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A Bi-objective Cold Supply Chain for Perishable Products Considering Quality Aspects: A Case Study in Iran Dairy Sector

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ABSTRACT

Improper handling in the food cold supply chain may compromise food safety and reduce quality, which can lead to economic losses and undesirable effects on food accessibility. Therefore, designing an efficient and reliable cold supply chain is extremely important for the company, suppliers, customers, and society. The majority of the traditional studies in the supply chain do not consider the cost of quality (prevention, appraisement, and failure) in supply chain network design. In this study, all dimensions of the cost of quality in a cold supply chain design such as the cost of quality related to suppliers and the cost of distribution service quality are investigated to close the problem to real-world conditions. Moreover, the quality of suppliers, manufacturers, and distributors is simultaneously considered throughout a supply chain with a new approach. To this end, the problem is formulated as a mathematical model for multi-item and multi-period cases considering two objective functions. The first objective function minimizes the total expected costs and the second objective function maximizes the total quality of the supply chain. The proposed bi-objective model has been transformed into a single-objective model by the solution of the parametric method (normalized weighted summation) and solved for a medium-sized instance considering data of a real-world case study. Computational results and analyzes indicate the efficiency of the proposed model as well as the exact solution method available for small and medium scales. The real case study which involves Kaleh Dairy Company is conducted to illustrate the potential of the proposed model and proper sensitivity analyses.

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1. INTRODUCTION

The supply chain includes all the steps (chain members) that are directly or indirectly involved in meeting a customer's request. In a typical supply chain, raw materials are sent from suppliers to factories, and then the products produced in the factories are sent to intermediate warehouses and distributors' warehouses, as well as to retailers and finally to the customer. They reach the end of the consumer. So a product goes through the supply chain to reach consumers.

Proper supply chain network design can provide ideal results and increase its revenues. Supply chain management has a vital impact on two outcomes. Firstly, it pays attention to any solution that reduces costs and plays a key role in meeting customer needs. In fact, in some supply chain analyses, it is necessary to focus on suppliers and customers because they have a huge impact on the formation of the chain. Second, supply chain management means increasing efficiency and reducing costs throughout the system. By applying the approaches in supply chain management, the cost of the whole system which includes transportation costs, inventory, material handling, etc. is reduced; Therefore, the purpose of designing a supply chain is to increase efficiency and reduce costs in the whole system but the emphasis is not only on reducing transportation costs, inventories, etc. but also on supply chain management using a device approach. It tries to improve the efficiency of the whole chain and also increase the level of customer service. In fact, customer satisfaction should be

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considered in the supply chain which can include customer satisfaction with the quality of products and services provided.

The purpose of this study is to create a comprehensive and integrated model for supply chain planning that simultaneously increases the efficiency of the chain and on the other hand to meets the needs of customers effectively. For this purpose, two objectives have been considered for the above supply chain. The first objective function is to minimize the costs of the entire supply chain and the second one is to maximize the quality of the entire supply chain. The first objective focuses on supply chain efficiency while the second one is related to customer satisfaction.

For the supply chain costs, in addition to the tangible costs considered in most studies, intangible costs such as producer quality costs are considered as a very important cost factor that is by no means negligible.

In this study, quality costs are considered in three groups of costs of prevention, appraisement, and failure. In addition to the cost of quality of the manufacturer, the cost of quality of raw materials imposed by suppliers on the supply chain and the cost of quality of service are included in the total cost of the supply chain.

As mentioned above, in addition to minimizing the total cost of the entire supply chain, this article focuses on customer satisfaction which is a prominent advantage in today's competitive world. Customer satisfaction is achieved by providing both of products and quality services. Therefore, the function of the second objective proposed in this study is to maximize quality in the whole supply chain. In this regard, the quality of suppliers, manufacturers, and distributors are considered. Supplier quality includes the quality of raw materials provided by the supplier and the time of delivery of raw materials from suppliers to the manufacturer. Producer quality is expressed as a percentage of conforming units produced. Finally, the quality of service of distribution centers and the time of delivery of goods from the distributor to customers are also considered as quality factors for the distributor. To express the manufacturer's satisfaction with suppliers as well as customers with distributors which is obtained through the quality provided by them, the Huff model [1] is used after customizing for the problem at hand. So far, the Huff model is used only in the field of location.

In general, this paper deals with the design of a four-echelon supply chain consisting of suppliers, manufacturers, distributors, and customers and provides a comprehensive model for the supply chain that minimizes total costs and as well as maximizes quality simultaneously. In the proposed model, supplier selection and multi-period planning are considered which adds to the comprehensiveness of the above model due to the four-echelon supply chain and its complexity.

So far, there have been very few studies that have included quality aspects in supply chain design, and the existing research has considered all aspects of quality cost (prevention, evaluation, failure). In addition, the cost of suppliers quality and the cost of service quality of distribution centers are considered as a function of the cost objective, which is the first time these two cost elements have been used in this way in chains.

According to the abovementioned explanations, the contribution of the article can be introduced as follows:

- Introducing the four-echelon cold supply chain for perishable products considering quality aspects
- Formulating the problem at hand, as a bi-objective mathematical model
- Proposed a solution approach based on reaching the destination technique
- Investigating performance of the proposed model and solution approach in tackling the problem using data of a real case study
- Risk assessment of economic variables such as inflation and demand is sensitively analysed.

The outline of the paper is as follows. Section 2 is devoted to the survey of works related to this article. The problem at hand is described completely in section 3 and formulated as a bi-objective mathematical model. In section 4, a solution approach is developed to solve the proposed problem with real-sized scales. The considered case study is illustrated in section 5. Section 6 provides the result of solving the problem and some sensitivity analysis. Finally, a summary of the work and a conclusion with some suggestions for future research are given in section 7.

2. RELATED STUDIES

Supply chain design was first introduced in 1974 by Geffrin and Graves. They created a multi-product logistics network design model to optimize the flow of goods produced to distribution centers. Since then, extensive research has been conducted in the field of supply chain design [2]. Most supply chain design issues that minimize total cost do not take into account the cost of quality, which can be used as an indicator of quality and used in these articles, and so far only a handful of articles. They considered the cost of quality in their supply chain.

