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Proposing a Model For a Resilient Supply Chain: A Meta-heuristic Algorithm

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The resilient supply chain considers many capabilities for companies to overcome financial crises and to supply and distribute products. In this study, we addressed the allocation of inventory distribution for a distribution network, including a factory, a number of potential locations for distribution centers and a number of retailers. Customers demand is assumed to be certain and deterministic for all periods but time varying in the limited planning horizon. The proposed model in this research is a linear complex integer programming model with two-objective functions. The first objective function minimizes the total costs of the entire distribution system in the planning horizon, and the second objective function seeks to minimize the difference between the maximum and minimum distances traveled by vehicles over the planning horizon. Therefore, the model tries to satisfy the demand and at the same time reduce costs using the best route transportation option configuration and transportation option. The routing problem is developed, and as the problem is a NP-hard problem, a meta-heuristic method is used to solve it. In this model, the demand volume for each customer in a period of the network, vehicle capacity, factory capacity, constant transportation cost, variable transportation cost, etc., are considered as factors affecting the model. The results show that the model proposed in the network can be used as a lever to improve the performance of the financial economic supply network through saving in routes.

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1. INTRODUCTION

The socio-political, economic and cultural parameters affecting the business environment in today's world face many turmoils and developments [1]. These turmoils increase the likelihood of the occurrence of effective events on supply chain performance. Therefore, if supply chain managers are incapable of well managing unforeseen disruptions, they will face dangerous negative consequences, and this will increase the risk of business continuity and result in financial losses [2]. Supply chain is a consecutive network of business partners involved in manufacturing processes and converting primary raw materials into final products or services to meet customer demand on due time with high quality and the least cost [3]. The occurrence of the events that interrupt the flow of materials, even if these events occur in a remote location, may lead to large-scale disturbances [4]. Disruptions are sudden and unexpected deteriorations caused by a variety of factors such as natural disasters, arson, loss of vital supplier, war, cyber attacks, economic recession, sanctions and economic shocks, terrorism, etc. [5]. Although the occurrence of these events is unlikely**,** they will have a lot of consequences for business if they occur [6]. Under such conditions, the need to design a resilient supply chain model becomes more evident because such a chain is ready to face any event; and in addition to providing an efficient and effective response, it is capable of returning to its original or more desirable state after disruption i.e., supply chain resilience. Melnyk et al. [7] believed that now, resilience is at the heart of current supply chain management thinking. Today, any one organization is incapable of establishing its existence without a resilient supply chain and effective

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communication because managing a company always requires having a dynamic supply and communication sector. Currently, goods supply from a secure supplier at the minimum cost and highest quality is the most important bridge between manufacturers and goods owners, exporters, importers, and consumers. This is while there are still challenges despite the importance of this issue. Offering a fair and affordable price and continuous follow-up of operations from loading to delivery are among these challenges in the network. In Inventory Routing Problem (IRP), the goal of optimization is to find the best strategy for product inventory management and determine the best vehicle configuration, routes, product types and their quantities to deliver to each customer, while minimizing the total cost of inventory and transportation [8]. As the problem of allocating and routing using a network is a hard problem, meta-heuristics are used to solve it. By proposing a mathematical model of inventory routing via a hypothetical network for the meat products industry in this study, we want to reduce the costs associated with the distribution, transportation, and storage of protein products. We use a small example to solve the problem using MATLAB software, and then develop the problem. As the routing problem is a hard-problem, meta-heuristics are used to solve it. The research structure is shown in Figure 1.

2. LITERATURE REVIEW

In this research, Internet network and scientific databases are the most important sources and data are obtained by searching among articles published in scientific journals because the present study is based on the scientific articles and previous works.

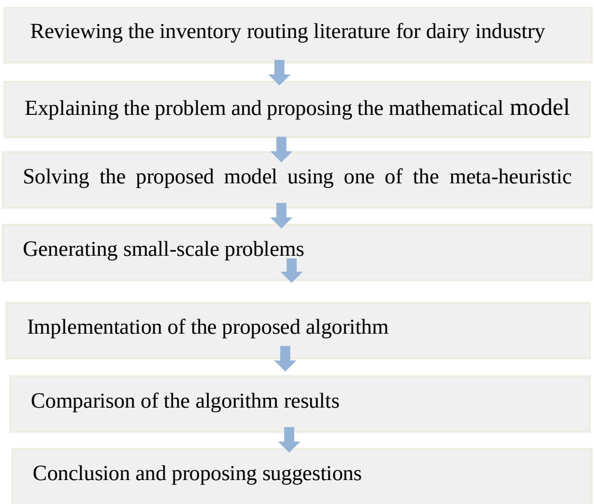

Figure 1. Research structure

2. 1. Transportation Definition

Any problem that seeks to generate a tour or a set of tours on a network or sub-network aiming to optimize one or multiple objectives is called a routing problem.

A routing problem includes the following components:

- Network

The network can be symmetric, asymmetric or hybrid. It can be displayed by a graph. The nodes in this graph represent cities, customers, or terminals, and the edges represent real connectors, such as roads, pipelines, etc.

- Demand

Demand can be constant or variable. It can be related to nodes and edges. The debate of demand is proposed in distribution problems in which a certain amount of goods must be transported and delivered to that node given the demand of the related node or edge. Moreover, these problems are observed in harvest and delivery problems.

- Fleet

Fleet creates constraints in the problem. Fleet can be homogeneous or heterogeneous. It can be generated by one or more vehicles, and can be affected by the vehicles capacity (limited or unlimited), time, or distance.

