing systems. The simulation and optimization integration can maximize the performance. It can be defined as the process of finding the best input variable values from among all possibilities without explicitly evaluating each possibility [31]. The precise concept of simulation, the cases in which it can be used, its applications, advantages, disadvantages, and processes are issues to be discussed further in the section.

Unlike many technical sciences which can be ranked based on the field of their origin (such as physics or chemistry), simulation can be used in all fields. The main motivation of simulation has its roots in space programs [32]. Nevertheless, even an informal investigation of the texts related to simulation can indicate their current wide areas of application. For example, Shannon [35] in his book (science and art of system simulation) mentions the books that have been written with regards to application of simulation in the following areas including trading, economics, marketing, education, politics, social sciences, behavioral sciences, international relations, transportation, human resources, and enforcement of laws, urban studies, and global systems. Further, numerous technical papers, reports, PhD and MA theses almost in all areas of social, economic, technical, and human sciences indicate the impact and progressive growth of use of simulation in all aspects of life. Various definitions have been provided for simulation, though the most comprehensive and complete one has been presented by Shannon [35]. He defined simulation as follows: simulation refers to the process of designing a real system and conducting experiments with models to understand the behavior of the system as well as to assess different strategies within a range applied through a criterion or a set of criteria [33].

In the above definition, a real system means a system that exists or can be implemented. Before dealing with other issues, it may be better to look at a simple example to explain the concept of simulation. Consider the money cashier system of a bank. Assume that a person works in the cash retrieval counter of a bank, whereby the time of entrance of clients is distributed up to 10 min uniformly (for simplicity, the size of all times is rounded to the closest integer number). Also assume that the time required for providing services to every client is distributed on 1-6 min uniformly. We want to calculate the average time the client spends in the system including client waiting time, service time, the percentage of the time the cashier does not work. To simulate this system, we should create an artificial experiment that would represent the above situation. For this purpose, we should create a method to generate fabricated referral of a group of clients and the time required for providing services to each of them. In one of the methods that can be used, we begin with 10 tokens and one dice. Then, the tokens are numbered from 1 to 10, and placed in a container. By shaking the container, we mix them up. By withdrawing one token from the container and reading the number on it, the time between entrance of current and previous clients can be determined. The service time to this client can also be obtained by tossing the dice and reading the number of points on its top surface. By repeating this operation (placing the tokens inside the container and shaking it after each withdrawal), we have generated the entrance and service times of a group of imaginary clients.

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In this research, to show the quality of modeling, we perform the model for a case study in the automotive industry. The details of this model are given in the form of a case study. Automotive industry is one of the most important and integral components of trade and industry in the world. The supply chain of this industry is one of the most dynamic chains. Due to this important, Iran-Khodro supply chain was selected as the largest active chain in this field in Iran. In this chain, each car contains thousands of parts. Regardless of the fact that some components are single source, many components are sourced from multiple sources. In other words, proper planning for the supply of parts by considering various criteria and also the high uncertainty of some indicators, has added to the importance of sound planning in this chain. In this study, robust planning for the supply of auto parts has been considered. The planning for the supply of these parts is based on the production plan of the Tehran factory, but the modeling has been generally developed to be applicable to several factories. Most of the research data is taken from SAPCO and Iran Khodro companies.

In order to modeling, solving and simulation the following parts are performed:

I. Determining the model assumptions (study of theoretical literature and continuous interviews with experts and experts of the company).
II. Mathematical modeling (defining variables, parameters, setting goals and constraints) by studying the theoretical literature, continuous interviews with experts and experts of the company.
III. Distinguish between definite and indefinite parameters: interviews with experts.
IV. Solid modeling (conversion of mathematical model to solid counterpart model): study of theoretical literature.
V. Determine the values of the parameters, solve the robust model, simulate and check the quality of the answers.

5 | Results

Due to the high complexity of the model regarding the number of variables, limitations and data, the model was programmed in a space set in LINGO software (linked with Excel), so that the input data of the model would be imported from Excel, thereby enhancing the computational efficiency of the model. Given the programming, it was always attempted to use heuristic programming techniques in order to prevent useless complication of the model. After completing the programming, the robust model was solved 11 times per 11 states of protection level. After each time of solving the model, the values of the obtained variables were considered constant, while the uncertain parameters were generated and simulated within the considered range randomly in the form of a symmetric distribution function for 10000 times. At each time of simulation, it was found how many constraints were violated. In other words, once the ratio of the total number of violated constraints to the total number of constraints with uncertain parameters was clarified, the risk of every protection level was determined. The following table summarizes the results:

Table 1. Objective function for each of the ideals.

State	Γ_1	Γ_2	Objective Function
1	0	0	819122
2	39	0.1	1057305
3	78	0.2	1288788
4	117	0.3	1518428
5	156	0.4	1744630
6	195	0.5	1979347
7	234	0.6	2204116
8	273	0.7	2430908
9	312	0.8	2662562
10	351	0.9	2889888
11	387	1	3164133

Table 2. Percentage of deviation values from each ideal to the value of each ideal in each state.

State	A	B	C	D	E	Γ_1	Γ_2
1	0.057	47.196	22.684	532.768	1.740	0	0
2	0.260	47.383	22.708	540.073	1.860	0.1	39
3	0.466	47.591	22.734	547.501	1.888	0.2	78
4	0.670	47.140	22.765	554.973	1.905	0.3	117
5	0.872	48.035	22.794	562.439	1.917	0.4	156
6	1.057	48.262	22.828	570.010	1.927	0.5	195
7	1.283	48.481	22.857	577.410	1.934	0.6	234
8	1.483	48.699	22.886	584.875	1.940	0.7	273
9	1.696	48.922	22.922	592.375	1.919	0.8	312
10	1.897	49.146	22.955	599.838	1.950	0.9	351
11	2.143	49.491	22.999	607.355	1.954	11	387

Table 3. Probability of violation of restrictions in different situations and based on different indicators.

State	A	B	C	D	E	F	Γ_1	Γ_2
1	0.001	0.006	0.107	0.523	0.893	0.477	0	0
2	0	0	0.097	0.436	0.903	0.564	0.1	39
3	0	0	0.086	0.388	0.914	0.612	0.2	78
4	0	0	0.075	0.339	0.925	0.661	0.3	117
5	0	0	0.065	0.291	0.935	0.709	0.4	156
6	0	0	0.055	0.246	0.945	0.754	0.5	195
7	0	0	0.044	0.196	0.956	0.804	0.6	234
8	0	0	0.033	0.149	0.967	0.851	0.7	273
9	0	0	0.023	0.099	0.977	0.901	0.8	312
10	0	0	0.011	0.049	0.989	0.951	0.9	351
11	0	0	0	0	1	1	11	387

Table 3 indicates the level of risk (probability of violating the constraints). The fifth ideal constraint as 387 uncertain parameters as well as Γ_1 protection level. Other constraints with volatile parameters (uncertain) have 387 capacity constraints which have volatile capacity parameter in them and have Γ_2 protection level. The simulation results indicated that only a number of capacity constraints (86 cases) are violable, since some capacities are beyond the demand or the model has considered under-capacity allocation for them. Thus, volatility or fluctuations in the mentioned range has no effect on them. Based on these explanations, overall two indicators were considered for calculating the risk levels:

Indicator 1: dividing the total number of violated cases by the total number of possible cases.

Indicator 2: dividing the total number of violated cases by the total number of cases dependent on constraints that can be violated.

Indicator 2 is stricter and generally, *Indicator 1* is more logical. In *Table 3*, cases 1 and 11 are the most optimistic and pessimistic cases respectively. Columns A and B represent the probability of violating the fifth ideal constraint (based on *Indicators 1* and *2*), columns c and d show the probability of violating the capacity constraints (based on *Indicators 1* and *2*), and columns e and f reveal the total confidence percentage (based on *Indicators 1* and *2*).

Table 1 suggests that with reducing the risk-taking (increasing the level of protection), the objective function (of minimization type) has worsened. Indeed, as the level of protection increased, the model has chosen the values of variables in a stricter way within the allowable range, such that the probability of violating the constraints has decreased and eventually the solution of the objective function has been aggravated. This in turn can explain the accuracy of the robust modeling as well as the performance of the model.

Table 2 and slope of the relevant diagrams suggest that changing the level of risk or level of conservativeness has had a considerable impact on increasing the slope of the line of the objective function values. In other words, robustification of the model is essential and influential for reducing the decision-making risk.

Based on *Table 2*, deviation from the first goal which has the highest importance coefficient could considerably approach zero. Meanwhile, this goal has had the minimum divination percentage compared to other goals, suggesting the proper performance of the model in the presence of numerous and sometimes conflicting goals.

Based on *Table 2* and the importance coefficients of goals, although goals 1, 2, 3, 4, and 5 have had the highest importance coefficients respectively, the model has been able to reduce deviation from goals 1, 5, 3, 2, and 4 respectively. Meanwhile, percentage of reduction of deviation from goals 1, 5, and 3 compared to the value of each goal is notable.

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The numbers in *Table 3* are an outcome of simulation, indicating that with increase in the level of protection, these numbers decrease. This indicates the proper performance of the robust model and simulation.

In *Table 3*, in the pessimistic state, the protection level numbers are maximum, and the probability number of violation of constraints becoming zero in this case means that no constraint is violated which coincides with the worst value of objective function. If this case does not actually occur (not all fluctuations or volatilities occur), selection of this option can compensate for the lost opportunity for decision-maker. In contrast, in the optimistic state, excessive optimism can lead to incurrence of costs and losses. Thus, the best state is the one in which the decision-maker accepts some risk based on which, they would apply the values of the variables selected by the model in practice. For example, if the decision-maker accepts risk of about 5%, based on *Table 3* and according to *Indicator 1*, the solutions obtained from case 7 guarantee 95% confidence for them, i.e. there is a balance between risk and reward.

In the model solution section, it was stated that there are 387 constraints with uncertain parameters, and only a limited number of these constraints can be violated. Thus, by observing the numbers, it can virtually be stated that 86 constraints that could be violated are of active constraint types. Presenting an algorithm for reducing these constraints before solving the solution can be the subject of future research.

Fig. 1, which is linear and has an uptrend, shows both the value of the objective function in each case and the risk or probability of breaking the constraint. In order to match the numbers of the objective function and the risk in terms of size, we have plotted the objective function on a million scales.

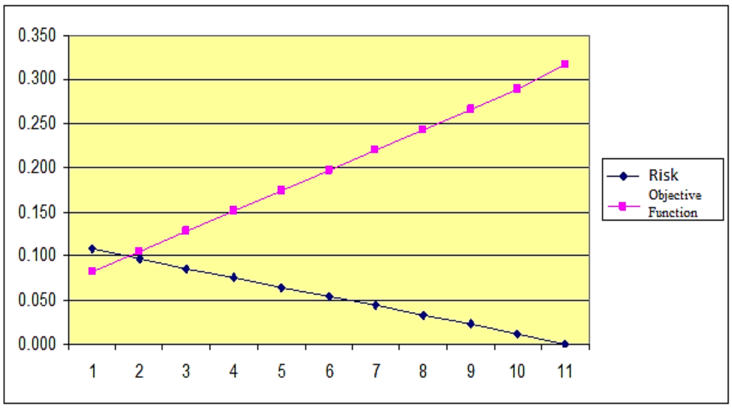

Fig. 1. Comparison of objective function trend charts and risk trend.

The diagram shows that the further we move towards mode 11, the lower the risk level and the worse the objective function.

6 | Conclusion

Given the money related bottlenecks confronting businesses in Iran and the weights on the natural angles of generation and dissemination, it is crucial to consider these issues in planning diverse measurements of commerce. In expansion to minimizing the full taken a toll, natural impacts of generation, transportation and dispersion of items were moreover minimized. Bertsimas and Sim [5] method are used to determine the uncertainty about the rate of return products. Investigation of the results of the solved model shows the positive effect of the assurance level of the model on the objective function value. Overall, the results show that increased costs are because of lower risk acceptance. Compliance with natural necessities moreover contains a coordinate effect on add up to costs. From the viable point of see, it is recommended that vital supply chain level choices be coordinates into line with natural choices. Such an approach not as it were decreases the hazard in generation and dissemination but too progresses supply chain execution both in fetched and natural terms. Also, the positive effect of observing uncertainty in the model indicates that manufacturers can improve the quality of their decisions in terms of production and distribution and design of the supply chain by considering the amount of returned goods. Moreover, the results reveal that the consideration of environmental constraints would impose additional costs on the supply chain anyway. This extra cost can be justified looking at social responsibility towards the environment and human destiny. Yet, in many developed countries because of the advancement of technology, economic efficiency is considered as much as environmental efficacy. Within the show ponder, it is appeared that the innovation utilized in reusing centers with reserve funds at the taken a toll of crude fabric supply not as it were does legitimize the natural issues but moreover has financial defense. To advance this inquire about within the future, the taking after recommendations are displayed to other analysts: the show can be amplified to a supply chain with more levels, counting discount and retail centers, central distribution centers and merchants. Natural imperatives can also be considered as an objective work instead of a confinement. For illustration, minimizing carbon emanations can be considered as one of the different destinations of the show. At long last, considering social perspectives in calculated optimization models can too be curiously.