A review of the research literature shows that in the past, most supply chain articles had single-objective models. Some of the objectives which researchers have considered as a function of the supply chain goal are: minimizing the total cost of commissioning, minimizing the longest distance between facilities, maximizing customer service, minimizing the average time/distance traveled, minimizing the number of established facilities, and maximizing the customer responsiveness. In the following, a summary of research in the field of supply chain considering the quality issues is presented.

Franca et al. [3] considered the cost of quality as a function of the second objective. Their model includes maximizing profits and minimizing the defective produced items as two objective functions. However, the discussion of the cost of quality has not been explicitly examined in their study [3]. Many studies have paid attention to the issue of quality and aimed to maintain the quality supply chain due to its complexity. Some of them have been looking for factors that can maintain and enhance quality in the supply chain. Supply chain coordination [4, 5,6], application of technology [7, 8], risk management [9], [10], and ensuring reliability [11, 12] are elements that have been paid attention in previous studies.

Two important aspects of quality are product quality and service quality. It is vital in the nowadays competitive marketing environment to produce products and services that exceed customer expectations and requirements. The emphasis on increasing the quality of products and services by companies has increased in response to the highly competitive environment. In other words, product and service quality are known as the main principles for the success and survival of today's competitive market. In each part of the supply chain, the quality of products and services must be considered, that is, each of the suppliers, manufacturers, and distributors must pay attention to issues that increase the quality of products and services and ultimately customer satisfaction [13].

Efficiency mechanisms for customer service have been reviewed in a variety of articles [14, 15]. In fact, retailers in a supply chain focus on activities and operations that differentiate them from their competitors. Therefore, they invest in service quality as a tool to improve the efficiency of the entire supply chain.

Hsieh et al. [16] dealt with the problem of supply chain network design consisting of one manufacturer and one supplier, and the inspection and production processes of this chain have quality problems and shortcomings. Both manufacturers and suppliers have invested in quality improvement activities in their production processes to reduce the production of defective items. In addition to investing in quality programs, the supplier inspects once before delivering his product to the manufacturer, and the manufacturer inspects twice, once when receiving products from the supplier and once when delivering the final product to customers. They investigated the quality and inspection strategies of the manufacturer and supplier based on the game theory technique and examined their profitability under different conditions [16].

One of the new topics that have been considered recently in the supply chain is the cold chain. A review of the most recent and relevant researches on the cold chain which applied quantities techniques is presented below.

Mendes and Matheus offered an analysis and optimization model of periodic inspection intervals in cold standby systems using Monte Carlo simulation. They developed a Monte Carlo simulation model to examine and optimize the time interval among periodic inspections in cold standby systems as the required availability and the deepest cost possible [17]. Mejjaouli and Babiceanu designed a cold supply chain system optimization model for real-time rerouting transportation solutions. They provided insights into the logistics decision models related to the cold supply chain of fresh products [18]. Zhang et al. [19] designed a decision-making framework of a regional cold chain logistics system in view of low-carbon low-cost. They proposed a decision-making model of a cold chain logistics system based on the method of two-stage programming.. Qin et al. presented a Vehicle Routing Optimization Problem for Cold Chain Logistics Considering Customer Satisfaction and Carbon Emissions. Their study proposes a comprehensive cold chain vehicle routing problem optimization model with the objective function of minimizing the cost of a unit satisfied customer. For customer satisfaction, this paper uses the punctuality of delivery as the evaluation standard. For carbon emissions, this paper introduces the carbon trading mechanism to calculate carbon emissions costs.

Zhang et al. [20] presented a low-carbon cold chain logistics using a ribonucleic acid-ant colony optimization algorithm. Their study aims to introduce the low-carbon economy into cold chain logistics. There are various costs needed to be considered in cold chain logistics, and a cold chain logistics route optimization model included the carbon emission cost was developed [21].

Goodarzian et al. [22] designed a Multi-objective Sustainable Medicine Supply Chain Network Design using a Novel Hybrid Multi-objective Metaheuristic Algorithm. In their study, they developed sustainable objectives in the supply chain optimization framework with different constraints. The trade-off between economic, environmental, and social effects objectives has been identified by ensuring the optimal allocation of different products among various levels. In this regard, a new sustainability multi-objective mixed-integer linear programming mathematical model in the medicine supply chain network is developed.

Theeb et al. [23] presented an optimization model for vehicle routing with inventory allocation problems in cold supply chain logistics. The joint optimization model in their study consists of inventory allocation problem, vehicle routing problem, and cold supply chain (CSC) that is formulated and denoted as IVRPCSC model, to minimize the total cost including the transportation and inventory costs. As the proposed model is NP-hard, a multi-phases solution approach is designed to solve the model in a reasonable computational effort. Qi, Chengming, and Lishuan Hu [24] presented a new optimization model for vehicle routing problems for emergency cold chain logistics based on minimum loss. In this study, the proposed optimization model adjusts the pheromone updating strategy adaptively which can balance the convergence rate and diversification of solutions. Shafiee et al. [25] presented a robust multi-objective optimization model for inventory and production management considering both environmental and social aspects with a real case of the dairy industry. Their research is about designing a three-echelon sustainable dairy supply chain under uncertainty. In addition, a multi-objective model is proposed to minimize the total costs and environmental impacts, and maximize the social impacts of a multi-period and multi-product chain composed of suppliers, producers, and retailers, which is applied to a dairy company. The delivery time and the first-in, first-out (FIFO) policy of the products are of particular importance in the proposed model. Theophilus et al. [26] presented a truck scheduling optimization at a cold-chain cross-docking terminal with product perishability considerations. Their study introduces a novel mixed-integer mathematical formulation for the truck scheduling optimization at a cold-chain CDT for the first time. Their considered objective function minimizes the total cost incurred during the truck service. Considering the complexity of the proposed model, a customized Evolutionary Algorithm (EA) is developed to solve the problem at hand with practical dimensions. The computational performance of the developed algorithm is assessed throughout the numerical experiments based on a detailed comparative analysis against the other metaheuristics. A set of additional sensitivity analyses are performed in order to provide some significant managerial implications, which would be of potential interest to the supply chain stakeholders that are involved in the distribution of perishable products in cold supply chains.