- Cost

Cost is often constant for vehicle and varies for the way of using it based on the passed distances and/or the travel time. It means that if a customer receives late or incomplete service, this type of service will result in a penalty. Moreover, here, it can propose the profit from the harvest when meeting the customer (node) or choosing the best edge for navigation.

- Objectives

Objectives can be multiple and different. The objective function can be calculated for one time interval or several time intervals. In this case, vehicles and appointments should be allocated to different intervals. Therefore, better results can be considered using multiobjective optimization [9].

2. 2. Resilience

Resilience defined as an organization's ability and capacity to face and overcome crises and challenges and to return to normal business conditions is a very important feature that organizations must be equipped with for the survival and continuity of their business [10]. However, the concern is not only restricted to disasters, but small deviations and uncertainties challenging the organizations are also considered [11]. In this regard, there are various businesses that are incapable of managing vulnerabilities such that they may be eliminated or taken in ownership by powerful organizations against business turmoils [12]. Therefore, all businesses' flexibility and adaptability have become an important necessity in today's rapidly changing environment, and the need to develop a strong attitude towards them is severely felt in all businesses [11]. Resilience literally means to spring back, being reversible, and resilient [13]. The term "resilience" has been defined in different forms: Masten [14] defined resilience as "a process, ability, or the outcome of successful adaptation in the face of threatening conditions". In fact, resilience is the positive adaptation in response to the adverse conditions [15]. Resilience is not the mere passive resistance against damages or threatening conditions, but the resilient person, is a participant who constructs his surrounding environment. Resilience is a person's ability to establish biological-psychological-spiritual balance when confronted with risky circumstances [11]. It is a kind of self-healing that is accompanied by positive emotional and cognitive consequences [16]. Thus, resilience cannot be regarded equivalent to recovery because in recovery, the person experiences negative consequences and emotional problems [10]. Resilience is a person's ability of successful adaptation in the face of a changing environment, stubbornness, invulnerability, and successful adaptation in the face of high levels of stress and adverse conditions [17]. Overall, resilience is a psychological concept explaining how individuals deal with unexpected situations. Resilience is defined as the resistance against stress, the ability to return to normal state and survive, and to make attempts in adverse circumstances [18].

The supply chain resilience is the adaptability of a supply chain for being ready for disruptions and responding to them, timely and cost-effective recursive recovery, and thus making progress toward post-disruptions situation, which in the ideal state is better than before the occurrence of disruption. It means that the supply chain resilience can be assessed based on four aspects: 1. The supply chain readiness to face a disruptive event; 2. Responding to that event; 3. Improvement and return; and 4. Growing and achieving a competitive advantage after the occurrence of the event. However, strategies and supply chain resilience capabilities should be directed toward ensuring that these aspects achieve their maxim possibility on due time by spending the least cost. In addition, adaptability is the basis of these four aspects. By adaptation we mean that the supply chain has a latent capability to develop different responses that are consistent with the nature of the threats that are faced by it. It means that the supply chain components are capable of changing themselves in such a way that at any time and on due time they can appropriately respond to disturbing events, rather than referring to an existing certain set of responses and selecting their responses among them whenever a disturbance occurs [19]. Tavakoli et al. develped a model for closed-loop supply chain network design with disruption risk by two factors including extra inventory and lateral transshipment are used as resilience strategies [20]. Table 1 summarized literature review for the comparative studies.

The transshipment option not only can be used to increase the economic supply network performance but also it can help the system to avoid risky routing when the cargos are categorized in decaying hazardous materials.

TABLE 1. Comparison of the recent articles

Solution	Limitations	Objective	Topic	Year	Authors
Meta-heuristic method	CO_2 emission, transportation costs, driving duration, rate of accidents, etc.	Reducing transportation costs and decreasing CO_2 emission	Carbon emission reduction in road freight transportation sector based on route optimization model	2020	Wei and Liu [21]
Serial and parallel structure	Traffic flow, balance of entry and exit and, etc.	The proper well- being and price of traffic flows and operating costs	Serial and parallel duopoly competition in multi-segment transportation routes	2020	Kuang et al. [22]
branch-and-cut algorithm	Availability, balanced flow, vehicle capacity, maintenance cost, clean vehicle, etc.,	Reducing logistics costs	Two-echelon inventory-routing problem with fleet management	2020	Schenekemberg et al. [23]
Heuristic mixed solution	Customer storage capacity, vehicle capacity, inventory maintenance, cost of customer loss, etc.	Integrated Optimization of decisions in a Supply Chain	Inventory routing under stochastic supply and demand	2020	Alvarez et al. [24]
Genetic algorithm	The amount of product shipped, the inventory of goods is equal to the demand for goods, the maximum number of selected routes is not more than the number of vehicles, etc.	Maximization of the total profit of the supply chain	Demand management to cope with routes disruptions in location-inventory-routing problem for perishable products	2020	Yavari et al. [25]
Gurobi programming algorithm	Satisfying the demand, the distribution capacity of the cold storage warehouse is less than its maximum inventory capacity; the time spent by the delivery routes is less than the time, maximum durability of their products etc.	Costs minimization	A mixed integer programming for two-echelon inventory routing problem of perishable products	2020	Wang et al. [26]