The gathering data process is the case study limited to a small period of time. For longer periods, frequent events may be occurred and more reliable estimation could be found. So simulation base settings may be changed on necessity, although this issue does not affect the proposed method, but it can affect the accuracy of the case study results. In addition to the issues of modeling and solving the model, new indicators have also been presented regarding the concept of supplier selection such as stopping the production line in response to the performance of suppliers and the production line complaint from suppliers' pieces, which do not exist in the theoretical literature at least this explicitly. Generally, even the robustness of solutions, interview-based modeling, and consideration of different as well as important indicators according to the decision-maker opinion, it can be claimed that the model is reasonably reliable. With regard to future research, presenting new and heuristic methods is suggested for solving models with variables as well as applying the presented model in a real study to attain real outputs, use Z-numbers calculations to examine variables and provide new and meta-innovative methods for solving models with verbal variables, and also can use senility analysis in order to compare the results under conditions of uncertainty.

Acknowledgments

The creators of this article need to thank and appreciate the close cooperation of the managers of the automotive industry to participate in this study.

Funding

No funding was received to assist with the preparation of this manuscript.

Conflicts of Interest

There is no conflict of interest in connection with this paper, and the material described here is not under publication or consideration for publication elsewhere.

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E-ISSN: 2676-6167 | P-ISSN: 2538-5100

Journal of Applied Research on Industrial Engineering

www.journal-aprie.com

J. Appl. Res. Ind. Eng. Vol. 10, No. 2 (2023) 286–339.

Paper Type: Review Paper

Nature-Inspired Metaheuristic Algorithms: Literature Review and Presenting a Novel Classification

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Citation:

Khadem, M., Toloie Eshlaghy, A., & Fathi Hafshejani, K. (2023). Nature-inspired metaheuristic algorithms: literature review and presenting a novel classification. *Journal of applied research on industrial engineering, 10*(2), 286-339.

Received: 24/05/2021 Reviewed: 26/06/2021 Revised: 18/08/2021 Accepted: 11/10/2021

Abstract

Over the past decade, solving complex optimization problems with metaheuristic algorithms has attracted many experts and researchers. Nature has always been a model for humans to draw the best mechanisms and the best engineering out of it and use it to solve their problems. The concept of optimization is evident in several natural processes, such as the evolution of species, the behavior of social groups, the immune system, and the search strategies of various animal populations. For this purpose, the use of nature-inspired optimization algorithms is increasingly being developed to solve various scientific and engineering problems due to their simplicity and flexibility. Anything in a particular situation can solve a significant problem for human society. This paper presents a comprehensive overview of the metaheuristic algorithms and classifications in this field and offers a novel classification based on the features of these algorithms.

Keywords: Optimization, Metaheuristic algorithms, Nature-inspired metaheuristic algorithms, Classification.

1 | Introduction

Today, optimization applications have become widespread in all areas such as engineering design, production planning, and financial markets, so the concept of optimization has become particularly important. The purpose of optimization is to minimize time, cost, and risk or maximize profit, quality, or effectiveness. There are exact methods and approximate methods to solve optimization problems. The exact methods can find the optimal solution to the problem. Non-derivative methods such as two-point, three-point, Fibonacci, and Golden Ratio methods, and derivative methods such as the semi-sectional method and the Newton-Raphson method, are precise methods. Many of the problems in nature are NP-hard. They cannot solve by exact methods, and the time required to solve those increases exponentially with the size. Often approximation algorithms are the only possible way to achieve near-optimal solutions with relatively low computational cost [1]. Approximate algorithms divide into three groups of heuristic, metaheuristic, and hyper-heuristic algorithms.

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https://doi.org/10.22105/jarie.2021.287733.1330

The two main problems of heuristic algorithms are falling into local optimal points and early convergence to these points. Metaheuristics are solution methods that harmonize interaction between local improvement methods and higher-level strategies to escaping from local optima [1]. Most of these algorithms are inspired by nature or biology, based on the successful evolutionary behavior of natural systems, by learning from nature. Nature has solved complex problems in more than millions or even billions of years. In nature, only the best and lasting solutions remain. This paper classifies these algorithms by comprehensively reviewing the literature.

2 | Literature Review of Metaheuristic Algorithms

In recent decades, due to the capabilities of nature-inspired metaheuristic algorithms in solving various problems, the number of these algorithms has grown significantly and has been expanding. Represents the cumulative trend of presented metaheuristic algorithms.

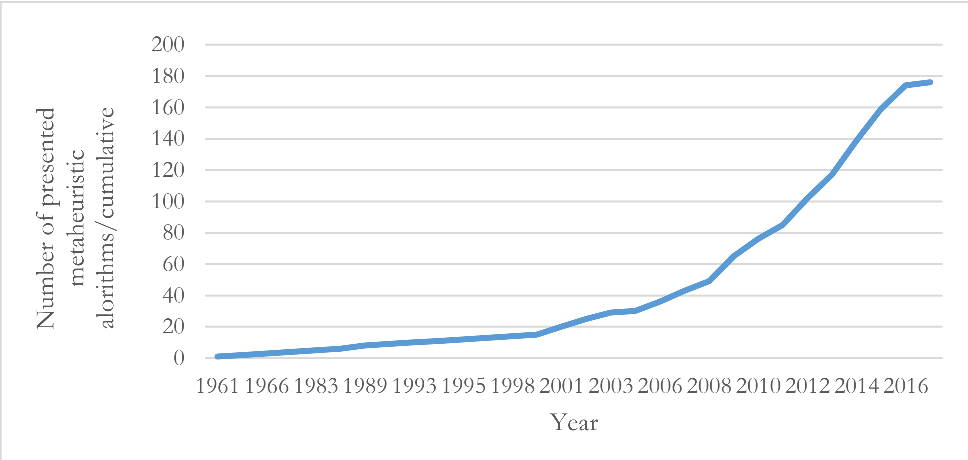

Fig. 1. The trend of presented metaheuristic algorithms.

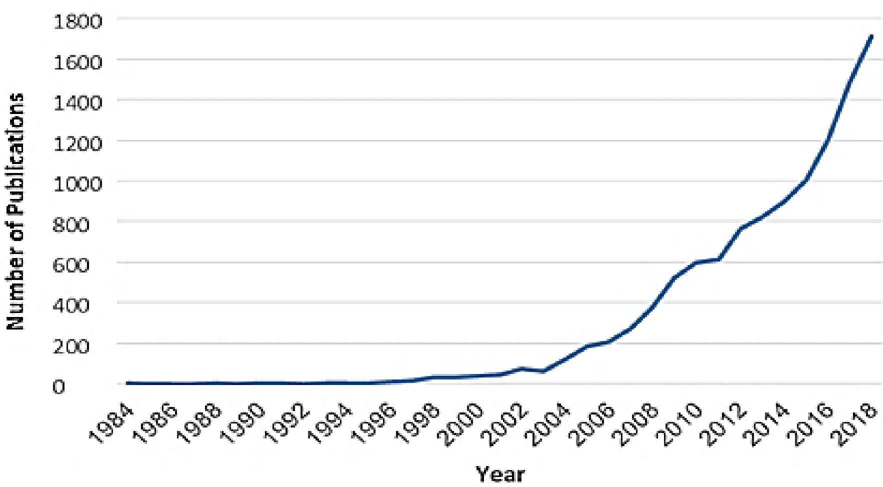

Fig. 2. The trend of papers published in the metaheuristic area (source: scopus).

Fig. 2 illustrates the trend of papers published in the metaheuristic area.

As shown in *Fig. 2*, the number of papers presented in the metaheuristic area have been significant growth after 2000.

Table 1 shows a glimpse of the perspective of the emergence of metaheuristic algorithms.

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Table 1. History of metaheuristic algorithms.

Year	Author/Presenter	Algorithm	Description
1960	Holland [191]	Genetic Algorithm (GA)	University of Michigan-biological evolution of species
1966	Fogel et al. [192]	Evolutionary programming	US
1983	Kirkpatrick et al. [146]	Simulated Annealing (SA)	Inspired by the annealing process of metals
1986	Glover [162]	Tabu search	Use memory
1988	Koza [193]	Genetic programming	
1992	Dorigo [194]	Ant Colony Optimization (ACO)	Swarm intelligence-ant colony
1995	Kennedy and Eberhart [122]	Particle Swarm Optimization (PSO)	Swarm Intelligence-bird flock
1996	Storn and Price [195]	Differential Evolution (DE)	
2001	Geem et al. [90]	Harmony search	Inspired by musicians
2005	Karaboga [196]	Artificial Bee Colony (ABC)	Simulates the foraging behavior of honey bees
2005	Pham et al. [190]	Bees algorithm	Foraging behavior of honey bees
2005	Krishnanand and Ghose [78]	Glowworm Swarm Optimization (GSO)	Behavior of glowworms
2006	Chu et al. [35]	Cat swarm optimization	Inspired by the behavior of cats
2007	Atashpaz-Gargari and Lucas [97]	Imperialist competitive algorithm	Simulation of human social evolution
2007	Rabanal et al. [133]	River formation dynamics	Imitating how water forms rivers
2009	Husseinzadeh Kashan [108]	League championship algorithm	The sports league championship inspires this algorithm.
2009	Yang and Deb [47]	Cuckoo search	Inspired by the brood parasitism of cuckoo
2010	Yang [24]	Bat algorithm	Inspired by the echolocation behavior of microbats
2011	Tamura and Yasuda [156]	Spiral Optimization (SPO) algorithm	Inspired by spiral phenomena in nature
2012	Yang [69]	Flower pollination algorithm	Based on the pollination process of flowering plants
2013	Eesa et al. [49]	Cuttlefish optimization algorithm	Inspired by skin color changing behavior of cuttlefish
2014	Mirjalili et al. [87]	Grey Wolf Optimizer (GWO)	Mimics the leadership hierarchy and hunting mechanism of grey wolves in nature
2015	Mirjalili [117]	The ant lion optimizer	Mimics the hunting mechanism of antlions in nature
2016	Mirjalili and Lewis [174]	The whale optimization algorithm	Mimics the social behavior of humpback whales

Fig. 3 shows that the most relevant areas of metaheuristic algorithms are computer science with 34.9%, engineering 21%, and mathematics 17.8%, respectively.

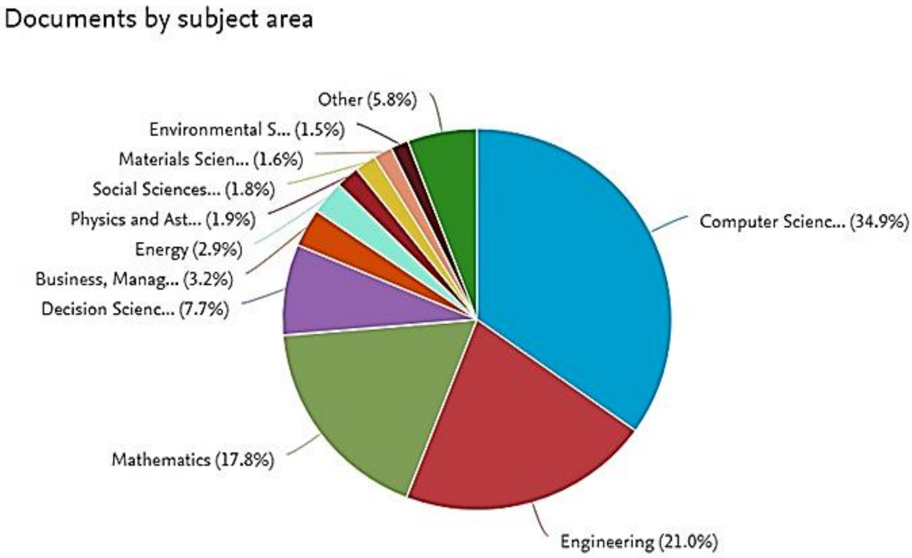

Fig. 3. Application areas of metaheuristic algorithms.

In 2017, Rajpurohit et al. [2] afforded a glossary of the metaheuristic algorithms.

Table 2 shows the metaheuristic algorithms presented from the beginning with a brief description, authors, the year of publication, the source of inspiration, the scope of their application, and the number of citations to them in the papers presented.