Wang et al. [27] developed a model to achieve a win-win scenario between cost and customer satisfaction for cold chain logistics. They focused on the customers' time requirements and establishes the penalty costs incurred when service time requirements are not met. In addition, in this paper combines different aspects, such as considering the refrigeration energy consumption and the damage costs.

TABLE 1. Comparison contributions on the problem of cold supply chain network design.

Reference	Main features				Objective functions					Case study	Solution approach
	Multi-period	Multi-product	Perishable products	Uncertainty	Cost	Time	Quality	Environmental impact	Social impact		
Ahmadi-Javid, and Hoseinpour [13]	✓		✓		✓						MINLP, Lagrangian relaxation
Saif and Elhedhli [28]		✓			✓			✓			MINLP, Simulation, Lagrangian decomposition
Hariga et al. [29]		✓	✓		✓			✓			MIP, Heuristic
Mejjaouli and Babiceanu [18]		✓	✓	✓	✓		✓			✓	RFID-WSN
Zhang et al. [19]	✓	✓			✓			✓	✓	✓	Bilevel programming (BLPM)-CSPO
Babagolzadeh et al. [30]		✓	✓	✓	✓			✓		✓	stochastic programming, Iterated Local Search (ILS)
Qi, and Hu [24]	✓		✓	✓	✓		✓				Heuristic based on Baidu map (API)
Shafiee et al. [25]	✓		✓	✓	✓	✓			✓	✓	Robust optimization, augmented ε-constraint
Theophilus et al. [26]	✓	✓			✓						MIP, Evolutionary Algorithm
Li and Zhou (2021) [31]		✓			✓	✓		✓			MIP, NSGA-II
Fasihi et al. [32]	✓		✓		✓	✓				✓	ε-constraint, Lp-metric
This study	✓	✓	✓	✓	✓	✓	✓			✓	MINLP-Parametric method (weighted)

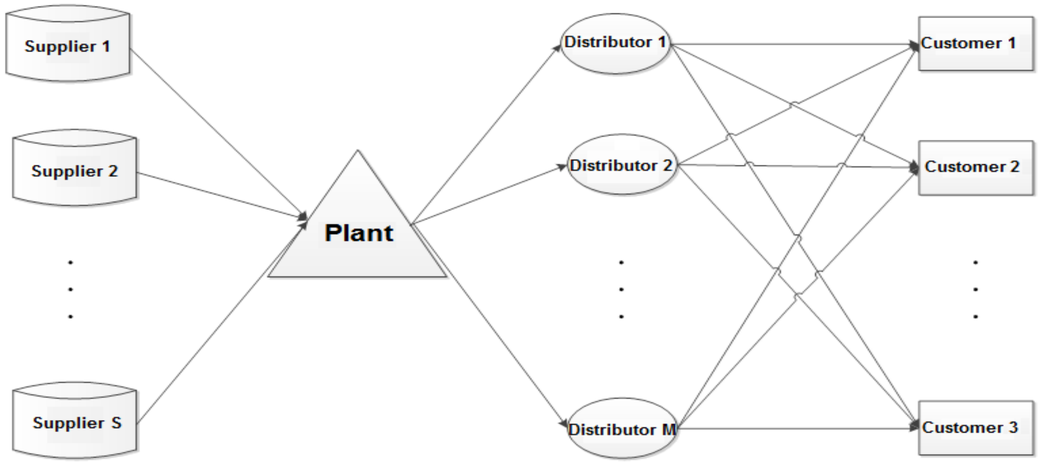

Figure 1. Proposed supply chain structure

Zhao et al. [33] presented a metaheuristics for solving the vehicle routing problem with the time windows and energy consumption in cold chain logistics. The objective of this study is to minimize the total cost including the fixed cost and the energy consumptions. An improved artificial fish swarm (IAFS) algorithm is proposed, where a special encoding approach is designed to consider the problem feature with a different types ofvehicles. Zhao et al. [33] presented a cold chain logistics path optimization via an improved multi-objective ant colony algorithm. In order to improve the performance and change the current situation of the cost minimization model widely used in the cold chain logistics distribution process, a multi-objective optimization model based on cost, carbon emissions, and customer satisfaction are proposed. Ji et al. [34] presented a robust optimization approach to two-echelon agricultural cold chain logistics considering carbon emission and stochastic demand. In this paper, a linear programming (LP) model is established, which takes the costs of vehicle transportation, time window, and carbon emission into consideration. The findings of this paper generate some implications for the low-carbon transformation of cold chain logistics enterprises [35].

Li and Zhou [31] designed Multi-objective cold chain logistic distribution center location based on carbon emission. This study presents the impact of carbon emission, customer satisfaction, construction cost, and operation cost on the location of cold chain logistics distribution center. A multi-objective location model for the cold chain logistics distribution centers considering carbon emission is established.

Fasihi et al. [32] developed a Bi-objective mathematical model to design a fish closed-loop supply chain. They tackled this problem to maximize responsiveness to customer demand and minimize the total cost of the fish closed-loop supply chain (CLSC) by proposing a novel mathematical model. To solve this model, the epsilon-constraint method and Lp-metric were employed. Then, the solution methods were compared with each other based on the performance metrics and a statistical hypothesis. The superior method is ultimately determined using the TOPSIS method.

Table 1 represents a summary of previous contributions of the existing literature related to this study's considered problem and novelty. As it is depicted in the table, the issue of quality in a cold supply chain network design such as the cost of quality related to suppliers and the cost of distribution service quality never have been faced by literature so far. Moreover, the quality of suppliers, manufacturers, and distributors is simultaneously considered in this study throughout a supply chain with a new approach.

3. PROBLEM DESCRIPTION

This study investigates the problem of four-echelon cold supply chain network design considering the quality aspects. Figure 1 represents a schematic view of the considered problem in this study. The problem at hand is a four-echelon cold supply chain including some suppliers, the main factory, some distributors, and several points as customers.