CPLEX	Place of loading and unloading, the amount of loading / unloading cannot be greater than the floating capacity and the capacity of the port, the amount of loading and unloading must be equal, etc.	Reducing sailing costs	Load-dependent speed optimization in marine inventory routing	2020	Eide et al. [27]
CPLEX	Service provision time, vehicle capacity, inventory capacity, etc.	Reducing routing problems	Mata-heuristic search techniques for the consistent inventory routing problem with time windows and split deliveries	2020	Ortega et al. [28]
Genetic algorithm	Perfect inventory flow balance, inventory flow balance of defective products, production launching, vehicle capacity, etc.	Reducing the inventory and transportation costs	A robust optimization approach for the production-inventory routing problem with simultaneous pickup and deliver	2020	Golsefidi and Jokar [29]
VaNSAS algorithm	The shopping center capacity, factory capacity, the rubber collection route from a farm, etc.	Minimizing the fuel consumption depending on the road distance and conditions	Variable neighborhood strategy adaptive search for solving green 2-echelon location routing problem	2020	Pitakaso et al.[30]
Firefly algorithm	Each node is visited at most once, vehicle capacity, integrity of variables, covering demand	Maximizing the prize and minimizing CO2 emission	The firefly algorithm for the environmental prize-collecting vehicle routing problem	2020	Trachanatzi et al. [31]
The ant colony optimization algorithm (ACO)	All equipment sent to a warehouse does not exceed their storage capacity, each route must start and end in the same warehouse, the working time of each vehicle cannot exceed the defined limit	Reducing the time it takes the relief aids to reach the damaged area and reducing the costs	A location-routing problem with post-disaster relief distribution	2020	Wang et al.[32]
hybrid genetic algorithm	Carrier expenses, vehicles capacity limitations, and/or long lead time.	Inventory routing problem for hazardous items with transshipment option	Proposing a model for a resilient supply chain: A meta-heuristic algorithm	-	Shafaghizadeh et al.

Despite the existence of a rather wide variety of studies on IRP problem for deteriorating items the transshipment option has been studied for hazardous items a little. The challenging research question in this context, therefore, is to identify the linkage between the deteriorating rate and the benefit brought by the transshipment policy in terms of economic gain.

3. MATHEMATICAL MODEL

Suppose a supply chain composed of a set of retailers ($\{1, 2, \ldots, N\}$) that provides the factory products to the public as a supplier of this type of product. For products such as protein products, the passage of time may lead to the loss of product health benefits and the irreversible health effects on consumers. Transportation vehicles must have particular equipment. There are predetermined routes between suppliers and retailers. To control and get access to the product more easily, a retransmission option has been embedded in the model to meet the demand directly from major suppliers or other retailers. The optimization problem is the ideal configuration of routes, pickups, deliveries, and transportation in each period in order to minimize the total cost of the supply chain (including ordering cost, inventory maintenance cost, constant and variable transportation costs, shortage cost, and pickup cost) and to minimize the perished products cost in distribution, while all retailers' demand is satisfied as much as possible. It should be noted that spoilage is allowed, but the demands must also be met in each period. In the proposed model, the "partial reorder shortage" is included in the model by introducing a parameter (β), which can be estimated on the basis of the customer time data in retail stores. When a retailer faces shortage, two possible states are identified in real situations.β % of individuals can wait until the next period(s) to receive the product. A period can be defined as the day, week, etc. Therefore the individuals' demand on the balance sheet is considered as saving. 1-β % of customers, who can not wait, either used the alternative products or left the retail store and referred to other centers.

3. 1. Problem Formulation

The two-objective mixed integer programming for the IRP re-shipment problem given the spoilage is formulated as follows:

Constraint (3) Models the equation of the retailer inventory and determines that the product inventory status in retail store i in the current period (t) equals $1 - \theta$ % of previous inventory level (I_{t-1}) plus the amount delivered in period t (transportation by vehicles) minus the amount collected by the vehicle in period t minus the current period demand and β % of the previous period shortage. It is supposed that only β % of the buyers, who face the product shortage, wait for the next period and the demand for the remaining $(1-\beta)$% is definitely removed. Moreover, it is supposed that the inventory reduces at a rate of θ and only $(1-\theta)$ % of the previous inventory remains for future use. Constraint (4) dictates that no supplier gets input. Constraints (5) and (6) ensure that each retailer must not be visited by a particular vehicle more than once per period. In these conditions, split distribution means that the retailer can be visited by different vehicles more than once in a period. If the split distribution is banned, then the constraint can be changed to$\sum_k Y_{ikt} \leq 1$. Constraint (7) is the inventory equation of the vehicle that visits the edge i, j in period t and ensures that the amount of the product transported by the vehicle from node i to node j in period t is equal to the amount of product sent to node i. In addition, the amount picked up by the vehicle from node i minus the amount delivered to this retailer in the current period. Constraint (8) guarantees that the vehicle capacity should not be exceeded and it means that only when x_{ijkt} variable gets a value the vehicle can visit the edge(i,j). Constraint (9) ensures that the vehicles cannot take the delivery of products from the retailer more than the amount of their inventory in the previous period. This constraint also guarantees that the inventory capacity of the retailer cannot be exceeded. Constraint (10) ensures that a journey must start at the center node (node 0) and end at the same point. Constraint (11) is the classic constraint of sub-tour removal. Constraint (12) prohibits product return and determines impossible edges, and finally, constraint (13) defines different types of variables. It should be noted that in constraints (3) and (9), the variable $I_{i(t-1)}$ is replaced with the initial inventory (I_0) in a particular case.