Table 2. Metaheuristic algorithms with a brief description, authors, the year of publication, the source of inspiration, the scope of their application, and the number of citations.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
1	African buffalo optimization	Odili et al. [3]	2015	Mimics foraging and organizational skills of African buffalos	32	17	10	Traveling salesman's problem, design of PID controller
2	African wild dog algorithm	Subramanian et al. [4]	2013	African wild dogs' hunting behavior inspires it	6	3	-	Design of steel structures, flow shop scheduling problems
3	Anarchic society optimization	Shayeghi and Dadashpour [5]	2012	Inspired by instability in the anarchistic group in society	23	8	7	PID control, flow-shop scheduling problem
4	Animal migration optimization algorithm	Li et al. [6]	2014	Mimics the migration behavior of animals	139	15	6	Clustering analysis, association rules mining

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
5	ACO	Colorni et al. [7]	1991	Inspired by ants path search behavior to find a food source	11276	14397	8925	Traveling salesman problem, vehicle routing problem, open shop scheduling, resource-constrained project scheduling, data mining, Wireless Sensor Networks (WSNs), image edge detection, feature selection, classification, object segmentation, JIT sequencing problem, power load forecasting, etc.
6	Ant Lion	Mirjalili [8]	2015	Inspired by ant lions hunting behavior	597	14	9	Automatic Generation Control (AGC), feature selection, economic load dispatch problem, design of skeletal structures, multi-layer perceptions trainer, optimal power flow, renewable distributed generations, flexible process planning
7	Artificial algae algorithm	Uymaz et al. [9]	2015	Imitates the adaption and movement behavior of algae.	62	17	17	Knapsack problem, binary optimization problems, wind turbine placement problem, parameter selection strategy
8	ABC	Karaboga and Basturk [10]	2007	Inspired by the action of searching food in the bee colonies.	1063	1200	244	Traveling salesman problem, distribution network configuration, reliability Redundancy Allocation Problem (RAP), discrete optimum design of truss structures, reconfiguring distribution network, job scheduling problem, Parameter estimation, WSN
9	Artificial chemical reaction optimization algorithm	Alatas [11]	2011	Inspired by chemical reactions	133	14	10	Knapsack problem, neural networks, sustainable network design problem, flexible job-shop scheduling problem, task scheduling in grid computing
10	Artificial cooperative search	Civicioglu [12]	2013	It inspires the mutual advantages of living species by organic interactions.	78	19	12	Energy consumption forecasting, quadratic approximation, parameter identification

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
11	Artificial ecosystem algorithm	Adham and Bentley [13]	2014	Inspired by characteristics of the ecosystem	5	5	3	Traveling salesman problems, clustering
12	Artificial fish school algorithm	Li [14]	2002	Inspired by fish swarm features such as avoiding dangers and searching for food	131	69	31	Design of robust PID controller, traveling salesman problem, clustering, parameter optimization, neural network, coverage problem, protein folding structure prediction
13	Artificial plant optimization algorithm	Li et al. [15]	2012	Inspired by the growing process of plants	34	20	10	Protein folding, WSNs, coverage problem
14	Artificial searching swarm algorithm	Chen [16]	2009	Inspired from principles of the bionic intelligent optimization algorithm	18	11	4	Reactive power optimization, constrained optimization problems
15	Atmosphere clouds model	Yan and Hao [17]	2013	Mimics from the spreading and moving of clouds	18	3	-	Optimal reactive power dispatch problem
16	Backtracking search optimization	Civicioglu [18]	2013	The algorithm has crossovers and mutation operators and a memory.	491	111	82	Distributed generators, optimal power flow, parameter identification, environmental power dispatch problems, feature selection
17	Bacteria chemotaxis algorithm	Muller et al. [19]	2002	Survival tactics adopted by bacteria, such as getting information from the environment	378	2	1	Economic emission load dispatch, assembly sequence planning
18	Bacterial colony optimization	Niu and Wang [20]	2012	Inspired by behaviors of Escherichia coli like migration, reproduction, elimination, and communication	65	23	16	Economic power dispatch, reactive power optimization

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
19	Bacterial evolutionary algorithm	Das et al. [21]	2009	Based on microbial evolution, it Utilizes two operator's gene transfer operation and bacterial mutation.	44	63	39	Data clustering, fuzzy system design, Nurse Scheduling Problem (NSP)
20	Bacterial foraging algorithm	Passino [22]	2002	Utilizes natural selection, such as supporting individuals with proper foraging and eliminate inadequate foraging.	2813	495	332	Economic emission load dispatch, parameter estimation, image segmentation, economic emission dispatch problem etc.
21	Bacterial swarming	Chu et al. [23]	2008	The algorithm uses the swarming and foraging process of E-coli.	71	94	73	Power transformer winding, optimal allocation, distributed optimal power flow, optimal estimation of harmonics
22	Bat algorithm	Yang [24]	2010	Imitates the echolocation behavior of bats.	2605	1628	1177	Feature selection, economic dispatch, image matching, path planning, economic load, and emission dispatch
23	Big bang-big crunch	Erol and Eksin [25]	2006	Inspired by the big-bang theory	793	316	226	Design of space trusses, design of skeletal structures, fuzzy PID controller, data clustering, parameter estimation
24	Biogeography based optimization	Simon [26]	2008	Imitates the biological organisms' geographical distribution.	2229	1068	917	Economic load dispatch problems, power flow problem, optimal power flow, flexible job shop scheduling problem
25	Bird mating optimizer	Askarzadeh [27]	2014	Imitates the mating behavior of birds.	73	25	22	Structural damage detection, parameter estimation
26	Bird Swarm	Meng et al. [28]	2016	Mimics the birds swarm flight and foraging behaviors.	95	75	31	Parameter estimation for chaotic systems, optimal power flow problems, parameters optimization, neural network

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
27	Black holes algorithm	Hatamlou [29]	2013	Imitates the black hole's features.	424	74	-	Optimal power flow, supply chain, set covering problem, optimal design of electromagnetic devices, software architecture recovery, optimal reactive power dispatch problem
28	Blind, naked mole-rats algorithm	Taherdangkoo et al. [30]	2013	Mimics blind, naked mole-rats behaviors such as foraging and protecting the colony.	18	1	-	Robust clustering
29	Brainstorm optimization	Shi [31]	2015	Mimics the brainstorming idea for solving problems.	256	196	139	Control parameter, wind speed forecasting, WSNs deployment, economic dispatch, clustering, optimal reactive power dispatch problem, TSP, classification, portfolio optimization
30	Bull optimization algorithm	Findik [32]	2015	The algorithm modifies the selection process of the GA.	_	1	1	_
31	Bumble bees mating optimization	Comellas and Martinez [33]	2009	The algorithm modifies the selection process of the GA.	16	9	8	Vehicle routing problem, feature selection, flow shop scheduling problem
32	Camel algorithm	Ibrahim and Ali [34]	2016	Imitating ground conditions, temperature, and water supply in a camel journey in the desert.	_	_	_	_
33	Cat swarm optimization	Chu et al. [35]	2006	Imitating the behavior of cats and has two sub-models, namely tracing and seeking mode.	342	293	188	Clustering, workflow scheduling, feature selection, artificial neural networks, power distribution network
34	Central force optimization	Formato [36]	2007	Imitates the movement of bodies under gravitational force	254	83	62	Training neural networks, antenna design, 3D UAV path planning, water distribution networks, clustering

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
35	Charged system search	Kaveh and Talatahari [37]	2010	Inspired by electromagnetic and gravitational forces	704	146	144	Optimal design of skeletal structures, economic power dispatch problem, data clustering, multilayer perceptron neural networks training, facility layout problems, structural reliability analysis, water distribution networks optimization
36	Chicken swarm	Meng et al. [38]	2014	Imitates the hierarchical of chicken swarms.	178	109	72	Feature selection, optimal trajectory planning, WSN, distributed wireless sensor node localization, parameter estimation, distribution network reconfiguration, solving flexible job-shop scheduling
37	Clonal selection algorithm	De Castro and Von Zuben [39]	2000	Inspired by the responses of the immune system to antibodies	1292	1041	668	Hydrothermal scheduling, windpower forecast, parameter estimation, image classification, dynamic facility layout problems, traveling salesman problem, power filter optimization, classification, virus detection, maintenance schedule
38	Cockroach swarm optimization	Obagbuwa and Adewumi [40]	2014	Mimics by the behavior of cockroaches like interaction and searching food and dispersion in danger.	30	15	11	TSP, vehicle routing problems, travel planning, product disassembly sequence planning, motion planning of mobile robot, traveling salesman problem
39	Colliding bodies optimization	Kaveh and Mahdavi [41]	2014	Mimics the collision of bodies to search for better situations in the space	272	109	116	Design of truss structures, optimal power flow, design of arch dams, damage detection of bridge structures, design and optimization of water distribution systems, design of truss structures

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
40	Community of scientist optimization	Milani and Santucci [42]	2012	Inspired by the community of scientist's behavior to gain research funds and share results for their research activities.	18	1	1	_
41	Consultant-guided Search	Iordache [43]	2009	Inspired from information exchange between individuals and the real-world based on advice by a consultant.	34	11	7	Quadratic assignment problem, traveling salesman problem, job shop scheduling problem
42	Coral reefs optimization algorithm	Salcedo-Sanz [44]	2014	Imitates life and reproduce of coral reef colonies.	77	42	29	Offshore wind farm design, optimal mobile network deployment, clustering problems, cluster ensembles optimization
43	Covariance matrix adaptation-evolution strategy	Hansen et al. [4]	2003	This algorithm accelerates the convergence by reducing the number of generations and using a larger population size.	47	524	377	Electromagnetics design problems, path integral policy improvement, PID controller, real parameter optimization
44	Crystal energy optimization algorithm	Feng et al. [46]	2016	Inspire by the self-organizational feature of the lake freezing.	1	1	1	_
45	Cuckoo search algorithm	Yang and Deb [47]	2009	Mimics the behavior of cuckoo in brood parasitic and levy flight.	3743	1548	1100	Traveling salesman problem, neural network training, structural design optimization, economic dispatch, image segmentation, flow shop scheduling, truss design optimization, feature selection, clustering of web search results, optimal path planning, face recognition, etc.

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
46	Cultural algorithms	Reynolds [48]	1994	It is a kind of evolutionary computation that has a knowledge component in addition to the population component.	987	690	212	Set covering problem, automatic fault isolation, designing electronic circuits, image segmentation, array antenna pattern synthesis, intelligent logistics
47	Cuttlefish algorithm	Eesa [49]	2013	Mimics from cuttlefish in changing color behavior.	35	17	9	Diagnosis of Parkinson's disease, feature extraction, traveling salesman problem, feature selection
48	Dialectic search	Kadioglu and Sellmann [50]	2009	The mental concept of dialectic inspires it.	34	2	1	_
49	DE	Storn and Price [51]	1997	It is inspired by the information exchange feature of chromosomes to generate better offsprings.	19916	16399	14997	Scheduling flow shops, automatic clustering, neural networks training, environmental/economic power dispatch problem, reactive power dispatch, design of digital FIR filters, implementation of PID controller tuning, water distribution system optimization
50	Differential search algorithm	Civicioglu [52]	2012	The brownian-like random walk movement inspires it.	275	100	76	Optimal power flow problem, structure design, knapsack problem, optimal reactive-power dispatch, reliability optimization problem
51	Dolphin echolocation	Kaveh and Farhoudi [53]	2013	It is inspired by dolphin echolocation behavior.	195	113	92	Optimum design of steel frame structures, solving manufacturing cell design problems, optimum design of trusses, layout optimization
52	Dolphin partner optimization	Shiqin et al. [54]	2009	The communication characteristics of dolphins inspire it.	39	5	3	_

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
53	Dragonfly algorithm	Mirjalili [55]	2016	Mimics from dragonflies behavior such as foraging and avoiding dangers.	399	153	99	Wireless node localization, feature selection, economic dispatch, parameter optimization, clustering, distribution networks
54	Eagle strategy	Yang and Deb [56]	2010	It is a hybrid search algorithm that combines the firefly algorithm and levy flight.	165	23	28	Power loss minimization, optimum design of frame structures, parameters identification
55	Eco-inspired evolutionary algorithm	Parpinelli and Lopes [57]	2011	It inspires by the successions of ecology in environment relationships.	25	1	-	Protein structure prediction problem, hierarchical clustering strategy
56	Egyptian vulture optimization	Sur et al. [58]	2013	It is inspired by searching the food skills of Egyptian vultures.	29	8	3	Travelling Salesman Problem (TSP), road traffic management, manufacturing cell design problem, vehicle routing problem
57	Electro-magnetism optimization	Cuevas et al. [59]	2012	Electromagnetic problems inspire it.	84	5	4	PID controller, array pattern optimization, inventory control, circle detection, single machine scheduling problem, layout design
58	Elephant herding optimization	Wang et al. [60]	2015	The herding behavior of elephants inspires it.	110	55	34	Vehicle path planning, PID controller tuning, energy-based localization, power flow problem, WSN localization problem
59	Elephant search algorithm	Deb et al. [61]	2015	Imitates the elephant searching strategy in which male elephants do a global search, and female elephants do local searches.	28	15	13	Data clustering, TSP

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
60	Evolutionary programming	Fogel and Fogel [63]	2005	It is the foundation of modern evolutionary methods.	73	2752	1914	Economic load dispatch, power flow algorithm, traveling salesman problems, HVAC system optimization, distribution network reconfiguration, reactive power planning
61	Exchange market algorithm	Ghorbani and Babaei [64]	2014	Inspired by the mechanism of trade in the stock market	57	21	20	Combined Heat and Power Economic Dispatch (CHPED)
62	FIFA world Cup	Razmjooy et al. [65]	2016	The soccer world cup competitions inspire it.	29	968	772	Image segmentation, robust control of power system
63	Firefly algorithm	Yang [66]	2009	Fireflies flashing light behavior inspired it.	2521	2882	2110	Optimization of a multi-zone HVAC system, vehicle routing problems, image segmentation, scalable parallel clustering, optimum design of structures, set covering problems
64	Fireworks algorithm	Tan and Zhu [67]	2010	Inspired by the explosion of firecrackers	522	302	224	Power loss minimization, multilevel image thresholding problem, image registration, portfolio optimization problem, resource scheduling problem, RFID network planning problem, WSN coverage problem, big data optimization, parameter estimation of chaotic systems

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
65	Fish-school search	Li [68]	2008	Mutual collaboration in the group of fishes to surviving from dangers inspired It.	118	56	43	Data clustering, reactive power optimization, parameter tuning method of robust PID controller, optimal multiuser detection, image segmentation, UCAV path planning
66	Flower pollination algorithm	Yang [69]	2012	The pollination process of flowers inspires it.	899	569	439	Parameter estimation, economic load dispatch, sizing optimization of truss structures, feature selection
67	Flying elephants algorithm	Xavier and Xavier [70]	2016	This algorithm is a generalization of the hyperbolic smoothing approach.	5	_	_	_
68	Forest optimization algorithm	Ghaemi and Feizi Derakhshi [71]	2014	The seeding process of trees inspires it.	49	18	10	Feature selection, image segmentation
69	Fruit fly optimization algorithm	Pan [72]	2012	The fruit flies foraging behavior inspire it.	839	491	314	Power load forecasting model, knapsack problem, PID controller designing, traveling salesperson problem, flow-shop scheduling problem, task scheduling, and resource allocation
70	Galaxy-based search algorithm	Shah Hosseini [73]	2011	The spiral galaxies inspire it.	104	17	9	Image segmentation, economic and emission dispatch
71	Gases brownian motion optimization	Abdechiri et al. [73]	2013	Mimics from the gas molecules dynamic motion.	39	10	8	_
72	Gene expression programming	Ferreira [74]	2002	It is a comprehensive phenotype-genotype system.	442	1379	1005	Date assignment in a simulated job shop, extracting fuzzy classification rules
73	General relativity search algorithm	Beiranvand and Rokrok [74]	2015	The general relativity theory inspires it.	6	3	3	_