After problem definition, a bi-objective model is developed in this section for the problem at hand to optimize both the total cost as well as the quality of the performance. The first objective function is to minimize the total expected cost consisting of the following elements:

- The cost of purchasing raw materials and parts from suppliers
- The cost of processing raw materials (production cost) in the factory
- The cost of transporting raw material, parts, and final products from different suppliers to the factory, from the factory to distribution centers, and from distribution centers to customers
- The inventory costs

- The cost of quality (prevention, appraisement, and failure)
- The cost of documentation and return the low-quality raw materials and parts
- The cost of follow up complaints from suppliers related to the low-quality raw materials and parts

The second objective function is to maximize the quality of the performance and related satisfaction. Supply chain quality and satisfaction includes the following items:

- The factory satisfaction with the quality of suppliers (quality of raw materials and parts and how it is delivered by suppliers to the factory)
- The customer satisfaction with the performance of the distribution centers (services quality and on-time delivery)
- The quality of the final products

As is evident in the existing literature, the higher the number of supply chain echelons, the less multi-cycle planning is used due to the complexity of the chain. But in this study, a multi-period planning horizon is used for the proposed four-echelon cold supply chain, which increases the complexity and comprehensiveness of the proposed model.

Given the gap in the supply chain literature, first a comprehensive model is developed that covers all considered features of the problem. After that, a solution approach is developed to solve the problem with practical dimensions in a reasonable time.

To formulate the problem at hand, first, the indices, parameters, and decision variables are defined as follows:

Indices

$s = 1, 2, \ldots, S$	Index for suppliers (potential suppliers)
$c = 1, 2, \ldots, C$	Index for customers
$r = 1, 2, \ldots, R$	Index for raw materials
$u = 1, 2, \ldots, U$	Index for service quality options
$t = 1, 2, \ldots, T$	Index for time periods
$p = 1, 2, \ldots, P$	Index for suppliers to supply raw materials
$j = 1, 2, \ldots, J$	Index for distribution centers

Parameters

CP_{rst}	The cost of purchasing raw material r from supplier s in period t
CM_t	Raw material processing cost (production cost) in period t
CA_{ju}	The cost of service quality in distribution centre j related to option u
Q_u	The quality level related to service option u
D_{ct}	Demand of customer demand c in the period t
CAP	The maximum of production capacity per time period
$CAPS_s$	The maximum capacity of supplier s in each time period
$CAPDC_j$	The maximum capacity of distribution centre j in each time period
Vol_r	The amount of volume occupied by the raw material r
U_r	The amount of raw material r used in the production of the product
W_r	The important of material r in production
y_{rs}^{s}	Defective rate of material r provided by supplier s
α_s	The cost of transporting raw material from the supplier s to the factory
β_j	The cost of transporting product from the factory to the distribution center j
γ_{jc}	The cost of transporting product from the distribution center j to customer c
h_j	The cost of holding one product in the distribution center j during a unit time
C_1	The minimum cost of prevention and appraisal that occur in the least quality level
C_2	The minimum cost of failure that occurs in the maximum quality level
e^{μ_1}	The rate of increasing the cost of prevention and appraisal
e^{μ_2}	The rate of increasing the cost of failure
U^{PD}	Maximum product transfer rate from the factory to each distributed center
L^{PD}	Minimum product transfer rate from the factory to each distributed center
U^{DC}	Maximum product transfer rate from each distributed center to each customer
L^{DC}	Minimum product transfer rate from each distributed center to each customer
d_s^2	Distance between supplier s to the factory
dP_j^2	Distance between the factory to distributed center j
dD_{jc}^2	Distance between distributed center j to customer c
θ	The cost of documentation with any defective material
δ	The cost of complaint for any defective material
Ω	The cost of inspection of any material unit
λ	The inflation rate
φ_1	The modification factor of suppliers' quality function to unify it with other quality functions
φ_2	The modification factor of factory quality function to unify it with other quality functions
φ_3	The modification factor of distribution centre's quality function to unify it with other quality functions
M	A very large number

Decision variables

b_{rst}	The amount of raw material r shipped from supplier s to the factory in period t
x_t^P	The amount of product produced in the factory in period t
x_{jt}^{PD}	The amount of product shipped from the factory to the distribution center j in period t
x_{jct}^{DC}	The amount of product shipped from the distribution center j to the customer c in period t
y^P	Percentage of defective products in the factory
I_{jt}	The amount of inventory in the distribution center j during period t
V_{ju}	Binary variable takes value 1 If option u is selected for the service quality of distribution center j; 0 otherwise
S_{jt}^{PD}	Binary variable takes value 1 If the factory transports the product to the distribution center j in period t; 0 otherwise
SN_{jt}^{PD}	1 If the product is not shipped from the factory to the distribution center j in period t; 0 otherwise
S_{jct}^{DC}	Binary variable takes value 1 If the product is shipped from the distribution center j to customer c in period t; 0 otherwise
SN_{jct}^{DC}	1 If the product is not shipped from distribution center j to customer c in period t; 0 otherwise

Finally, the mathematical model of the problem at hand is developed as follows:

$$Z_1 = Min \sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{t=1}^{T} CP_{rst}.(1+\lambda)^{t-1}.b_{rst} + \sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{t=1}^{T}\alpha_s.d_s^2.(1+\lambda)^{t-1}.b_{rst} + \sum_{t=1}^{T} CM_t.(1+\lambda)^{t-1}.x_t^p + \sum_{j=1}^{J}\sum_{t=1}^{T}\beta_j.dP_j^2.(1+\lambda)^{t-1}.x_{jt}^{PD} + \sum_{j=1}^{J}\sum_{t=1}^{T} h_j.(1+\lambda)^{t-1}.I_{jt} + \sum_{j=1}^{J}\sum_{c=1}^{C}\sum_{t=1}^{T}\gamma_{jc}.dD_{jc}^2.(1+\lambda)^{t-1}.x_{jct}^{DC} + \sum_{t=1}^{T}\left(c_1.e^{\mu_1\left(\frac{1-y^p}{y^p}\right)} + c_2.e^{\mu_2\left(\frac{1-y^p}{y^p}\right)}\right).(1+\lambda)^{t-1}.x_t^p + \sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{t=1}^{T}(\theta+\alpha_s.d_s^2).(1+\lambda)^{t-1}.y_{rs}^s.b_{rst} + \sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{t=1}^{T}\delta.(1+\lambda)^{t-1}.y_{rs}^s.b_{rst} + \sum_{r=1}^{R}\sum_{s=1}^{S}\sum_{t=1}^{T}\Omega.(1+\lambda)^{t-1}.b_{rst} + \sum_{j=1}^{J}\sum_{u=1}^{U} CA_{ju}.V_{ju} \quad (1)$$