4. THE PROPOSED MODEL TO SOLVE THE PROBLEM

To solve this problem, we use the genetic algorithm-based method. In the following, this method is briefly explained. The reason why we use the genetic algorithm is that the decision variables include two binary matrices (X and$Y$) and three matrices consisting of integers (Q,Qd, and Qp); which are very consistent with the discrete nature of the genetic algorithm and do not lead to unacceptable solutions, and there is no need to add a stage to test the accuracy of the algorithm solutions.

$$\boldsymbol{min\, Z_1} = \sum_{i\in\omega,k,t} \boldsymbol{fc_k \cdot X_{0ikt}} + \sum_{(i,j)\in\Omega}\sum_{k,t} \boldsymbol{vc_k \cdot d_{ij} \cdot Q_{ijkt}} + \sum_{i\in\omega,t} \boldsymbol{h_i \cdot I_{it}} + \sum_{i\in\omega,t} \boldsymbol{\pi_i \cdot \beta_i \cdot S_{it}} + \sum_{i\in\omega,t} \boldsymbol{\pi_i^{'} \cdot (1-\beta_i). S_{it}} + \sum_{i\in\omega,k,t} \boldsymbol{pc_i \cdot Qp_{ikt}} \quad (1)$$

$$MinZ_2 = \underset{t}{Max} \sum_{i,j\in\Omega,k}\left(c.\, Q_{ijkt} + f_k\right) \times X_{ijkt} \quad (2)$$

$$I_{it} - S_{it} = (1-\theta) \times I_{i(t-1)} - \beta \times S_{i(t-1)} + \sum_k Qd_{ikt} - \sum_k Qp_{ikt} - D_{it} \quad \forall i \in \omega, t \quad (3)$$

$$Qd_{ikt} = 0 \quad \forall i \in O \quad (4)$$

$$\sum_{j\in\Omega} \boldsymbol{X_{jikt}} = \sum_{j\in\Omega} \boldsymbol{X_{ijkt}} = \boldsymbol{Y_{ikt}} \quad \forall \boldsymbol{i} \in \boldsymbol{\Omega}, \boldsymbol{k}, \boldsymbol{t} \quad (5)$$

$$Y_{ikt} \leq 1 \quad \forall i \in \omega, t, k \quad (6)$$

$$\sum_{j\in\Omega} Q_{jikt} - Qd_{ikt} + Qp_{ikt} = \sum_{j\in\Omega} Q_{ijkt} \quad \forall i \in \omega, k, t \quad (7)$$

$$Q_{ijkt} \leq cv_k . x_{ijkt} \quad \forall i \in \Omega, k, t \quad (8)$$

$$\sum_k \boldsymbol{Qp_{ikt}} \leq (\boldsymbol{1-\theta})\boldsymbol{I_{i(t-1)}} \leq (\boldsymbol{1-\theta})\mathrm{Ic}_{\boldsymbol{i}} \quad \forall \boldsymbol{i} \in \boldsymbol{\omega}, \boldsymbol{t} \quad (9)$$

4. 1.Genetic Algorithm Genetic algorithm (GA) is a meta-heuristic method in computer science to find approximate solutions for optimization and search problems. GA is a special type of evolutionary algorithms that use biological concepts such as inheritance and mutation. This algorithm was introduced by John Holland for the first time. In GAs, first, multiple solutions are generated for problem randomly or intelligently. This set of solutions is called the first population and each solution is called a chromosome. Then using the GA operators, we combine chromosomes after selecting the best chromosomes and create a mutation in them. Finally, we combine the current population with the new population obtained from the combination and mutation of chromosomes. Figure 2 displays the GA flowchart.

4. 1. 1. Generating The Problem Solutions As Chromosomes To solve this problem, all the

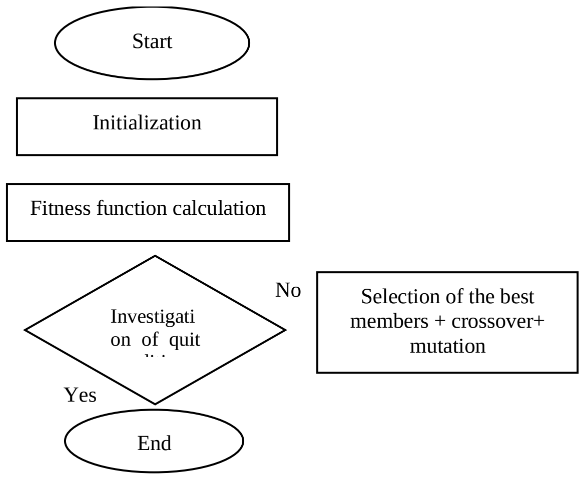

Figure 2. GA flowchart

problem decision variables need to be turned into chromosomes and move towards the optimal answer during the algorithm run. Two variable I_{it} and S_{it} are calculated using other variables. X_{ijkt}, Y_{ikt}, Q_{ijkt}, Qd_{ikt}, Qp_{ikt}, and XQ_{ijkt} are variables to be determined and are considered components within the chromosome. X is a binary four-dimensional matrix, Y is a binary three-dimensional matrix, Q is a four-dimensional matrix of positive integers, Qd is a three-dimensional matrix of positive integers, and Qp is a three-dimensional matrix of positive integers. At each stage of the GA, these variables are updated by operators and the result of changing them is reflected in the objective function.

An example of the first dimension of X variable in the GA chromosome of the proposed method is shown in Figure 3.

4. 1. 2. Introduction of Fitness Function Equation (3) is the first fitness function of the proposed model whose aim is to minimize the total cost of the supply chain, including the constant and variable transportation cost, inventory maintenance cost, shortage cost, and transportation costs. The second objective function is the Equation (2)-(3) that seeks to minimize the maximum path traveled by each product during distribution among all periods. The final fitness function is considered to be a combination of two objective functions to solve this problem: The final fitness function to solve this problem is considered to be combined of two objective functions:

$$F = \alpha Z_1 + \beta Z_2 \tag{14}$$

where the two sub-functions existing in this function are obtained from relations (1) and (2) and α and β are two parameters in this relation showing the importance of each objective function. The nature of the problem requires the minimization of this function value.