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
74	GA	Goldberg [75]	1989	The darwinian evolution theory inspires it.	2095	182985	111782	Job shop scheduling, traveling salesman problem, feature selection, design of water distribution networks, placement of wind turbines, flow shop scheduling problems, optimization of system reliability, resource allocation, power system damping controllers, pattern recognition, chemical laser modeling, traveling salesman problem, control system optimization, manufacturing systems design, optimization of antenna array patterns, vehicle routing, power distribution systems, etc.
75	Glowworm swarm optimization	Krishnanand and Ghose [78]	2009	The bioluminescence characteristic of glowworms inspires it.	362	345	182	Signal source localization, clustering analysis, optimal power flow, economic dispatch problem, knapsack problem, tsp problem, vehicle routing problem, multi-dimensional knapsack problem
76	Golden ball	Osaba et al. [79]	2014	Mimics from the soccer game	41	7	6	Capacitated vehicle routing problem, flow shop scheduling problem
77	Good lattice swarm algorithm	Su et al. [80]	2007	This algorithm inspires by number theory.	11	1	1	Constrained engineering design optimization

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
78	Grasshopper optimization algorithm	Saremi et al. [81]	2017	Mimics the grasshopper's swarm behavior.	226	109	65	Feature selection, financial stress prediction, automatic voltage regulator system, power loss minimization, data clustering, design of linear antenna arrays, robot path planning
79	Gravitational search algorithm	Webster and Bernhard [82]	2003	The gravitational force inspires it.	3259	1697	1356	Filter modeling, optimal power flow, economic and emission dispatch, optimal capacitor placement, unit commitment problem, reactive power dispatch, parameter adaptation, data clustering and classification, feature selection
80	Great deluge algorithm (and record-to-record travel)	Dueck [83]	1993	It has only one parameter. Initially, one set of values pick, then each step slightly adjusts the values and fitness is compared with the former one. If the new fitness value is better than the new set of values is treated as past values.	916	1	-	Vehicle routing problem, rough set attribute reduction, reliability optimization
81	Great salmon run	Mozaffari [84]	2012	Inspired by millions of salmon fishes return from the Pacific Ocean to the streams of North America.	37	7	9	Design of truss structures
82	Greedy politics optimization	Melvix [85]	2014	It simulates the politician's behavior to win elections.	-	1	1	Hierarchical clustering
83	Grenade explosion method	Ahrari and Atai [86]	2010	It inspires by grenades explosion.	109	20	18	Optimal power flow, dynamic cell formation problem

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
84	GWO	Mirjalili et al. [87]	2014	Mimics the hierarchical leadership and hunting behavior of grey wolves.	2083	714	482	Training multi-layer perceptions, economic dispatch, parameter estimation, flow shop scheduling problem, optimal power flow, vehicle path planning, image segmentation, feature selection
85	Group counseling optimization	Eita and Fahmy [88]	2010	It inspires by counseling problem-solving behavior.	12	4	4	–
86	Group search optimizer	He et al. [89]	2009	It inspires by animal searching food behavior.	566	191	148	Economic dispatch problem, truss structure design, neural network training, breast cancer diagnosis, optimal structural design, flow shop scheduling problem, power system dispatch
87	Harmony search	Geem et al. [90]	2001	The improvision process of jazz musicians inspires it.	4459	3109	2666	Water distribution networks, power economic dispatch, discrete structural optimization, optimal network reconfiguration, design of steel frames, optimal power flow problem, feature selection, time-cost trade-off, flow shop scheduling problem
88	Heart	Hatamlou [91]	2014	The heart and vascular system inspire it.	16	2	1	Knapsack problem
89	Hierarchical swarm model	Chen et al. [92]	2010	The algorithm proposed a hierarchical model for swarm-based metaheuristic algorithms.	26	1	1	Economic dispatch, data clustering
90	Honey-bees mating optimization algorithm	Abbass [93]	2001	Honey bee's mating behavior inspires it.	420	78	21	Euclidean traveling salesman problem, financial classification problems, vehicle routing problem, process planning problem, water distribution networks, feature selection problem, task assignment

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
91	Hoopoe heuristic optimization	El-Dosuky et al. [94]	2012	Mimicking hoopoes levy flight and searching food behavior.	4	1	1	Parameter optimization
92	Human-inspired algorithm	Zhang [95]	2009	It is simulating by mountaineers to explore the peak.	22	2	2	_
93	Hunting search	Oftadeh and Mahjoob [96]	2009	Animal hunting techniques inspire it.	153	38	25	Real-time seizure prediction, flow shop scheduling, design of PID fuzzy controller
94	Imperialist competitive algorithm	Atashpaz-Gargari and Lucas [97]	2007	Mimics the behavior of the imperialists in expanding their colonies.	1715	950	853	Design of skeletal structures, product mix-outsourcing problem, a robust PID controller, economic power dispatch, scheduling of the assembly flow shop problem, PID controller design, color segmentation, traveling salesman problems, capacitated hub covering location problem
95	Intelligent water drops algorithm	Shah-Hosseini [98]	2009	Imitates the rivers to find the best route between origin and destination.	341	115	47	Knapsack problem, job-shop scheduling, WSNs, feature selection, economic load dispatch, vehicle routing problem, cloud computing, road graph network, robot path planning problem, parallel machines scheduling, graph coloring
96	Interior design and decoration	Gandomi [99]	2014	It is an optimization algorithm inspired by buildings internal design and decoration.	161	18	11	Economic load dispatch, machine allocation, optimal power flow
97	Invasive tumor growth optimization algorithm	Tang et al. [100]	2015	An invasive Tumor growth mechanism inspires it.	7	2	2	Data clustering

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
98	Invasive weed optimization	Mehrabian and Lucas [101]	2006	This algorithm base on the growth of weed colonies.	952	574	391	Antenna configurations, unit commitment problem, traveling salesman problem, economic dispatch of power systems, flow shop scheduling problem, capacitated vehicle routing problem, parameter estimation
99	Ions motion algorithm	Javidy et al. [102]	2015	This algorithm imitates the movement of ions.	60	8	3	Short-term hydrothermal scheduling
100	Jaguar algorithm with learning behavior	Chen et al. [103]	2015	Based on the hunting behavior of jaguars.	6	1	1	_
101	Japanese tree frogs calling	Hernández and Blum [104]	2012	Mimics the Japanese tree frogs calling behavior.	33	5	7	Graph coloring
102	Kaizen programming	Melo [105]	2014	Mimics the kaizen approach in solving problems.	30	11	9	Classification, breast cancer detection
103	Keshtel algorithm	Hajiaghaei and Aminnayeri [106]	2014	Based on the food searching strategy of a bird called a keshtel.	41	4	3	Scheduling of production, rail transportation problem
104	Krill herd	Gandomi and Alavi [107]	2012	Emulates the krills behavior in herding and searching food.	887	297	308	Economic load dispatch, design of truss structures, optimal power flow, clustering, network route optimization, feature selection, hydrothermal scheduling problem, tuning of a PID controller, reactive power dispatch, flexible job-shop scheduling problem, breast cancer detection, the portfolio selection problem

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
105	League championship algorithm	Husseinzadeh Kashan [108]	2009	The sports league championship inspires this algorithm.	99	46	34	Optimal power flow, tasks scheduling technique, cloud computing, Resource Allocation Mechanism, cloud scheduling, production scheduling, job scheduling, flow-shop scheduling problem, clustering, manufacturing cell formation
106	Lightning search algorithm	Shareef et al. [109]	2015	Based on the natural lightning phenomenon.	101	50	43	Power systems, the learning process of feed forward neural networks, a fuzzy logic speed controller, Parameter extraction
107	Lion optimization algorithm	Yazdani and Jolai [110]	2016	Lions' cooperative and social behavior inspires this algorithm.	123	75	43	Community detection, task scheduling in cloud computing, WSN
108	Locust swarms	Chen [111]	2009	Imitates the locust swarms, the exploration agents begin with the least distance from the previous optimum.	42	96	57	Joint replenishment problem, intrusion detection systems
109	Magnetotactic bacteria optimization algorithm	Mo and Xu [112]	2013	That inspires by the behavior of magnotactic bacteria in the geomagnetic field.	16	12	8	Multimodal optimization
110	Migrating birds optimization	Duman et al. [113]	2011	Imitates the "V" arrangement of bird migration to minimize energy.	9	77	55	Quadratic assignment problem, fraud detection, closed-loop layout in flexible manufacturing systems, flow shop sequencing problem, machine-part cell formation problems, knapsack problem, flexible job shop scheduling problem, university course timetabling problem, low-carbon scheduling problem, multi-objective task allocation problem

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
111	Mine blast algorithm	Sadollah et al. [114]	2012	A mine blast inspires it.	118	35	34	Optimization of truss structures, optimal sizing of hybrid PV-wind-FC system, water distribution systems, economic load dispatch, ANFIS training
112	Monarch butterfly optimization	Wang et al. [115]	2015	Monarch butterflies' massive journey from North America to California and Mexico inspire it.	20	47	25	Solving 0–1 knapsack problem, neural network training, dynamic vehicle routing problem, localization in WSNs, TSP problem, RFID network planning, denoising brain images, patch antenna design, optimal power flow, facility layout design, optimal design of PID controller, classification, breast cancer diagnosis, resolve resource contention for multi-tier cloud service
113	Monkey Search	Mucherino and Seref [116]	2007	It inspires by the behavior of monkies in climbing trees for searching for the food.	180	29	17	Clustering analysis, traveling salesman problem, optimal sensor placement in structural health monitoring, WSNs, 0-1 knapsack problem, flow shop scheduling problem, transmission network expansion planning, allocation of capacitor banks in distribution systems, hybrid power systems optimization, multidimensional assignment problem
114	Moth-flame optimization algorithm	Mirjalili [117]	2015	Mimics by the behavior of moths in flying and traveling	531	87	58	Determine optimal machining parameters, parameters extraction for the multi-crystalline solar cell/module, power load forecasting, feature selection, tomato diseases detection, optical network unit placement, power system operation, web service composition in cloud computing
115	Multi-verse optimizer	Mirjalili et al. [118]	2015	It inspires by cosmology theories, namely blackhole, warm hole, and white hole	309	74	39	Intrusion detection systems, fuzzy-PID controller, image segmentation, power distribution networks

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
116	Optics inspired optimization	Kashan [119]	2015	The optical phenomenon inspires it.	59	10	8	Design of steel tower structures, optimal PID parameters tuning
117	Paddy field algorithm	Premaratne [120]	2009	It inspires by dispersing the seed.	48	8	6	RBF neural network parameters optimization
118	Parliamentary optimization algorithm	Borji [121]	2007	Group competitions in a parliament inspire it.	11	5	5	Community detection in social networks, web pages classification, automatic mining of numerical classification rules
119	PSO	Eberhart and Kennedy [122]	1995	The intelligent movements of bird swarms inspire it.	54331	61214	42557	Recurrent network design, flow shop sequencing problem, optimal power flow, environmental/economic power dispatch, capacitated vehicle routing problem, training feed forward neural networks, task assignment in distributed systems, loT-sizing problem, thermodynamic optimization, image clustering, structural design optimization
120	Pattern search	Hooke and Jeeves [123]	1961	An optimization technique proposed by Hooke and Jeeves and has two steps, namely pattern movement and exploratory search.	4847	2463	1721	Motor design optimization, mixed variable optimization, optimize the control system, Induction motor electromagnetic design optimization, economic dispatch problem, optimize the control sy stem
121	Penguins search optimization algorithm	Gheraibia and Moussaoui [124]	2013	The hunting behavior of penguins inspires it.	36	19	3	Traveling salesman problem, optimal operation of reservoir systems, vehicle routing problem, quadratic assignment problem, features selection

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
122	Photosynthetic learning algorithm	Murase and Wadano [125]	1998	Mimics the Benson Calvin cycle in photosynthesis process in plants.	1	-	2	Training of neural network, finite element inverse analysis, machine learning, TSP
123	Plant growth optimization	Cai et al. [126]	2008	The growth process of plants inspires it.	27	11	5	_
124	Plant propagation algorithm	Salhi and Fraga [127]	2011	Mimics plants runners' behavior to search for light and nutrients.	50	14	8	Constrained engineering optimization problems, traveling salesman problem, image segmentation, economic load dispatch problem
125	Partial optimization metaheuristic under special intensification conditions	Taillard and Voss [128]	2001	An optimization algorithm that partitioned a problem into subsections and locally optimized them.	109	7	5	Berth allocation problem, traveling salesman problem, large-scale vehicle routing problem, world location-routing problem
126	Queen-bee evolution	Jung [129]	2003	It imitates by the queen bees' role in a bee colony.	139	9	7	Economic power dispatch, tuning of scaling factors of fuzzy knowledge base controller, boost converter controller design, WSNs, task scheduling in grid computing, voltage regulation enhancement
127	Raven roosting optimization algorithm	Brabazon et al. [131]	2014	The social roosting habits of raven inspired it.	10	4	2	Task scheduling in cloud computing
128	Ray optimization	Kaveh and Khayatazad [130]	2012	The refraction of light rays inspires it.	254	33	28	Design of truss structures, optimal design of cantilever retaining walls
129	Reincarnation	Sharma [132]	2010	It mimics the rebirth of a human soul in a different body.	4	-	1	_