$$Z_2 = Max\left(\varphi_1 \sum_{s=1}^{S}\sum_{t=1}^{T}\left(\frac{1}{1+d_s^2}\right).\left(\prod_{r=1}^{R}(1-y_{rs}^s)^{w_r}\right).\left(\frac{\sum_r^R b_{rst}}{\sum_s^S\sum_r^R b_{rst}}\right) + \left(\varphi_2 \sum_{j=1}^{j}\sum_{c=1}^{C}\sum_{t=1}^{T}\sum_{u=1}^{U}\left(\frac{Q_u.V_{ju}}{1+dD_{jc}^2}\right).\left(\frac{x_{jct}^{DC}}{D_{ct}}\right)\right) + \left(\varphi_3(1-y^P)\right)\right) \quad (2)$$

$$\sum_{j=1}^{J} x_{jct}^{DC} = D_{ct} \qquad \forall\, C \text{ and } t \quad (3)$$

$$I_{jt} = I_{jt-1} + x_{jt}^{PD} - \sum_{c=1}^{C} x_{jct}^{DC} \qquad \forall\, j \text{ and } t \quad (4)$$

$$x_t^P \le CAP \qquad \forall\, t \quad (5)$$

$$I_{jt} \le CAPDC_j \qquad \forall\, j \text{ and } t \quad (6)$$

$$\sum_{r=1}^{R} Vol_r.b_{rst} \le CAPS_{ss}.zz_s \qquad \forall\, s \text{ and } t \quad (7)$$

$$U_r.x_t^p = \sum_{s=1}^{S} b_{rst}.(1-y_{rs}^s) \qquad \forall\, r \text{ and } t \quad (8)$$

$$\sum_{j=1}^{J} x_{jt}^{PD} = (1-y^p).x_t^p \qquad \forall\, t \quad (9)$$

$$x_{jt}^{PD} \le U^{PD}.S_{jt}^{PD} \qquad \forall\, j \text{ and } t \quad (10)$$

$$x_{jt}^{PD} \ge L^{PD} - M.SN_{jt}^{PD} \qquad \forall\, j \text{ and } t \quad (11)$$

$$S_{jt}^{PD} + SN_{jt}^{PD} = 1 \qquad \forall\, j \text{ and } t \quad (12)$$

$$x_{jct}^{DC} \le U^{DC}.S_{jct}^{DC} \qquad \forall\, j, c \text{ and } t \quad (13)$$

$$x_{jct}^{DC} \ge L^{DC} - M.SN_{jct}^{DC} \qquad \forall\, j, c \text{ and } t \quad (14)$$

$$S_{jct}^{DC} + SN_{jct}^{DC} = 1 \qquad \forall\, j, c \text{ and } t \quad (15)$$

$$\sum_{s=1}^{S} zz_{s=\rho} \quad (16)$$

$$\sum_{u=1}^{U} V_{ju} = 1 \qquad \forall\, j \quad (17)$$

$$b_{rst}, x_t^P, x_{jt}^{PD}, x_{jct}^{DC}, y^P, I_{jt} \ge 0 \qquad \forall\, r, s, j, c \text{ and } t \quad (18)$$

$$zz_s, S_{jt}^{PD}, SN_{jt}^{PD}, S_{jct}^{DC}, SN_{jct}^{DC} \in \{0, 1\} \qquad \forall\, r, s, j, c \text{ and } t \quad (19)$$

3. 1. Objective Functions The first objective function calculated as Equation (1) includes the following elements respectively. Term 1 demonstrates the total cost of purchasing raw materials from suppliers. Term 2 is related to the cost of transporting raw materials from suppliers to the factory. Term 3 highlights the cost of producing the product in all periods, taking into account the inflation rate. Term 4 states the cost of transporting products produced from the factory to distribution centers. Term 5 shows the total cost of maintaining the remaining products at the end of each period, taking into account the time value of money. Term 6 considers the distance between the distribution center j from the customer c. The amount of product shipped from the distribution center j to customer c in period t. Terms 7 and 8 show costs of failure assessment (cost of quality products produced in all periods), or processing. Term 9 shows the cost of documenting and referring defective raw materials. Term 10 demonstrates the cost of reviewing complaints from suppliers. Finally, term 11 shows the cost of the raw material inspection.

The second objective function calculated as Equation (2) includes the following elements respectively. Term 1 shows the plant satisfaction with supplier s if it supplies all the required raw materials in p certain period. Term 2 demonstrates customer satisfaction from distribution centers in all periods. Finally, term 3 indicates the quality of manufactured products.

3. 2. Constraints Constraints include the following in respectively: Equation (3) ensures that the demand of customer c in period t is satisfied completely. Equation (4) states that in each period, the amount of inventory at the end of the period of each distribution center is equal to the sum of the inventory value at the end of the previous period and the amount received by those centers from the factory in this period mins the number of goods in this period from the distribution center for different customers. Equations (5) to (7) are required due to capacity limitations of the production process. Moreover, these Equations guarantee that in each period, the amount of inventory at the end of the period of each distribution center should not exceed the maximum capacity of that distribution center. This is also true for suppliers. In addition, each supplier has a limited capacity due to the volume occupied by raw materials. Equation (8) ensures that the number of raw materials used in the production of a particular product is equal to the percentage of conforming raw materials supplied from that raw material by all suppliers. Equation (9) shows that the total number of products that arrive from the factory to the distribution centers is equal to the conforming units produced by the factory. Equations (10) to (12) indicate that the transfer of products from the factory to the distribution centers. Equations (13) to (15) guarantee that from each distribution center to a specific customer if the goods are to be delivered, at least more than a certain amount. The reason for these constraints is to avoid delivering very small quantities of goods, despite being optimal, which in these circumstances does not seem logical to transport due to the delivery of very small quantities of goods. For this purpose, a set of the above-mentioned restrictions is formed. Also, the goods can be delivered to a customer from each distribution center up to a certain size. Equation (16) emphasizes that the number of suppliers is specified and is equal to ρ. Equation (17) enforces that only one service quality option should be selected for each distribution center. Finally, Equations (18) and (19) specify the domains of the decision variables.