4. 1. 3. Initialization To start the algorithm, we randomly initialize these chromosomes' genes and generate a population with n chromosomes. Each chromosome is regarded as a solution to the problem. We can calculate the value of the objective function using chromosomes. Here, the important issue is to preserve the constraints of the problem by chromosomes. In the following, we will discuss this issue.

4. 1. 4. Using Selection Operators In the next step, the chromosome selection is discussed. Considering the theories in the genetic area, to create the next generation from the current population, we should select some chromosomes from this population for integration and replication that have higher optimality (each chromosome optimality is calculated using the fitness function). The better the chromosome, the greater its chance of being selected. The important point is that we should select a number of chromosomes from the current population and create the next generation accordingly. The most important point in this process is the way in which the chromosome is selected. There are different methods to select chromosomes, and each of which has its own advantages and disadvantages. These methods are as follows:

1. Elitist selection
2. Roulette selection
3. Scaling selection
4. Tournament selection

4. 1. 5. Using Reproduction Operators combine the genetic information of two parents and generate their offspring. Crossover can be used to stochastically generate offspring from an existing population by combining the information of parents like what happens in sexual reproduction. The resulting offspring usually undergoes a mutation (stochastic change in the genes of offspring's chromosome) after the crossover operator to achieve the final result. Different genetic-based algorithms use various data structures to store genetic information, and using different types of crossover operators, new combinations can be created in each of these genetic representations.

Usually the crossover operator is used on bit array data structures, vectors of real numbers, and trees. There are different types of crossover as follows:

1. Single point crossover
2. K points cross over
3. Flat crossover
4. Crossover for ordered lists

4. 1. 6. Observing the Problem's Constraints Two techniques are used to observe the problem's constraints. The first technique is observing the constraints implicitly using the algorithm design method. Calculation of I_{it} and S_{it} after initialization or updating chromosomes leads to the implicit observation of the constraint (3). After each genetic operator is executed, the dimension of X matrix becomes symmetric in terms of the two first dimensions, and Y also becomes updated accordingly to observe the constraint (5).Y is binary and this leads to the observation of constraint (6). By calculating the amount of matrix Qp from relation (7),

N	N-1	N-2	......	10	9		8	7	6	5	4	3	2	1
0	1	1	......	0	1		1	0	1	0	0	0	1	0

Figure 3. An example of the first dimension of X variable in the GA chromosome of the proposed method

this constraint can also be observed. In the first dimension of Y, if the first gene is zero, the other genes are also considered to be zero to meet the constraint (10). We substitute the main diagonal of the first and second dimensions of X and the first gene of the second dimension of Q with zero. Therefore, the constraint (12) is also true. Due to the way in which the chromosomes are defined, constraint (13) is also always true. If constraints (8), (9), and (11) are not observed by a chromosome, then we consider the fitness value to be infinite to gradually get distance from solutions and create solutions by observing all constraints.
The proposed model flowchart is illustrated in Figure 4.

5. NUMERICAL REPRESENTATION

In this part, we present a small example for optimal solution. Suppose that a supply chain is composed of 5 retailers. The travel distances are given in Table 2**.** The routes' matrix is an asymmetric directed graph. It means that the roads can be one-way. The deterioration and reorder ratios are supposed to be 0.05 and 0.2, respectively. Table 3 shows the unit maintenance cost, unit repayment and ***lost*** sales ***cost*** (LSC) (in terms of the monetary unit per period per product), initial inventory (product unit) and predicted demand (product unit) for each retailer within five periods. The constant and variable costs (in terms of the monetary unit per product per Km), capacity (product unit), and the value of each vehicle (monetary unit) are shown in Table 4. Due to practical reasons, the delivery lots (Qd) and vehicle (Qp) are assumed to be multiplayers of 50 and 5, respectively. The unit pickup cost for all vehicles is set at 0.1 (monetary unit). The price of each unit of product is equal to 1000 (monetary unit). Additionally, it is assumed that the orders can be ordered at most until the last period. The proposed model and formulation should be applied based on these data.

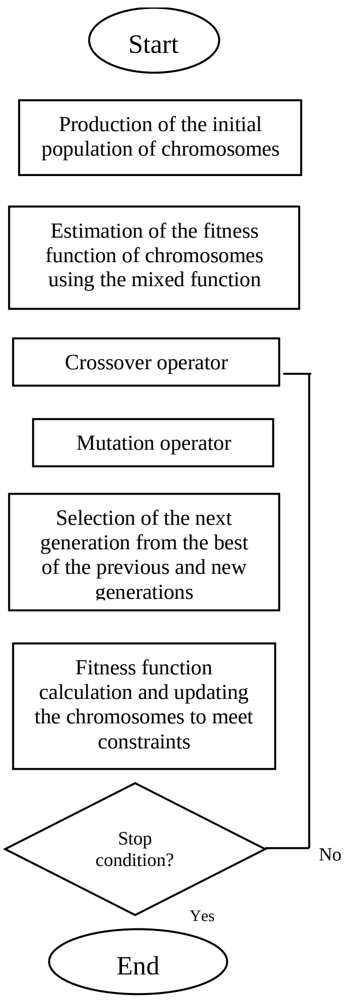

Figure 4. The proposed model flowchart

TABLE 2. Distances between nodes d_{ij} (Km)

node	0	S1	S1	S1	S1	S1
0	-	31	-	73	21	31
S1	31	-	-	-	13	62
S2	78	-	-	-	90	-
S3	73	-	-	-	62	96
S4	21	13	90	62	-	-
S5	31	62	-	96	-	-