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
130	River formation dynamics	Rabanal et al. [133]	2007	The algorithm Inspires by the formation of rivers by water drops.	110	42	32	Dynamic TSP, mobile robot navigation, generating optimal paths in dynamic environments, sequence-dependent disassembly line balancing problem, steiner tree problem, WSNs, generating optimal paths in dynamic environments, CMOS analog circuit optimization, optimal placement of PMUs, analyze VLSI power grid networks, optimal data aggregation tree in WSNs, routing protocol for wireless mesh network
131	Roach infestation optimization	Timothy et al. [134]	2008	It is based on the individual and collective behavior of cockroaches to search for food.	82	10	5	Clustering, dynamic step-size adaptation
132	Root growth optimizer	He et al. [135]	2015	Mimics the self-similar distribution of plant roots.	2	1	2	_
133	Rooted tree optimization algorithm	Labbi et al. [136]	2016	The growth process of plant roots inspires it.	45	4	3	Economic dispatch
134	Runner-root Algorithm	Merrikh-Bayat [137]	2015	It simulates the purpose of runners and the roots of plants.	38	16	6	Multi-objective electric distribution network reconfiguration, feature selection
135	Saplings growing up algorithm	Karci and Alatas [138]	2006	Based on the growing up process of saplings	21	5	4	_
136	Scatter search	Glover et al. [139]	1977	This algorithm is based on systematic methods to produce new solutions.	1665	832	799	Vehicle routing problem, feature selection, nurse rostering problem, capacitated clustering problem, disassembly sequence problem, flow shop scheduling problem, graph coloring
137	Scientificalgorithms for the car renter salesman problem	Felipe et al. [140]	2014	Modeled the scientific research methodology	4	1	1	Car renter salesman problem

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
138	Seven-spot ladybird optimization	Wang et al. [141]	2013	Mimics the behavior of foraging in the seven-spot ladybird.	7	5	5	Feature selection
139	Shark smell optimization	Wang et al. [142]	2016	It inspires the smelling behavior of the shark in the ocean.	70	16	14	Short-term wind power prediction, planning of distribution networks, optimal placement of capacitors in the radial distribution system, optimal distribution of reactive power
140	Sheep flocks heredity model	Kim and Ahn [143]	2001	Sheep flocks' reproduction behavior inspires it.	8	6	2	Scheduling problem, job shop scheduling problems, scheduling of AGVs and machines in FMS, transportation problem, cell formation problem, spur gear design
141	Shuffled frog leaping algorithm	Eusuff and Lansey [144]	2003	The collaborative behavior of frogs inspires it in search of food.	1392	909	536	Water distribution network design, clustering, Unit commitment problem, assembly line sequencing problem, resource-constrained project scheduling problem, TSP, optimal tuning of multivariable PID controllers, flow-shop problem,0/1 knapsack problem, reservoir flood control operation, vehicle routing problem, set covering problem, fault diagnosis, Color image segmentation, Power control algorithm, training strategy for neural network, power system, tasks scheduling problem, parameter estimation, fuel management optimization, maintenance scheduling
142	Simplex heuristic	Pedroso [145]	2001	This algorithm is an extension of the Nelder and Mead simplex algorithm for non-linear problems.	2	4	2	Timetabling problem

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
143	SA	Kirkpatrick et al. [146]	1983	It imitates the heating and cooling process at metallurgy.	44469	33556	23264	Job shop scheduling, automated docking of substrates to proteins, vehicle routing problem, economic dispatch algorithm, clustering, transmission system expansion planning, water distribution network design, quadratic assignment problems, economic dispatch, complex portfolio selection problems, resource-constrained project scheduling problem, VLSI design, analog circuit design optimization, maintenance scheduling, dynamic layout problem etc.
144	Small-world optimization algorithm	Du et al. [147]	2006	It inspires the scientific experiments of the psychology of human communication.	52	22	12	Predictive controller, robot path planning, feature selection, neural network predictive control, job scheduling, clustering, image edge detection, economic load dispatch problem, wind power prediction, multi-dimensional knapsack problem
145	Soccer game optimization	Purnomo and Wee [148]	2012	The algorithm is based on an innovative combination of swarm intelligence and evolutionary algorithms by sharing information.	13	6	3	_
146	Social cognitive optimization	Xie et al. [149]	2002	Inspired by the social learning process in humans.	77	24	13	Reactive power optimization, power economic dispatch
147	Social-emotional optimization	Xu et al. [150]	2010	It inspires human beings' effort to achieve higher social status.	30	32	15	Chaotic systems, machine training and parameter settings for support vector machine, optimal coverage problem

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
148	Social spider algorithm	Cuevas et al. [151]	2013	It inspires the collaborative behavior of spiders in a colony.	248	42	33	Economic load dispatch problem, designing evolutionary feed forward neural networks, clustering, electromagnetic optimization, transmission expansion planning problem, base station switching problem for green cellular networks, task scheduling in cloud computing, flexible job-shop scheduling
149	Society and Civilization	Ray and Liew [152]	2003	It inspires social behavior in all human and insect societies.	358	48	23	–
150	Sperm motility algorithm	Raouf and Hezam [153]	2017	Inspired by the human reproduction system.	1	1	1	–
151	Sperm whale algorithm	Ebrahimi and Khamehchi [154]	2016	The sperm whale's lifestyle inspires it.	28	4	3	Power load forecasting
152	Spider monkey optimization	Bansal et al. [155]	2014	Mimics the social behavior of spider monkey to search for food.	172	79	51	Antenna optimization, optimal placement, and sizing of the capacitor, WSN, optimal design of pida controller, economic dispatch problem
153	Spiral dynamics inspired optimization	Tamura and Yasuda [156]	2011	The algorithm modeled the spiral patterns observed in nature.	65	5	3	Controller design, mixed-integer nonlinear programming problems, combined economic and emission dispatch, design of digital filters, modeling of flexible systems
154	Stochastic diffusion search	Bishop [157]	1989	Inspired by "the restaurant game," in which delegates in a new city search for the best restaurant to dine.	185	82	47	Resource allocation, euclidean steiner minimum tree

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Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
155	Stochastic fractal search	Salimi [158]	2015	Mimics the natural phenomenon of growth named fractal.	165	67	59	Design of PID controller, system reliability optimization, surface grinding process, meshed power networks, optimization of neural network parameters, environmentaleconomic dispatch,3D protein structure prediction
156	Strawberry algorithm	Merrikh-Bayat [159]	2014	The strawberry plant runner and the roots inspire it.	23	11	12	Multi-objective knapsack problem, demand side management in smart grid, energy management
157	Swallow swarm optimization algorithm	Neshat et al. [160]	2013	Imitates the Swallow swarms movement behavior.	38	8	6	Traveling salesman problem
158	Symbiotic organisms search	Cheng and Prayogo [161]	2014	It inspires the relationship of the species that depend on each other for survival.	442	221	145	Structural design optimization, optimal power flow of power system, congestion management, scheduling of tasks on cloud computing environment, economic dispatch problem, capacitated vehicle routing problem, traveling salesman problem, training feed forward neural networks, power loss minimization, truss optimization problem,0-1 knapsack problem
159	Tabu search	Glover [162]	1986	Enhancement of local search by essential rules modifications	4823	9809	9240	Vehicle routing problem, graph coloring, job-shop scheduling problem, timetabling and rostering, quadratic assignment problem, network synthesis, clustering, optimal power flow, location routing problem, berth-allocation problem, feature selection, balancing assembly lines, RAP, knapsack problem, traveling salesman problem, container loading problem, project scheduling problem, transportation problem, capacitated network design, machine sequencing problem

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
160	Teaching-learning based optimization	Rao et al. [163]	2011	The teaching-learning process inspires it.	1604	1133	812	Design of planar steel frames, sizing truss structures, data clustering, dynamic economic emission dispatch, optimal power flow, fuzzy-PID controller, flexible job-shop scheduling problem, parameters identification of solar cell models, quadratic assignment problem, simultaneous allocation of distributed resources
161	Termite colony optimization	Hedayatzadeh et al. [164]	2010	It is inspired by termites' intelligent behaviors to adjust their search paths.	44	10	8	WSN, retail market recommendations, optimizing retail inventory market, satellite image contrast enhancement
162	Viral systems	Cortés et al. [165]	2008	Viruses' characteristics, such as infection and replication, Inspire it.	39	1	_	Optimization of wind turbine placement, traveling salesman problem, optimize the car dispatching in elevator group control systems of tall buildings, optimize the daily drayage problem
163	Virus colony search	Li et al. [166]	2016	It is inspired by spreading and growth strategies used with viruses.	70	10	9	Optimal placement of distributed generators, unit commitment in smart grids with wind farms
164	Virus optimization algorithm	Juarez et al. [167]	2009	Virus growth, replication, and infection strategies modeled in this algorithm.	18	9	7	Flexible job-shop scheduling problem, multilevel image thresholding
165	Vortex search algorithm	Doğan and Tamer [168]	2015	Imitates the vertical flow shape of fluids.	108	26	19	Filter component selection problem, energy optimization, protein folding problem, economic load dispatch, analog filter group delay optimization
166	Wasp swarm optimization	Pinto et al. [169]	2005	The foraging behavior and wasps inspire it.	19	6	6	Clustering, feature selection, logistic systems
167	Water cycle algorithm	Eskandar et al. [170]	2012	This algorithm modeled the hydrological cycle of water.	415	138	118	Optimal operation of reservoir systems, optimal reactive power dispatch, optimization of truss structures, design of water distribution systems

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
168	Water evaporation optimization	Kaveh and Bakhshpoori [171]	2016	Water molecules' evaporation property inspires it.	63	8	7	Optimization of skeletal structures, economic dispatch, optimal power flow problems
169	Water wave optimization	Zheng [172]	2015	The water wave theory inspires it.	174	33	-	Flow shop scheduling problem, traveling salesman problem, economic dispatch problems
170	Water-flow algorithm	Tran and Ng [173]	2011	It bases on ablation due to the hydrological cycle.	19	15	15	Manufacturing cell formation problems, object grouping problems, text line segmentation, flexible flow shop scheduling, segmentation, and text parameters extraction
171	Whale optimization algorithm	Mirjalili and Lewis [174]	2016	This algorithm imitates the hunting habits of whales.	949	209	272	Feature selection, image segmentation, optimizing connection weights in neural networks, parameter estimation of photovoltaic cells, distribution network, optimization of skeletal structures, wind speed forecasting, flow shop scheduling problem, economic dispatch problem, mobile robot path planning
172	Wind-driven optimization	Bayraktar et al. [175]	2010	Mimics by wind generation by moving air from high-pressure regions.	78	48	82	Image segmentation, robust control of power system,0-1 knapsack problem, a cloud resource allocation, estimation of solar photovoltaic parameters, vehicle path planning, transformer design, robust optimizations of electromagnetic devices under interval uncertainty
173	Wolf search algorithm	Tang et al. [176]	2012	Mimics the hunting behavior of wolves.	123	9	16	Numeric association rule mining, feature selection, classification
174	Worm optimization	Arnaout et al. [177]	2014	Inspired by unique properties of Caenorhabditis Elegans	2	3	3	Traveling salesman problem, layout problem, energy management system
175	Zombie survival optimization	Nguyen and Bhanu [178]	2012	Mimics the questionable behavior of zombies.	1	1	1	_

Table 2. Continued.

Row	Algorithm	Authors	Year	Brief Description	Number of Citation in Google Scholar	Number of Papers in Scopus	Number of Papers in Web of Science	Scope of Application in Papers (Based on Google Scholar)
176	Keshtel algorithm	Hajiaghaei-Keshteli and Aminnayeri [182]	2014	Inspired by Keshtel's feeding	72	48	43	Solving the integrated scheduling of production and rail transportation problem
177	Keshtel algorithm	Hajiaghaei-Keshteli [183]	2013	Inspired by Keshtel's feeding	42	14	14	Vehicle routing problem
178	Red Deer Algorithm (RDA)	Fathollahi-Fard [184]	2020	A new optimization algorithm inspired by red deer mating is developed. The scottish red deer (cervus elaphus scoticus) is a sub-species of red deer, which lives in the british isles.	86	72	69	12 standard functions were considered. A number of realworld engineering problems including SMSP, TSP, FCTP and VRP were used. Furthermore, the multi-objective version of the RDA was considered and evaluated by a multi-objective NRP via four assessment metrics to analyze pareto optimal sets.
179	Tree Growth Algorithm (TGA)	Cheraghalipour Hajiaghaei-Keshteli [185]	2018	The proposed algorithm is inspired by trees competition for acquiring light and foods.	68	68	76	Single machine scheduling problems with earliness and tardiness costs without allowing standstill as NP-hard problem has been studied.
180	The Social Engineering Optimizer (SEO)	Fathollahi-Fard et al. [186]	2018	Social engineering optimization is defined as indirect attacks to obtain the people revealing their information by using certain techniques. Attackers want to reach their desired goals or objectives usually by advance technologies.	114	110	110	A single machine scheduling problem is considered. Single-machine scheduling or single-resource scheduling is the process of assigning a group of tasks to a single machine or resource.
181	Find-Fix-Finish-Exploit-Analyze (F3EA) meta-heuristic algorithm	Husseinzadeh Kashan and Tavakkoli-Moghaddam [187]	2019	The F3EA algorithm is classified into the population based algorithm which simulates battleground and mimics the F3EA targeting process of object or installations selection for destruction in the warfare.	18	14	19	-

Table 2 illustrates a list of the applications of metaheuristic algorithms to solve various problems. Metaheuristic algorithms have essential applications in solving complex problems in different domains, such as industrial engineering, mechanical & chemical engineering, control & electrical & power & telecommunication engineering, civil engineering, data & computer science, image processing, neural networks & fuzzy systems, mathematics, medical.