4. SOLUTION APPROACH

The technique of reaching the destination that is used in this study to solve the considered problem is one of the multi-objective decision-making techniques in which the preferential information of the decision maker is obtained before solving the model. This method requires the decision maker to provide the destination vector as well as the weight vector depending on the level of access to those destinations. In this method, the optimal solution which is the same as the partial optimal solution of the original model directly depends on the destination vector and the weight vector given by the decision maker.

One of the advantages of this technique, compared to other multi-objective decision-making techniques, is that, unlike interactive methods, fewer variables are required and solved in one step, which is a very computationally wide method. Althought this method was introduced in classic form to solve k maximization or minimization objective functions simultaneously, it has been developed for solving models consisting of both maximization and minimization objective functions simultaneously [36].

Since the proposed model consists of one maximization objective function and one minimization objective function, this technique is used as bellow to solve the problem:

$$\text{Min } Z = (\propto . Z_1 - (1 - \alpha).Z_2)$$

Wherein,

$$0 \leq \propto \leq 1$$

In addition, augmented ε − constraint method (AUGMECON) is also used to provide the exact Pareto front solutions as different alternatives for decision makers.

5. CASE STUDY

In this section, a real case study with medium dimensions is presented and solved with the proposed mathematical model. We have investigated the Kaleh Dairy Products Company as an appropriate instance for the proposed problem. This example is solved using two approaches of reaching the destination (the so-called as parametric and weighted) and augmented ε − constraint method (AUGMECON) and run in GAMS. The Baron solver was used to find the exact Pareto front. All calculations and result in analyses were carried out on a PC running at Intel Core i5-4210U 2.4GHz CPU and 4GB RAM.

Kaleh Dairy Products Company is one of the subsidiaries of Soliko Group which was established in 1991. Over the years, the company has expanded greatly in various aspects of production capacity, quality, variety of products, global distribution network, and exports. Figure 2 represents a schematic view of this company's supply chain from receiving milk to sending the final products. The company currently has three business units of cheese, pasteurized products, and ultra high temeprature (UHT) that with its innovation, offers the highest quality and most diverse products in the high production volume. All factory production lines are flexibly designed so that the raw materials of different inputs enter the production line and various products leave. So that more than 20 products are sometimes produced through only one production line. Kaleh currently provides more than 160 different kinds of dairy products, which will be doubled in the near future in development plans.

We have considered 19 key suppliers, the planet, 2 main distributors, and 4 large chain stores as important customers. Summary information of these suppliers, distributors, and customers are shown in Tables 2 and 3.

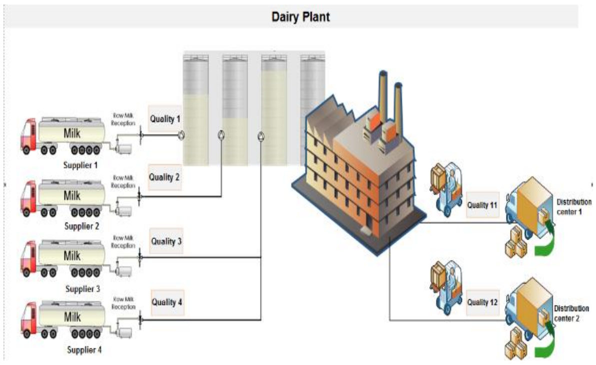

Figure 2. Receiving milk and sending the product in Dairy Products Company

TABLE 2. Data of suppliers

Supplier code	Distance (km)	Supply amount (Ton/Year)
S-1	744	5957
S-2	564	7762.8
S-3	644	8955.3
S-4	432	4304.2
S-5	159	1339
S-6	95	308.4
S-7	81	4936.9
S-8	256	15088.1
S-9	186	7942.8
S-10	186	4570.4
S-11	186	16541.6
S-12	186	2156.2
S-13	186	11032.5
S-14	1094	6395.4
S-15	336	3011.9
S-16	336	9912.2
S-17	336	7898.1
S-18	370	3282.2
S-19	370	4218.1

TABLE 3. Data of distributed centers

Distributers code	Distance from the plant	Related customers	Distance from the customer
D-1	212	C-1	42.1
		C-2	21.4
D-2	640	C-3	7.7
		C-4	4.3

Other characteristics of the case study are as follows: Factory production capacity is 9000 units, the values of β and γ are 0.03 and 0.04 monetary units respectively (each monetary unit is considered equal to 10^7 Iranian Rial). The annual inflation rate is equal to 10%. The upper bound and the lower bound of shipment from distributers centers to customers are considered 4000 and 100 respectively. Moreover, the upper bound and the lower bound of shipment from the factory to distributer centers are assumed as 3800 and 30 respectively. Distribution centers capacity is also 10000.

Production cost per unit s 0.04 monetary unit. In addition, the values of θ, δ, and Ω are 0.002, 0.001, and 0.003 monetary unit respectively. Correction coefficients of quality control functions are considered as 300, 50, and 1000 for suppliers, factories, and distribution centers respectively. Cost of transporting materials from supplier i to factory is demonstrated as α_i per unit distance. Furthermore, four different kinds of vehicles are available for transportation with different cost and capacities. The remain of data used in this case study has been obtained from the company site[1].

[1] https://gb.kompass.com/c/amol-kaleh-dairy-products-mfg-p-j-s/ir036405/
https://en.wikipedia.org/wiki/Kalleh_Dairy

6. FINDINGS

6. 1. Result of Problem Solving

This section presents the result analysis of solving these problems using the proposed mathematical model. The problem has been solved on a PC with COMPILATION TIME = 0.016 SECONDS 4 MB 24.1.3 r41464 WIN-VS8. Table 4 demonstrates the result of solving the problem with different values of α.

In this table, the first column shows the case number created using different values of α. The second and third columns demonstrate weights of two objective functions according to the different values of α. The fourth and the fifth columns show the optimal solutions for the first and the second objective function respectively obtained by solving the mathematical model. Finally, the last column shows the optimal rate of defective products.