TABLE 3. Retailers' data

#	IC_i	I_0	Demand in time period t					π_i'	π_i	h_i
			1	2	3	4	5			
1	300	0	0	470	310	100	0	200	20	22
2	500	0	500	0	120	480	120	100	10	12
3	300	0	0	150	320	0	390	400	40	25
4	500	0	210	0	230	0	115	200	20	30
5	300	0	330	120	0	180	0	100	10	15

TABLE 4. Retailers' data

Vehicle	f_k	fc_k	vc_k	cv_k
1	50000	400	0.1	120
2	70000	600	0.08	210
3	90000	700	0.06	270
4	100000	800	0.04	380
5	150000	900	0.02	530

As the proposed model is a multi-objective IRP and the calculation time to determine the solution severely depends on the dimensions of the problem, we develop the proposed algorithm using a compromise programming (lp-metrics) algorithm that enables the proposed GA to generate Pareto solutions. In GA, the fitness function is a criterion to assess the quality of solutions (chromosomes). As the proposed model is a two-objective programming, we have two unaligned fitness functions. As explained before, we merge both objectives to create a single fitness function called lp-metrics. This fitness function is the weighted sum of the normalized deviation of each objective function from its optimum value. The optimum values are separately obtained by running GA and the fitness function is set on its corresponding objective function.

The proposed model and formulation are solved under the MATLAB programming language using CPLEX and the proposed algorithm. By considering only three periods and solving the provided example twice for objective functions, the optimum values are obtained for each of them and allow you to build the lp-metric model:

$$l_p - metrics = w \times \left|\frac{z_1-14509}{326070-14509}\right| + (1-w) \times \left|\frac{z_2-6696}{28551-6696}\right| \qquad (15)$$

Here (1-w) means that how much the decision maker is concerned over the second objective function in comparison to total costs. After that, we solve the lp-metric problem under w=0.8 (as a clear example) and show the results in Tables 5, 6 and 7 report the details of the optimal solution of the problem for w=1 and w=0.8.

For w=0.8, the economic performance of the system forms 80% of the priority of the decision makers and the route reduction accounts for 20%. Under this value of w, according to Table 5, the values for Z1 and Z2 are equal to 29612 and 8406, respectively. By changing the relative weight (w), different solutions can be obtained.

TABLE 5. Result of the example problem

Min lp-metric (w= 0.8)	Min Z_2 (w= 0)	Min Z_1 (w= 1)	
29612	325690	14509	**Z_1**
84.6	6451	2891	**Z_2**

TABLE 6. The best solution for w=1

Period 1		**Period 2**		**Period 3**	
$X_{(i,j,k,t)}$	**Value**	$X_{(i,j,k,t)}$	**Value**	$X_{(i,j,k,t)}$	**Value**
X(0, 4, 2, 1)	1	X(0, 4, 2, 2)	1	X(0, 4, 2, 3)	1
X(4, 2, 2, 1)	1	X(4, 2, 2, 2)	1	X(4, 2, 2, 3)	1
X(2, 0, 2, 1)	1	X(2, 0, 2, 2)	1	X(2, 0, 2, 3)	1
X(0, 4, 4, 1)	1	X(0, 4, 3, 2)	1	X(0, 1, 4, 3)	1
X(4, 0, 4, 1)	1	X(4, 3, 3, 2)	1	X(1, 4, 4, 3)	1
X(0, 1, 5, 1)	1	X(3, 5, 3, 2)	1	X(4, 0, 4, 3)	1
X(1, 5, 5, 1)	1	X(5, 0, 3, 2)	1	X(0, 1, 5, 3)	1
X(5, 0, 5, 1)	1	X(0, 1, 5, 2)	1	X(1, 4, 5, 3)	1
-	-	X(1, 0, 5, 2)	1	X(4, 3, 5, 3)	1
-	-	-	-	X(3, 5, 5, 3)	1
-	-	-	-	X(5, 0, 5, 3)	1
-	-	-	-	-	-
$Qd_{(i,,k,t)}$	**Value**	$Qd_{(i,,k,t)}$	**Value**	$Qd_{(i,,k,t)}$	**Value**
Qd(2, 2, 1)	200	Qd(2, 2, 2)	200	Qd(4, 2, 3)	50
Qd(4, 4, 1)	350	Qd(3, 3, 2)	150	Qd(2, 2, 3)	150
Qd(5, 5, 1)	400	Qd(5, 3, 2)	50	Qd(1, 4, 3)	300
-	-	Qd(1, 5, 2)	500	Qd(4, 4, 3)	50
-	-	-	-	Qd(4, 5, 3)	150
-	-	-	-	Qd(3, 5, 3)	350
$Qp_{(i,,k,t)}$		$Qp_{(i,,k,t)}$		$Qp_{(i,,k,t)}$	
Qp(4, 5, 1)	140	-	-	Qp(1, 5, 1)	15