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Table 3. Classification of applications of metaheuristic algorithms for solving problems.

Industrial Engineering	Mechanical and Chemical Engineering	Control and Electrical and Power and Telecommunication Engineering		Civil Engineering	Data and Computer Science	Image Processing	Neural Networks and Fuzzy Systems	Mathematics	Medical	Other
Flow shop scheduling problems	Inventory control	Thermodynamic optimization	Design of PID controller	Design of steel structures	Clustering analysis	Image edge detection	Multi-layer perceptrons trainer	Traveling Salesman's Problem	Breast cancer diagnosis	Parameter selection strategy
Vehicle routing problem	Assembly sequence planning	HVAC system optimization	Power load forecasting	Design of skeletal structures	Association rules mining	Denoising brain images	ANFIS training	Knapsack problem	Protein folding problem	Portfolio optimization problem
Resource-constrained project scheduling	RAP	Energy consumption forecasting	AGC	Berth allocation problem	Feature selection	Image segmentation	Fuzzy system design	Graph coloring	Virus detection	University course timetabling problem
JIT sequencing problem	Manufacturing cell design problems	Wind turbine placement problem	Economic load dispatch problem	Container loading problem	JIT sequencing problem		Fraud detection	Quadratic approximation	NSP	
Flexible process planning	Reliability optimization	Chemical laser modeling	Optimal power flow	Structural damage detection	Task scheduling in grid computing		Extracting fuzzy classification rules	Coverage problem	Diagnosis of parkinson's disease	
Job scheduling problem	Intelligent logistics	Spur gear design	Economic emission load dispatch	Rail transportation problem	Software architecture recovery		rough set attribute reduction	Circle detection		
The flexible job-shop scheduling problem	Maintenance scheduling	Power transformer winding	VLSI design	Structural damage detection	Cloud computing					
RFID network planning	Robot path planning	Water distribution networks	Optimal reactive power dispatch problem	Damage detection of bridge structures						
Facility layout problem	Quadratic assignment problem	Distribution network configuration	Antenna design	Structural reliability analysis						
	Fault prediction		Power filter optimization	Road traffic management						
				Road graph network						

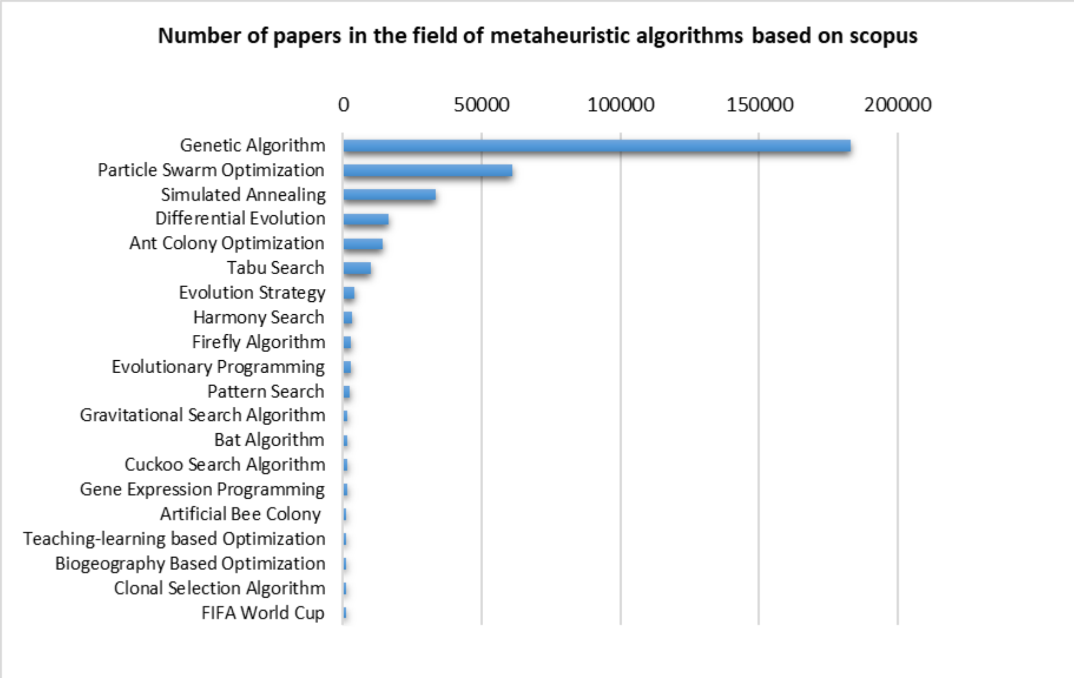

Fig. 4. Display the most number of papers in the subject of metaheuristic algorithms based on the scopus scientific database.

According to this database, GA algorithm with 182985 articles and 51.1% share in first place, PSO algorithm with 61214 papers and 17.1% in second place, and SA algorithm with 33556 in the third and the 9.4% of the articles, respectively, accounted for 77.5% of the total number of items in the field of metaheuristic algorithms.

Table 5. Number of papers in the subject of metaheuristic algorithms based on the scopus scientific database.

Rank	Algorithm	Number of Papers in Scopus	Percent of the Total
1	GA	182985	51.1
2	PSO	61214	17.1
3	SA	33556	9.4
4	DE	16399	4.6
5	ACO	14397	4.0
6	Tabu search	9809	2.7
7	Evolution strategy	4167	1.2
8	Harmony search	3109	0.9
9	Firefly algorithm	2882	0.8
10	Evolutionary programming	2752	0.8
11	Pattern search	2463	0.7
12	Gravitational search algorithm	1697	0.5
13	Bat algorithm	1628	0.5
14	Cuckoo search algorithm	1548	0.4
15	Gene expression programming	1379	0.4
16	ABC	1200	0.3
17	Teaching-learning based optimization	1133	0.3
18	Biogeography based optimization	1068	0.3
19	Clonal selection algorithm	1041	0.3
20	FIFA world cup	968	0.3

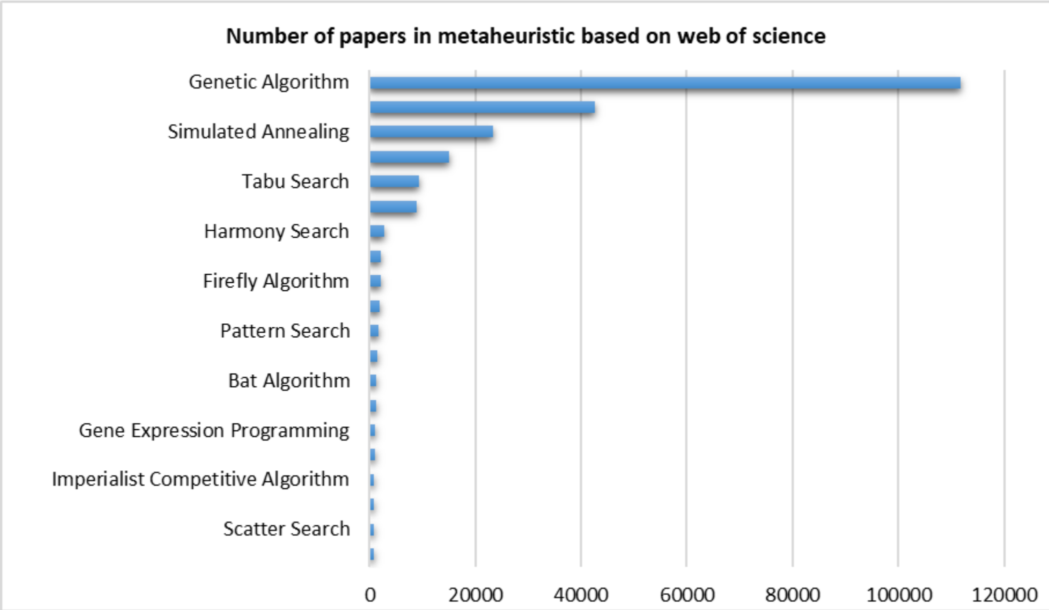

Fig. 5. Rank of metaheuristic algorithms based on number of papers (web of science).

Tabel 6 and *Fig. 6* represent the number of citations of metaheuristic algorithms based on google scholar. As shown, the PSO, SA, and DE algorithms are ranked first, second, and third, respectively, with 54331, 44469, and 19916 citations. These three algorithms together account for almost 60% of the total citations in the field of metaheuristic.

Table 6. Number of citations of metaheuristic algorithms based on google scalar.

Rank	Algorithm	Number of Citation in "Google Scholar"	Percent of the Total
1	PSO	54331	27.4
2	SA	44469	22.5
3	DE	19916	10.1
4	ACO	11276	5.7
5	Pattern search	4847	2.4
6	Tabu search	4823	2.4
7	Harmony search	4459	2.3
8	Cuckoo search algorithm	3743	1.9
9	Gravitational search algorithm	3259	1.6
10	Bacterial foraging algorithm	2813	1.4
11	Bat algorithm	2605	1.3
12	Firefly algorithm	2521	1.3
13	Biogeography based optimization	2229	1.1
14	GA	2095	1.1
15	GWO	2083	1.1
16	Imperialist competitive algorithm	1715	0.9
17	Scatter search	1665	0.8
18	Teaching-learning based optimization	1604	0.8
19	Shuffled frog leaping algorithm	1392	0.7
20	Clonal selection algorithm	1292	0.7

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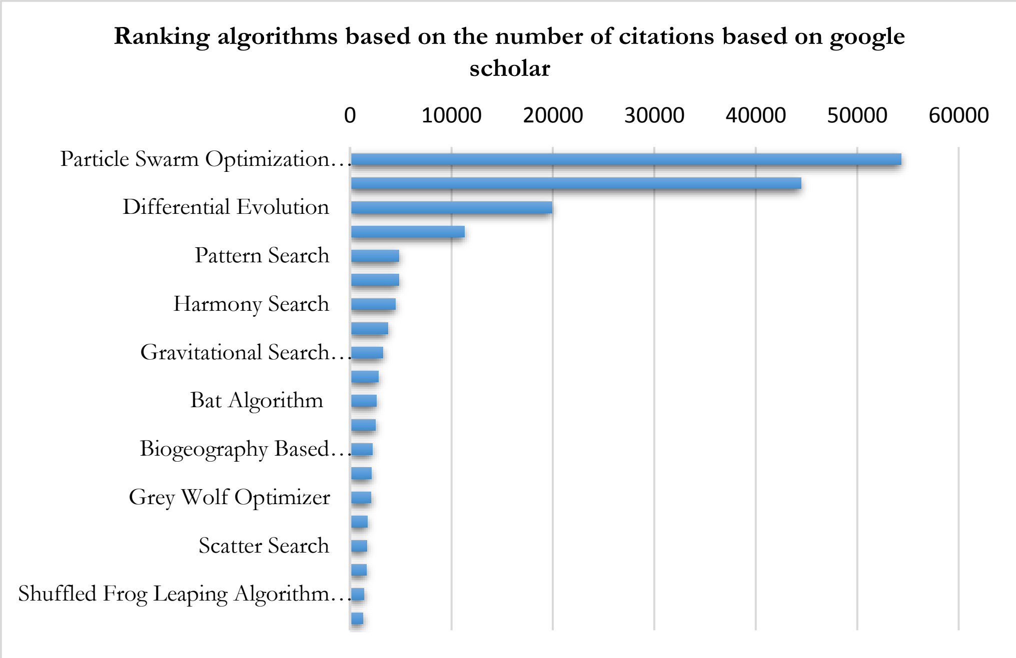

Fig. 6. Rank of metaheuristic algorithms citations (google scholar).

3 | A Review of the Classification of Nature-Inspired Metaheuristic Algorithms

Birattari et al. [179] divided the metaheuristic algorithms into four groups continuous and discrete, population-based and single-solution, memory and non-memory, one-neighbor, and several neighborhoods, a static and dynamic objective function, inspired by nature and without inspiration from nature.

Mirjalili and Lewis [174] categorized the metaheuristic algorithms in four categories of evolutionary algorithms, swarm-based algorithms, physics-based algorithms, human-based algorithms.

Dhiman and Kumar [180] classified metaheuristic algorithms into five groups of evolutionary algorithms, physics-based algorithms, swarm-based algorithms, biology-based algorithms, and nature-inspired algorithms.

Memari et al. [181] classified the metaheuristic algorithms into three categories of single solution algorithms, population-based algorithms, and hybrid algorithms.

Rajpurohit et al. [2] classified metaheuristic algorithms into three categories: evolutionary, logical search, and other nature-inspired algorithms.

4 | Presenting a Novel Classification for Metaheuristic Algorithms

This paper categorized metaheuristic algorithms according to the characteristics and source of inspiration for each of the algorithms described in *Table 7*.

Table 7. Proposed classification for metaheuristic algorithms.