Figure 3 represents the Pareto front of final solutions for the problem. Due to this figure, the model has provided

TABLE 4. Solution results with different values of alpha

Case	α	$1-\alpha$	Z_1	Z_2	y^p
1	1	0	60,236,010	-	0.041
2	0.99	0.01	57,030,945	3,450,560	0.021
3	0.9	0.1	62,665,456	16,273,504	0.045
4	0.9	0.1	63,665,456	44,522,304	0.031
5	0.9	0.1	64,665,456	66,297,904	0.021
6	0.8	0.2	66,556,987	28,957,348	0.035
7	0.6	0.4	67,564,958	10,762,312	0.042
8	0.5	0.5	68,546,235	8,156,475	0.042
9	0.4	0.6	71,002,564	7,075,526	0.042
10	0.3	0.7	72,356,214	5,062,549	0.043
11	0.2	0.8	74,256,325	3,467,381	0.042
12	0.1	0.9	75,659,125	1,680,228	0.043
13	0.1	0.96	76,256,124	1,604,948	0.043
14	0.05	0.95	126,820,064	800,256	0.029

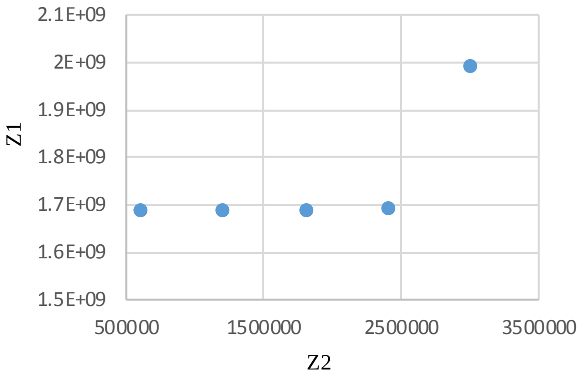

Figure 3. The Pareto optimal set for the numerical instance

five different solutions as options for choosing by decision makers. The trend of the first four points indicates that, although the second objective is improving, the total expected cost as the first objective function does not get worse significantly.

6. 2. Sensitivity Analysis In order to choose the proper strategy for the retailer, here we need to determine the impact of key parameters on the result. Therefore, in this section, the effect of four bellow key parameters on decision variables and objective functions are investigated:

The cost of purchasing raw material (cp);

The holding cost (h);

Number of Customer (C);

Elasticity of demand (α).

The results of model sensitivity analysis have been shown graphically as Figures 4 to 8 for uniform supply time mode. It is noteworthy that the weight of the first and second objective functions is considered equal to 0.6 and 0.4 respectively for sensitivity analysis. As can be seen, with increasing cost parameters (cp, h, C), the selling price will increase, the accumulated size will decrease, and as a result, the profit (Z^*) will increase due to the increase in selling price. As the elasticity of demand (α) increases, the accumulated size decreases because the more sensitive the commodity is to the selling price. The decline in demand will be more pronounced in the face of high prices. Changes in the resale point are also directly related to the service level.

In addition, changes in shortage costs will have the greatest impact on profit and service level, and the model is more sensitive to changes in shortage costs and purchase costs.

In addition, changes in shortage costs will have the greatest impact on profit and service level, and in determining the selling price, the model is more sensitive to changes in shortage costs and purchase costs. Given that the price is affected by the costs of purchase, maintenance, and shortage, in the present example the above parameters are considered equal.

The results show that the average accumulated size is also the level of customer service in a situation where supply time is exponentially distributed; It is higher, but in contrast to the amount of annual profit from the model with a uniform preparation time, is higher. In other words, if the retailer is looking to make more profit; A model with a uniform preparation time is proposed.