TABLE 7. The best solution for w=0.8

Period 1		**Period 2**		**Period 3**	
$X_{(i,j,k,t)}$	**Value**	$X_{(i,j,k,t)}$	**Value**	$X_{(i,j,k,t)}$	**Value**
X(0, 4, 3, 1)	1	X(0, 1, 4, 2)	1	X(0, 4, 3, 3)	1
X(4, 1, 3, 1)	1	X(1, 5, 4, 2)	1	X(4, 0, 3, 3)	1
X(0, 5, 4, 1)	1	X(5, 0, 4, 2)	1	X(0, 1, 4, 3)	1
X(5, 0, 4, 1)	1	X(0, 1, 5, 2)	1	X(1, 4, 4, 3)	1
X(0, 4, 5, 1)	1	X(1, 4, 5, 2)	1	X(4, 2, 4, 3)	1
X(4, 2, 5, 1)	1	X(4, 3, 5, 2)	1	X(2, 0, 4, 3)	1
X(2, 0, 5, 1)	1	X(3, 0, 5, 2)	1	X(0, 3, 5, 3)	1
-	-	-	-	X(3, 5, 5, 3)	1
-	-	-	-	X(5, 1, 5, 3)	1
-	-	-	-	X(1, 4, 5, 3)	1
-	-	-	-	X(4, 2, 5, 3)	1
-	-	-	-	X(2, 0, 5, 3)	1
$Qd_{(i,,k,t)}$	**Value**	$Qd_{(i,,k,t)}$	**Value**	$Qd_{(i,,k,t)}$	**Value**
Qd(4, 3, 1)	250	Qd(1, 4, 2)	150	Qd(4, 3, 3)	250
Qd(5, 4, 1)	350	Qd(5, 4, 2)	100	Qd(1, 4, 3)	300
Qd(2, 5, 1)	500	Qd(1, 5, 2)	350	Qd(2, 4, 3)	50
-	-	Qd(3, 5, 2)	150	Qd(3, 5, 3)	350
-	-	-	-	Qd(2, 5, 3)	100
$Qp_{(i,,k,t)}$		$Qp_{(i,,k,t)}$		$Qp_{(i,,k,t)}$	
Qp(4, 5, 1)	40	-	-	Qp(1, 5, 1)	15

5. 1. Evaluation of the Performance of the Proposed Method As we observed in the fitness relation, there are two objective functions that must be minimized. At first, the proposed algorithm calculates the fitness function of the initial population. In each iteration, the best chromosomes are selected for the next generation and if in up to 10 consecutive chromosome replications no chromosome with better performance than the best chromosome in the previous step was generated, the optimization algorithm is stopped. Another stopping condition is to pass a certain amount of iterations. We considered the number of iterations to be 1000. Obviously, the minimum amount of fitness is zero, and if a chromosome can be found with this fitness, the algorithm must be terminated as its continuation is meaningless.

5. 2. Performance Evaluation By changing the GA parameters, the obtained amount for fitness also changes. We seek the most optimum possible case i.e., the minimum value. In Table 8, we examined the amount of the system fitness for the possibility of different crossovers and obtained the best value.

Another important parameter of GA is the possibility of mutation. As the mutation increases, scanning increases in algorithm such that, as compared to before, the algorithm generates different solutions and may reach the better or even worse solutions than parents. Therefore, the following change is observed.

Figure 5 shows the process of achieving the best filter using the proposed algorithm. It is necessary to mention that in running the GA, the probability of crossover and mutation was 0.8 and 0.3, respectively (Tables 8 and 9). We used a single-point crossover such that 80% of the best chromosomes are combined. In this combination, two chromosomes are broken from a random point and linked together, and two new chromosomes are produced. To select chromosomes, the tournament selection operator was used for performing crossover in which a sub-set of the people in a population is selected and the members compete with each other. Finally, only one person from each sub-group is selected for production. In the proposed method, the number of the members within each set was considered 3.

TABLE 8. Fitness per the possibility of different crossovers

Crossover possibility	Fitness value
0.5	27869
0.6	26412
0.7	25893
0.8	25370
0.9	2601

TABLE 9. Fitness for the possibility of different mutations

Mutation possibility	Fitness value
0.05	26231
0.1	2610
0.15	25760
0.2	25632
0.25	25399
0.3	25370
0.35	25422

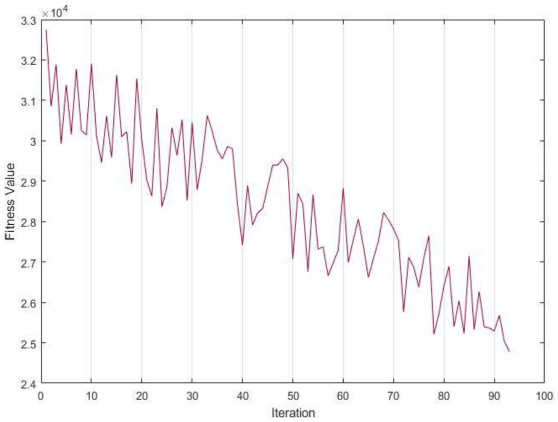

Figure 5. The process of getting access to the near optimal solution using the proposed algorithm

As shown in Figure 5, the proposed algorithm goes through a very good process to acquire a more appropriate solution, and finally in the iterations above 90, it reaches the value of the fitness function for the best member.

5. 3. Comparison To show the efficiency of the proposed meta-heuristic method, 15 testing problems with different dimensions were generated and solved using the proposed algorithm in the previous chapter, and compared with the lower bound of CPLEX. The proposed method was coded in MATLAB R2018a and all computations were run under Microsoft Windows 10. The number of retailers and periods range from 5, 2 (in problems with small sizes) to 50, 12 (in large problems), respectively. At first, each problem was solved using the lp-metrics method via CPLEX, and then was solved using the proposed GA. The variable cost and demand were respectively generated between (0-130) and (0-500). Table 10 displays the best values of the first objective function of the two algorithms (AOV^1_{LP},AOV^1_{GA}) and the second objective function of the two algorithms (AOV^2_{LP},AOV^2_{GA}).