Level 1	Level 2	Level 3	Inspiration	Paper
Living things	Animals	Mammals	Foraging/ Hunting	African buffalo optimization (2016) African wild dog algorithm (2013) Cat swarm optimization (2006) Egyptian vulture optimization (2013) GWO (2014) Wolf search algorithm (2012) Jaguar algorithm with learning behavior (2015) Monkey search (2007) whale optimization algorithm (2016)
Living things	Animals	Mammals	Social behavior	Elephant herding optimization (2015) Elephant search algorithm (2015) Sperm whale algorithm (2016) Lion optimization algorithm (2016)
Living things	Animals	Mammals	Change in group size	Spider monkey optimization (2014)
Living things	Animals	Mammals	Biosonar/ Echolocation	Bat algorithm (2010) Dolphin echolocation (2013)
Living things	Animals	Mammals	Reproduction	Sheep flocks heredity model (2001)
Living things	Animals	Mammals	Protect the territory	Blind, naked mole-rats algorithm (2013)
Living things	Animals	Mammals	Travel/Immigration	Animal migration optimization (2014) Camel algorithm (2016) Penguins search optimization (2013)
Living things	Animals	Birds	Foraging	Hoopoe heuristic optimization (2012) Keshtel algorithm (2014) Cuckoo search algorithm (2009)
Living things	Animals	Birds	Fly	Hoopoe heuristic optimization (2012) Swallow swarm optimization algorithm (2013)
Living things	Animals	Birds	Nesting	Raven roosting algorithm (2014)
Living things	Animals	Birds	Mating	Bird mating optimizer (2014)
Living things	Animals	Fishes	Smell	Shark smell optimization (2018)
Living things	Animals	Fishes	Migration	Great salmon run (2012)
Living things	Animals	Fishes	Escape from danger	Artificial fish school algorithm (2002) Fish-school search (2008)
Living things	Animals	Insects	Foraging	ABC algorithm (2007) Dragonfly algorithm (2016) Fruit fly optimization algorithm (2012) Seven-spot ladybird optimization (2013) Wasp swarm optimization (2005) Ant lion (2015)
Living things	Animals	Insects	Routing	Termite colony optimization (2010)
Living things	Animals	Insects	Mating	Honey-bees mating optimization algorithm (2001)
Living things	Animals	Insects	Migration	Locust swarms (2009) Monarch butterfly optimization (2015)
Living things	Animals	Insects	Escape from the danger	Roach infestation optimization (2008)
Living things	Animals	Crustaceans	Foraging	Krill herd (2012)

Table 7. Continued.

Level 1	Level 2	Level 3	Inspiration	Paper
Living things	Animals	Crustaceans	Social relations	Social spider algorithm (2013)
Living things	Animals	Worms	Nervous system	Worm optimization (2014)
Living things	Animals	Worms	light	Firefly algorithm (2009) GSO (2009)
Living things	Animals	Coelenterata	Reproduction	Coral reefs optimization algorithm (2014)
Living things	Animals	Mollusca	Color change	Cuttlefish algorithm (2013)
Living things	plants		Growth and reproduction	Invasive weed optimization (2006)
Living things	plants		Rooting	Flower pollination algorithm (2012) Paddy field algorithm (2009) Root growth optimizer (2015) Rooted tree optimization algorithm (2016) Runner-root algorithm (2015) Strawberry algorithm (2014)
Living things	plants		Photosynthesis	Artificial plant optimization algorithm (2012) Photosynthetic learning algorithm (1998)
Living things	Protist	Algae		Artificial algae algorithm (2015)
Living things	Bacteria		Reproduction	Bacterial colony optimization (2012) Bacterial swarming (2008)
Living things	Bacteria		Evolution	Bacterial evolutionary algorithm (2009)
Living things	Bacteria		Foraging	Bacterial foraging algorithm (2002)
Living things	Bacteria		Magnet	Magnetotactic bacteria optimization (2013)
Living things	Bacteria		Survive	Bacteria chemotaxis algorithm (2002)
Human interactions			Social behavior	Society and civilization (2003) Social emotional optimization (2010) Social cognitive optimization (2002) Anarchic society optimization (2012) Group counseling optimization (2010) Community of scientist optimization (2012) Consultant-guided search (2009) Small-world optimization algorithm (2006)
Human interactions			Education	Teaching-learning based optimization (2011) Brainstorm optimization (2015)

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Table 7. Continued.

Level 1	Level 2	Level 3	Inspiration	Paper
Human interactions			Politics	Greedy politics optimization (2014) Parliamentary optimization algorithm (2007) Imperialist competitive algorithm (2007)
Human interactions		Sport	Soccer	Fifa world cup (2016) Golden ball (2014) Soccer game optimization (2012)
Human interactions		Sport	Championship	League championship algorithm (2009)
Human interactions		Sport	Mountaineering	Human-inspired algorithm (2009)
Human interactions		Culture		Cultural algorithms (1994)
Natural phenomena	Atmospheric phenomena		Vortex	Vortex search algorithm (2015)
Natural phenomena	Atmospheric phenomena		Lightning	Lightning search algorithm (2015)
Natural phenomena	Atmospheric phenomena		Clouds	Atmosphere clouds model (2013)
Natural phenomena	Water flow		Flood	Great deluge algorithm (1993)
Natural phenomena	Water flow		Water drops	Intelligent water drops algorithm (2009)
Natural phenomena	Water flow		River	River formation dynamics (2007)
Natural phenomena	Water flow		Rotation	Water-flow algorithm (2011) Water cycle algorithm (2012)
Natural phenomena	Water flow		Evaporation	Water evaporation optimization (2016)
Natural phenomena	Water flow		Waves	Water wave optimization (2015)
Science	Natural sciences	Medical	Reproduction system	Sperm motility algorithm (2017)
Science	Natural sciences	Medical	Heart and circulatory system	Heart (2014)
Science	Natural sciences	Medical	Immune system	Clonal selection algorithm (2000) Invasive tumor growth optimization algorithm (2015)
Science	Natural sciences	Medical	Viruses	Viral systems (2008) Virus colony search (2016) Virus optimization algorithm (2016)
Science	Natural sciences	Medical	Inheritance	GA (1989)
Science	Natural sciences	Physics	Classical mechanics/ Gravitational force	Central force optimization (2007) Gravitational search algorithm (2003)

Table 7. Continued.

Level 1	Level 2	Level 3	Inspiration	Paper
Science	Natural sciences	Physics	Classical mechanics/ Energy	Wind driven optimization (2010) Gases brownian motion optimization (2013) Colliding bodies optimization (2014)
Science	Natural sciences	Physics	Thermodynamics	Crystal energy optimization algorithm (2016) Sa (1983)
Science	Natural sciences	Physics	Electromagnetism	Charged system search (2010) Electro-magnetism optimization (2012)
Science	Natural sciences	Physics	Quantum theory	General relativity search algorithm (2015)
Science	Natural sciences	Physics	Light	Optics inspired optimization (2015) Ray optimization (2012)
Science	Natural sciences	Chemistry		Artificial chemical reaction optimization algorithm (2011) ions motion algorithm (2015)
Science	Natural sciences	Mathematics and statistics	Dynamic planning	Popmusic: partial optimization metaheuristicunder special intensification conditions (2002)
Science	Natural sciences	Mathematics and statistics	Statistical dispersion	Covariance matrix adaptation-evolution strategy (2006)
Science	Natural sciences	Mathematics and statistics	Simplex	Simplex heuristic (2007)
Science	Natural sciences	Mathematics and statistics	Number theory	Good lattice swarm algorithm (2007)
Science	Natural sciences	Mathematics and statistics	Markov chain theory	Evolution strategy (1965)
Science	Natural sciences	Mathematics and statistics	Geometry/ Fractal	Stochastic fractal search (2015)
Science	Natural sciences	Mathematics and statistics	Geometry/ Spiral	Spiral dynamics inspired optimization (2011)
Science	Natural sciences	Astronomy	The galaxy	Galaxy-based search algorithm (2011)
Science	Natural sciences	Astronomy	Black holes	Multi-verse optimizer (2015)
Science	Non natural sciences	Philosophy and religion		Dialectic search (2009)
Science	Non natural sciences	Management		Kaizen programming (2014)
Science	Non natural sciences	Research methodology		Scientific algorithms for the car renter salesman problem (2014)
Science	Non natural sciences	Art	Architecture	Interior design and decoration (2014)
Science	Non natural sciences	Art	Music	Harmony search (2001)

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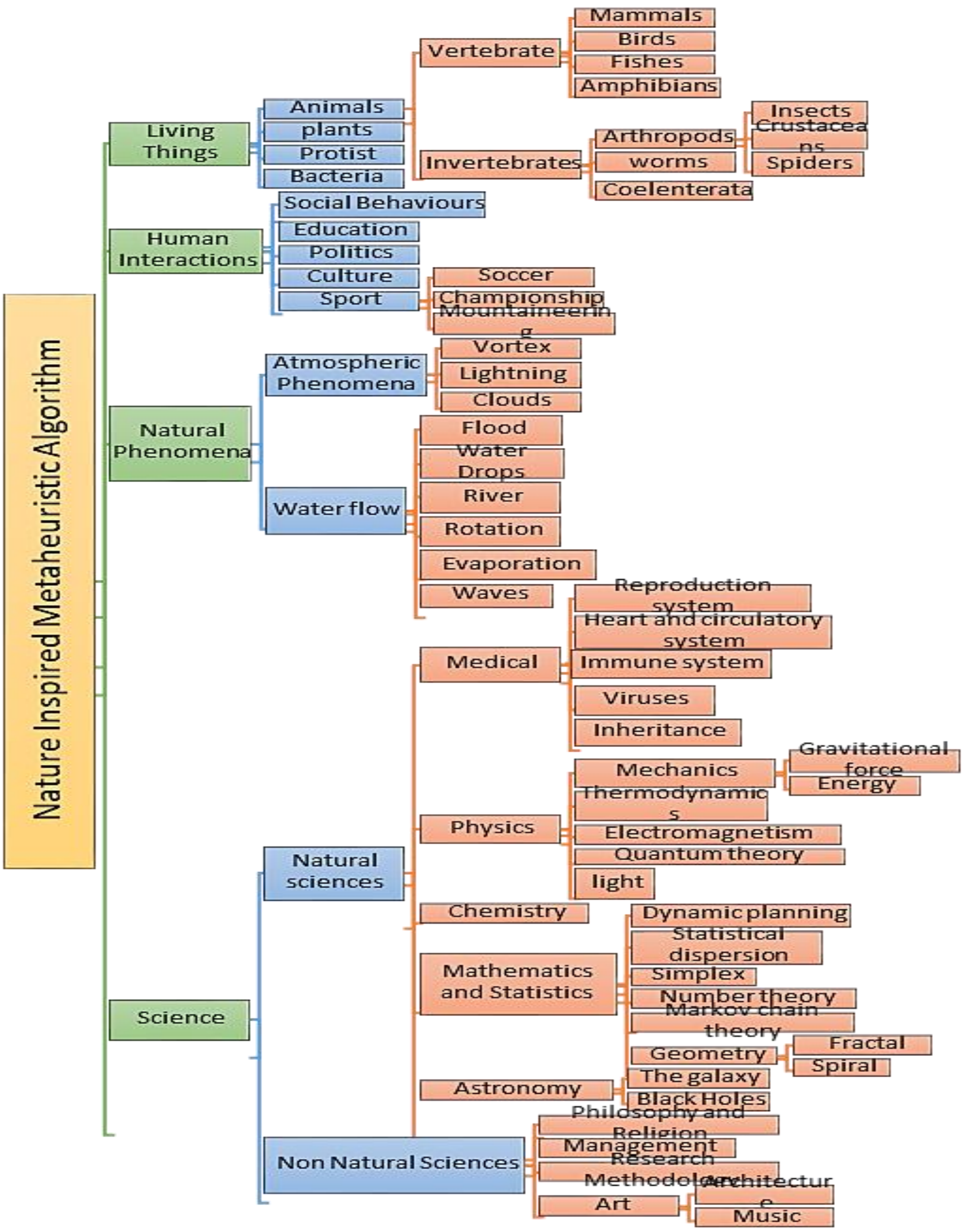

Fig. 7. Chart of metaheuristic algorithms classification.

Fig. 7 and *Fig. 8* illustrate the classification of metaheuristic algorithms in this paper, including living things, natural phenomena, human interactions, and science.

Living things involved animals, plants, protist, and bacteria. Animals divided into vertebrates and invertebrates. Vertebrate divide into mammals, birds, fishes, and amphibians. Invertebrates include arthropods, worms, and coelenterata. Arthropods divide into insects, crustaceans, and spiders. Human interactions include social behaviors, education, politics, culture, and sport.

Natural phenomena includes atmospheric phenomena and water flow. Atmospheric phenomena involved vortex, lightning, and clouds. Water flow inspired by flood, water drops, river, rotation, evaporation, and waves.