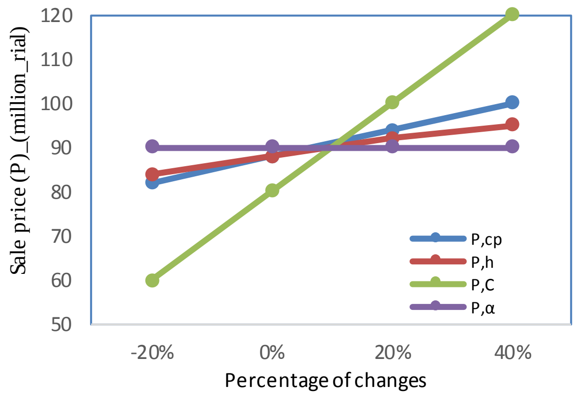

Figure 4. The sale price responding to changes in cp, h, C, and α

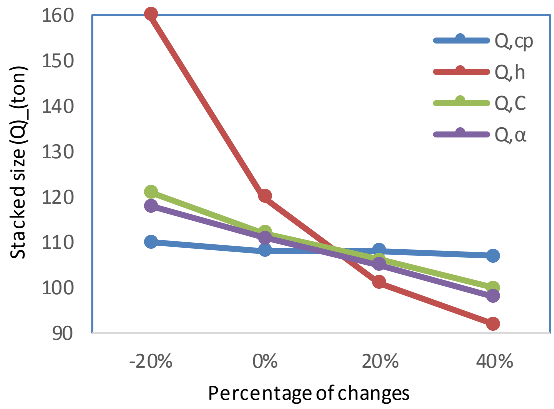

Figure 1. The Stacked size responding to changes in cp, h, C, and α

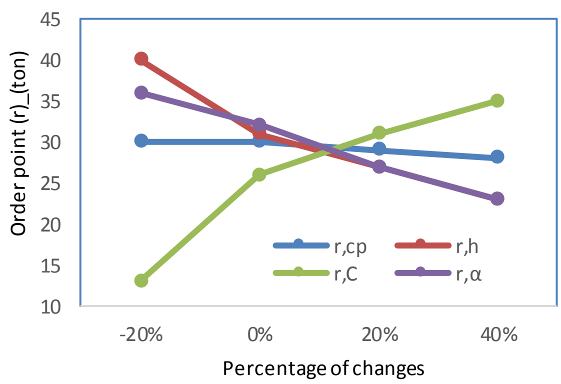

Figure 6. The order point responding to changes in cp, h, C, and α

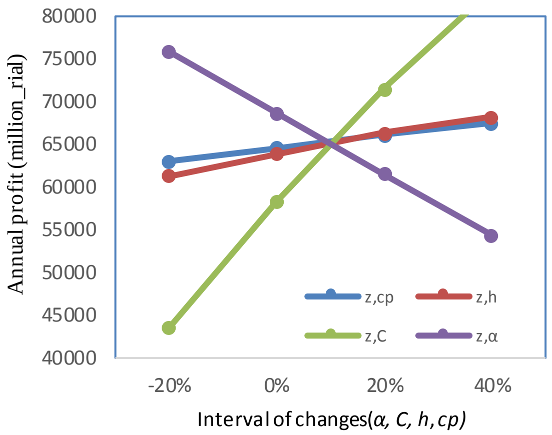

Figure 7. The annual profit responding to changes in cp, h, C, and α

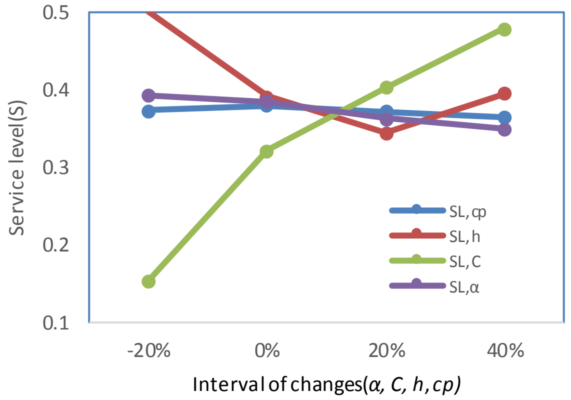

Figure 8. The service level responding to changes in cp, h, C, and α

6. 3. Managerial Insight The purpose of this study was to properly manage food cold supply chain for prevent of reducing food quality which the improper manage can lead to economic losses and undesirable effects on food accessibility. In addition, the proposed model can assist the food cold supply chain managers in making strategic decisions. According to conducted research in the field of food cold supply chain in Iran, it can be understood that despite many costs paid in this area and several facilities opened Iran has not reached its proper place in this field yet. In fact, if Iran can optimize costs and efforts in this area and have a proper food cold supply chain network, it is hoped that in recent years, it can improve its situation and be able to even provide a model for developing countries. In the following, some of the recommendations for food cold supply chain managers are presented to improve this chain in Iran:

- In order to be present in the international and even domestic arenas, quality control and cost management must be among the main goals of economic enterprises, because today the field of production is not only national and regional. Cost and standard costing policies alone cannot be responsible for product production and international integration and new methods such as activity-based costing and quality costing will be the solution to the problems of institutions in this field.
- For organizations that have a market development strategy, such as diversifying and increasing product production, supply chain management and using a quality costing approach is a vital requirement, because there is complete coordination between all the required activities that the operation helps to increase profitability.
- In order to produce in a timely manner and of course with appropriate quality, the product or service produced must be distributed in the right place and in a timely manner. Achieving this goal in order to create and expect customer satisfaction with the minimum cost and quality control costs at an acceptable level at the system level is a vital need.

7. CONCLUSION

The supply chain is the complete process of providing goods and services to the end consumer, and its management includes coordination between all activities required for an operation to increase profitability. In supply chain management, the goal is to optimize all the decisions that occur during this chain, and cost reduction is the driving force of supply chain management. Because the benefits of quality costs include lowering the cost of the product, creating greater competitiveness with competitors, investing and taking remedial steps to achieve more standard conditions, and the possibility of improving production, companies stay in the global competitive arena and produce products. Competing with cheaper and higher quality products of others, they need to use quality costing method and the present article has analyzed this field so that companies can have efficient management in the supply chain by using this costing method.

This study aimed to present an integrated and comprehensive model which greatly pays attention to important key factors of the efficiency and effectiveness in a cold supply chain. In the research, besides noticing comprehensively both supply chain quality and cost, an appropriate and comprehensive design is considered for four echelon supply chain consists of several suppliers, one manufacturing plant, different distribution centers and customers and the proposed model are used in a real world and can be customized a little in order to be applicable for other supply chain. In the supply chain costs include both tangible costs and intangible costs. Supplier Quality manufacture quality and distribution center quality are also considered. The proposed bi-objective model in changed by parametric optimization into the one objective function and solved by an exact solver for a numerical example (a medium-sized problem) in the real condition. The computational results and the existed analysis represent the efficiency of the proposed model and the exact solution for small-sized scales.

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Persian Abstract

چکیده

مدیریت نادرست زنجیره تامین سرد مواد غذایی ممکن است ایمنی غذایی را به خطر انداخته و کیفیت را کاهش دهد که می‌تواند منجر به ضررهای اقتصادی و اثرات نامطلوب بر دسترسی به غذا شود. بنابراین طراحی یک زنجیره تامین سرد کارآمد و مورد اعتماد برای شرکت، تامین کنندگان، مشتریان و جامعه بسیار مهم است. اکثر مطالعات سنتی در زنجیره تامین هزینه کیفیت (پیشگیری، ارزیابی و شکست) را در طراحی شبکه زنجیره تامین در نظر نمی‌گیرند. در این مطالعه، تمام ابعاد هزینه کیفیت در طراحی زنجیره تامین سرد مانند هزینه کیفیت تامین کنندگان و هزینه کیفیت خدمات توزیع مورد بررسی قرار گرفته است تا مشکل به شرایط دنیای واقعی نزدیک گردد. علاوه بر این، کیفیت تامین کنندگان، تولید کنندگان و توزیع کنندگان به طور همزمان در سراسر زنجیره تامین با رویکردی جدید در نظر گرفته می‌شود. برای این منظور، مسئله به عنوان یک مدل ریاضی برای موارد چند محصولی و چند دوره‌ای با در نظر گرفتن دو تابع هدف فرمول‌بندی شده است. تابع هدف اول کل هزینه‌های مورد انتظار را به حداقل می‌رساند و تابع هدف دوم کیفیت کل زنجیره تامین را به حداکثر می‌رساند. مدل دو هدفه پیشنهادی با حل روش پارامتری (جمع وزنی نرمال شده) به یک مدل تک هدفه تبدیل شده و برای یک نمونه متوسط با در نظر گرفتن داده‌های یک مطالعه موردی در دنیای واقعی حل شده است. نتایج محاسباتی و تحلیل‌ها نشان‌دهنده کارایی مدل پیشنهادی و همچنین روش حل دقیق موجود برای مقیاس‌های کوچک و متوسط است. مطالعه موردی واقعی که شرکت لبنیات کاله را شامل می‌شود، برای نشان دادن پتانسیل مدل پیشنهادی و تحلیل‌های حساسیت مناسب انجام شده است.