TABLE 10. Fitness of methods

#	Retailers	Period	GA		CPLEX	
			AOV[1]	AOV[2]	AOV[1]	AOV[2]
1	5	2	67752	1235	84976	1821
2	5	3	68012	1935	92577	3171
3	6	3	74213	2781	76852	4144
4	10	5	78201	4331	80434	5323
5	12	6	84102	5651	85957	7377
6	15	6	91110	6381	93207	10354
7	18	9	96555	9152	996312	10731
8	20	9	111445	10242	121605	10921
9	22	9	112606	11245	123763	11638
10	24	10	119024	14524	145867	15531
11	26	10	130417	15241	153808	15431
12	28	10	139907	16324	163475	16645
13	30	11	203447	17542	211913	18445
14	30	12	294103	21321	351621	22172
15	30	12	366211	22457	386841	24132

In the experimental results, we saw that the proposed method excels over CPLEX in all cases.

5. 4. Concluding Remarks It is seen that the obtained fitness value also changes by changing the GA parameters. We seek the most optimum state i.e., the minimum value. The value of fitness for the crossover probability of 0.8 was obtained to be the best fitness. The other important parameter of GA is the probability of mutation. The algorithm with mutation probability of 0.3 generated the best solution using a single-point crossover and the tournament selection operator for performing crossover.

The number of retailers and periods range from 5 to 50, in 15 test beds. At first, each problem was solved using the lp-metrics method via CPLEX, and then was solved using the proposed GA. In this comparison, the proposed method showed a better performance in both objective functions.

6. CONCLUSION

There are still major challenges in resilient supply chain. Following up transportation operations from beginning to end is one of the challenges in this area. Products inventory management, routes determination, vehicle selection, etc., are among the problems to be considered in network design. In its traditional state, IRP minimizes the total inventory costs, but it does not take many items into account. The routing problem is a NP-hard problem, thus meta-heuristics should be used to solve it.

Distribution systems include all transportation stages. Research studies indicate that using up-to-date methods in distribution process planning leads to a significant amount of saving in all transportation costs. Making progress in technology whether in terms of hardware or software, and enhancing correlation in information systems in production and trade lead to success in the operation of the distribution network. The development of modeling instruments over recent years has also acted as a factor leading to further development. A proper model must take all the characteristics of the network in the real world into account and develop algorithms that find proper solutions for real instances within logical time. Meta-heuristics such as GA are a very suitable option for this issue.

The mathematical model of this research is of integer type that solves the perishable inventory routing problem. The proper route selection and the reduction of the improper transportation options are among the features of this model that reduce the total costs of the supply chain. The efficiency of the GA was assessed in the results. In fact, the time of finding the solution depends on the problem's dimensions because the proposed model is considered a multi-objective IRP. The GA-based method proposed here should preserve the constraints. The comparison in 15 problems showed a better performance by the proposed method compared to Cplex. It is suggested that reaserchers propose and compare other bi-objective algorithms and meta-heuristics to solve the problem using the formulation.

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Persian Abstract

چکیده

زنجیره تامین تاب‌آور، قابلیت‌های فراوانی برای عبور از بحران‌های مالی و تامین و توزیع محصولات برای شرکت‌ها قائل می‌شود. در این مطالعه، ما به یک مسئله تخصیص توزیع موجودی برای سیستم شبکه توزیع که شامل یک کارخانه، تعدادی محل بالقوه برای مراکز توزیع و تعدادی خرده فروش است می‌پردازیم. فرض بر این می‌باشد تقاضای مشتریان برای تمام دوره‌ها به صورت قطعی و مشخص است. اما مدت زمان آن در افق برنامه‌ریزی محدود متفاوت است. مدل پیشنهادی این تحقیق به صورت یک مدل برنامه‌ریزی عدد صحیح مختلط خطی و با دو تابع هدف مدلسازی می‌شود.که در تابع هدف اول مجموع هزینه‌های کل سیستم توزیع را در افق برنامه‌ریزی حداقل می‌کند و تابع هدف دوم به دنبال حداقل کردن اختلاف حداکثر و حداقل مسافت طی شده توسط وسائل نقلیه در طول افق برنامه‌ریزی است بنابراین مدل سعی دارد با استفاده از بهترین پیکربندی مسیرها و گزینه حمل و نقل ، تقاضا را برآورده کند و هزینه‌ها را به طور همزمان کاهش دهد. برای حل مسئله از یک مثال کوچک استفاده کرده و آن را با نرم افزار MATLAB حل و سپس مسئله را توسعه داده و ازآنجائیکه مسأله مسیریابی یک مسأله سخت یا NP HARD می‌باشد، برای حل آن از روش‌های حل فراابتکاری استفاده می‌شود. در این مدل عواملی چون: حجم تقاضا برای هر مشتری در یک دوره در شبکه ، ظرفیت وسیله نقلیه، ظرفیت کارخانه، هزینه ثابت حمل ونقل، هزینه متغیر حمل و نقل و غیره به عنوان عوامل مؤثر بر مدل مد نظر قرار گرفته است. نتایج نشان می‌دهد که مدل ارائه شده در شبکه می‌تواند به عنوان اهرمی برای افزایش عملکرد شبکه تأمین اقتصادی از طریق صرفه‌جویی در مسیرها استفاده شود.