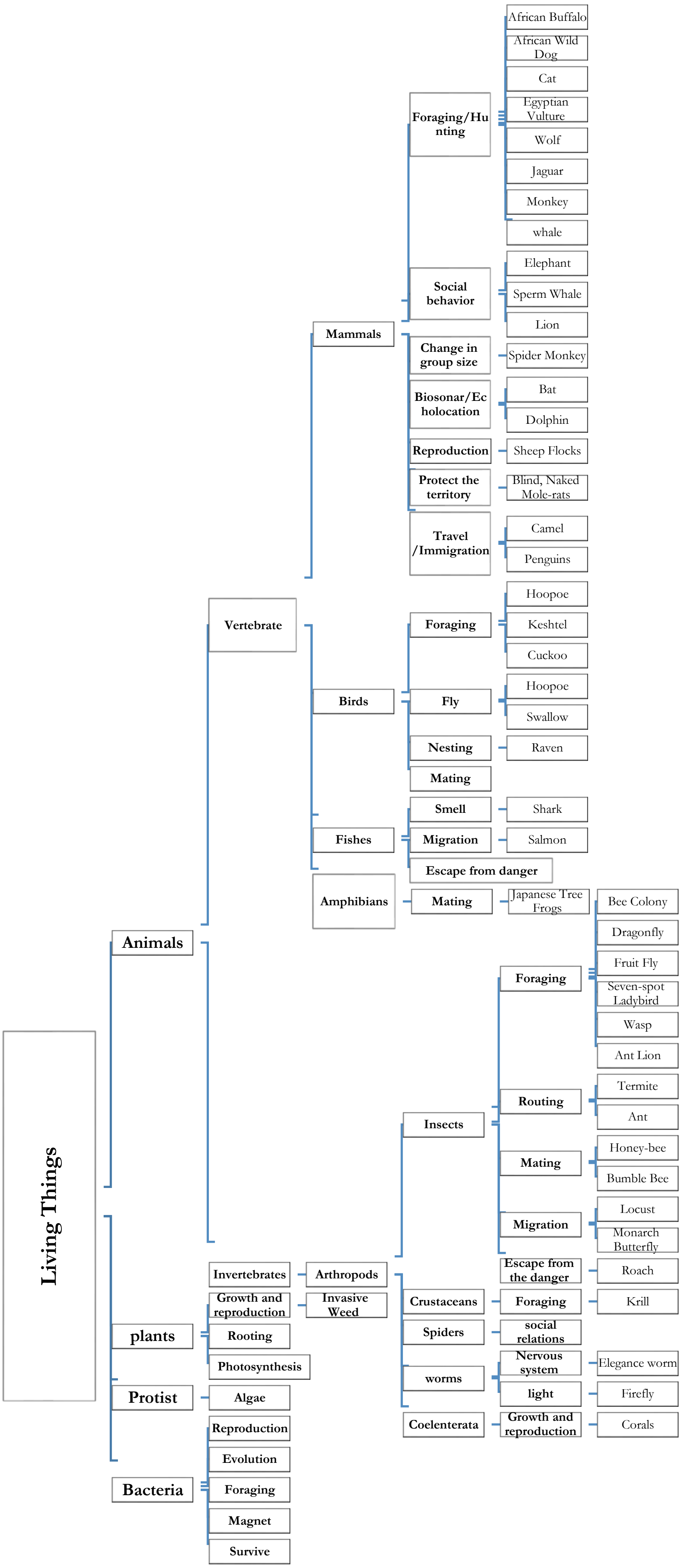

Fig. 8. Chart of metaheuristic algorithms classification (living things).

Science subset divided into natural sciences and non-natural sciences. Natural sciences involved medical, physics, chemistry, mathematics and statistics, and astronomy. Medical include reproduction system, heart and circulatory system, immune system, viruses, inheritance. Physics-based algorithms inspired by mechanics, thermodynamics, electromagnetism, quantum theory, and light. Mathematics and statistics include dynamic planning, statistical dispersion, simplex, number theory, markov chain theory, and geometry. Astronomy section inspired by the galaxy and black holes. Philosophy and religion, management, research methodology, and art fall into the category of non-natural sciences. Art, in turn, consists of architecture and music.

Fig. 8 and *Fig. 9* demonstrate the trends for presenting papers in the field of metaheuristic algorithms in the essential subcategories.

Table 8. The trends for presenting papers in the field of metaheuristic algorithms in the essential subcategories (source: web of science).

Echolocation	Reproduction	Fly	Mating	Migration	Routing	Plants	Bacteria	Water flow	Sport	politics
4	79	60	22	98	542	562	60	13	20	3
7	131	106	27	167	833	813	80	42	43	2
4	142	66	27	135	651	697	85	26	29	3
16	168	75	29	131	646	679	83	26	30	4
5	104	60	30	120	612	586	81	22	22	4
9	49	63	27	145	642	537	91	20	42	3
2	63	52	25	126	599	500	118	16	44	1
2	58	53	36	134	531	521	81	11	30	2
2	70	29	57	109	503	576	65	13	15	0
1	64	29	39	101	519	512	64	18	14	1
1	72	49	44	90	518	460	67	11	11	4
0	66	40	29	63	446	453	70	15	9	1
1	55	33	24	69	347	326	60	7	6	2
0	53	32	23	49	277	271	53	9	11	0
0	40	23	18	51	229	234	38	8	5	1
2	64	20	16	42	198	231	31	8	5	0
0	32	13	16	38	131	175	22	2	3	0
0	29	6	12	41	106	159	13	4	4	1
1	35	8	11	30	71	113	15	6	5	0
0	32	7	10	19	53	142	12	0	2	1
0	43	2	18	19	51	99	9	0	3	0
0	44	4	13	17	47	98	9	2	0	0
0	36	3	6	19	30	76	6	4	2	0
0	29	5	6	8	40	83	12	2	0	0
0	28	0	5	14	42	50	8	0	1	0
0	21	2	8	13	34	41	7	0	1	0
2	15	0	4	5	18	31	1	0	0	0
0	6	1	2	3	11	19	5	0	1	0
59	1628	841	584	1856	8727	9044	1246	285	358	33

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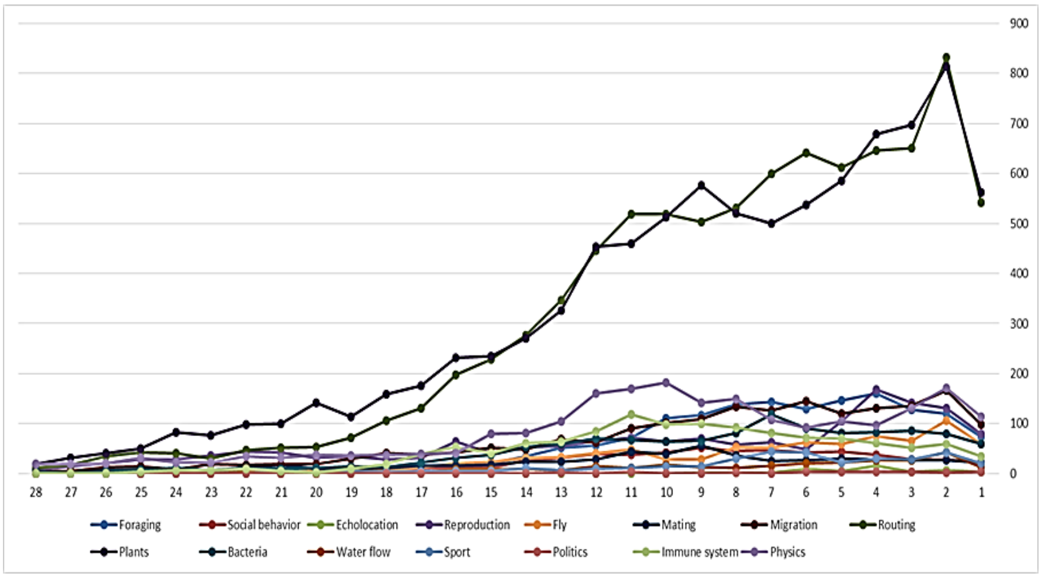

Fig. 9. The trend of metaheuristic algorithms by the source of inspiration.

Table 9 shows that many of the complex problems solved by metaheuristic algorithms inspired by plant growth, routing, and chemistry.

Table 9. The complex problems solved by metaheuristic algorithms based on features and inspiration source.

Rank	Source of Inspiration	Number of Paper
1	Plants	9044
2	Routing	8727
3	Chemistry	3605
4	Travel	2444
5	Physics	2273
6	Migration	1856
7	Reproduction	1628
8	Foraging	1550
9	Bacteria	1246
10	Immune system	1245
11	Fly	841
12	Mating	584
13	Social behavior	567
14	Sport	358
15	Water flow	285
16	Echolocation	59
17	Politics	33

Fig. 10 shows the number of metaheuristic algorithms sponsored by the world's leading scientific centers. Plant-inspired heuristic algorithms, routing, and chemistry are at the top.

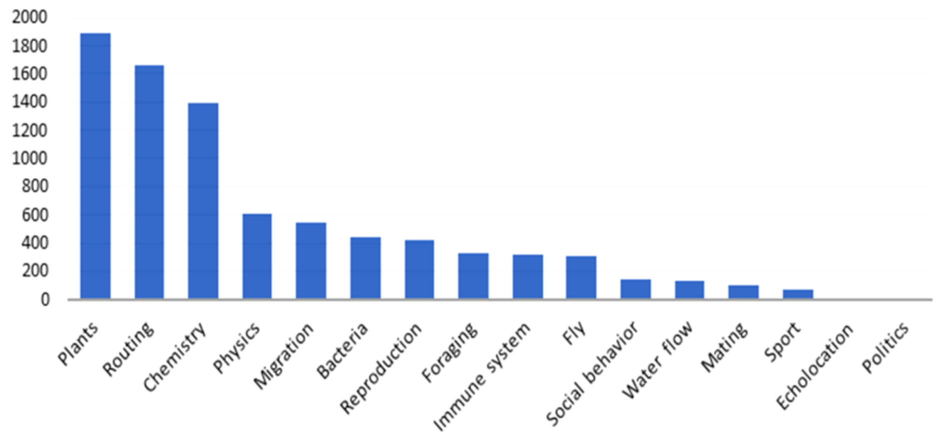

Fig. 4. Number of sponsored metaheuristic by the source of inspiration.

Table 10 shows the grants awarded in the field of metaheuristic algorithms by institutions and universities around the world in various fields of meta-heuristic algorithms.

Table 7. The most critical sponsoring science centers in the field of metaheuristic algorithms by the source of inspiration.

Source of Inspiration	Institutions	Number	Institutions	Number	Institutions
Plants	National natural science foundation of China	513	Fundamental research funds for the central universities	83	Conselho nacional de desenvolvimento científico e tecnológico
Routing	National natural science foundation of China	516	Fundamental research funds for the central universities	65	National science foundation
Chemistry	National natural science foundation of China	246	National institutes of health	100	National science foundation
Physics	National natural science foundation of China	113	National science foundation	55	U.S. department of energy
Migration	National natural science foundation of China	162	Fundamental research funds for the central universities	23	National science foundation
Plants	National natural science foundation of China	513	Fundamental research funds for the central universities	83	Conselho nacional de desenvolvimento científico e tecnológico
Routing	National natural science foundation of China	516	Fundamental research funds for the central universities	65	National science foundation
Chemistry	National natural science foundation of China	246	National institutes of health	100	National science foundation
Physics	National natural science foundation of China	113	National science foundation	55	U.S. department of energy
Migration	National natural science foundation of China	162	Fundamental research funds for the central universities	23	National science foundation
Bacteria	National natural science foundation of China	65	National science foundation	30	National institutes of health
Reproduction	National natural science foundation of China	87	National science foundation	16	National institutes of health
Foraging	National natural science foundation of China	81	National science foundation	9	Fundamental research funds for the central universities
Immune system	National natural science foundation of China	61	Engineering and physical sciences research council	8	Conselho nacional de desenvolvimento científico e tecnológico
Fly	National natural science foundation of China	61	Fundamental research funds for the central universities	11	National basic research program of China
Social behavior	National natural science foundation of China	21	Conselho nacional de desenvolvimento científico e tecnológico	5	Federación española de enfermedades raras
Water flow	National natural science foundation of China	22	National research foundation of Korea	4	Ministry of education
Mating	National natural science foundation of China	13	National science council	5	National science foundation
Sport	National natural science foundation of China	6	National science foundation	4	China postdoctoral science foundation
Echolocation	National natural science foundation of China	2	Distinguished middle-aged and young scientist encourage and reward foundation of shandong province	1	Eusko jaurlaritza
Politics	Bureau of energy, ministry of economic affairs, republic of Taiwan	1	Inoue foundation for science	1	Korea agency for infrastructure technology advancement

5 | Conclusion

Optimization has many applications for solving different problems. In recent decades, with the increasing complexity of problems, metaheuristic algorithms have been able to demonstrate their performance by providing near-optimal solutions within a reasonable time. Many metaheuristic algorithms inspired by nature. Nature is a source of inspiration, fascinating, and diverse to solve very complex problems. Nature has had the opportunity for billions of years to create, revise, and edit species to adapt to it, and has been able to provide a solution to each challenge.

In this article, we provide a comprehensive overview of the metaheuristic algorithms and categories. We then present a novel classification with emphasis on the source of inspiration and features of these algorithms. The presented classification includes four main categories of living things, human interactions, natural phenomena, and sciences. Each of these main sections divides into several subcategories. The category of living things includes animals, plants, protists, and bacteria. Features of metaheuristic algorithms include foraging/hunting, social behaviors, group size change, bio sonar/echolocation, reproduction, territory protection, immigration/travel, flying, nesting, mating, smell, hearing, escape from danger, illumination, nervous system, discoloration, rooting, pollination, photosynthesis. Metaheuristic algorithms inspired by natural phenomena include atmospheric phenomena such as vortex, lightning, and clouds, and water flows, including waves, flows, evaporation, floods, and rivers.

Science-inspired metaheuristic algorithms include the natural sciences and the non-natural sciences. The natural sciences include medicine, physics, chemistry, mathematics and statistics, and astronomy, and engineering sciences. Non-natural sciences include philosophy and religion, management, research, and the arts. A survey of world-renowned scientific sites such as google scholar, scopus, and web of science showed that attention to nature-inspired algorithms is growing. Many grants are awarding by universities and prestigious scientific centers for research in these fields. Because the environment and nature-inspired computing algorithms are so young, there is still room for growth in this community.

This paper categorizes and briefly introduces a range of different nature-inspired algorithms. For future work, it is suggested to combine this classification with the previous ones, to make a new classification and to complete the taxonomy of metaheuristic algorithms.

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