Advances in Industrial Engineering, June 2023, 57(1): 1-20
DOI: 10.22059/AIE.2022.338983.1825
RESEARCH PAPER

A Location-Inventory Model for Multi-Product Supply Chain with Perishable Products and Price-Dependent Demand

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Received: 13 February 2022, Revised: 21 May 2022, Accepted: 29 May 2022

Abstract

One of the most challenging tasks in the perishable products industry is to control the inventory of products and find the optimum location to store them. This paper tries to respond to these challenges in a way that is close to reality. In this paper, a location-inventory model has been studied for a supply chain with perishable products, considering the dependence of demand to price. The investigated multi-product and multi-period supply chain includes manufacturers, distributors, retailers and customers. Products and centers of this chain are equipped with Radio Frequency Identification (RFID) technology. The location-inventory model, by simultaneously capturing strategic, tactical and operational decisions, can be very effective in increasing the supply chain efficiency. For this purpose, a mixed integer nonlinear programming model is presented. The purpose of the model is to maximize the profitability of the supply chain, which is achieved by the simultaneous decision-making of location, inventory, pricing and demand. Finally, in order to show the efficiency of the proposed model, numerous examples with various parameters are solved and sensitivity analysis is done. The results show that as the dependence of customer demands on price increases, it is inevitable that the supply chain sells the product to customers at a lower price and lower profit, and this causes an extreme decrease in supply chain profit. The lower dependence on the supply chain results in higher profit.

Keywords:
Supply Chain Management; Location-Inventory; Perishable Products; Dependence of Demand on Price.

Introduction

In this paper, a multi-product supply chain model has been developed that includes four levels, manufacturers, distributors, retailers and customers. The products of this supply chain are perishable. The main goal is to increase profitability by reducing costs and increasing revenues. A well-designed and integrated supply chain can facilitate the achievement of the stated goal.

Supply chain decisions are divided into three categories: strategic, tactical, and operational. Strategic decisions have long-term effects, such as locating manufacturers and distributors. tactical decisions have medium-term effects, such as inventory and demand, and operational decisions have short-term effects, such as distribution and routing. In the past, these decisions were examined separately. However, the optimal solution for each of these decisions separately does not necessarily mean that they are optimal for the other. The situation where each level tries to maximize their benefit regardless of the others may lead to a local optimum and

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sometimes lead to higher total costs[1-6]. Generally, supply chain design consists of three issues of locating, inventory, and routing the vehicle. Most researchers consider a combination of these three issues and focus more on locating-inventory, location-routing, and inventory-routing and location-inventory-routing issues than others (e.g., Diabat et al. [7], Amiri-Aref et al. [8], Zheng et al. [9], Mousavi et al. [10], Rodrigues et al. [11], and Saragih et al. [12]).

In locating -inventory issues, the number and location of active production and distribution centers, how customers are allocated to the centers and finally, the amount of inventory of the centers is set so that increase profits and reduce costs. In the chain designed in this paper, customer demand is controlled by price leverage. In this paper, the inventory-based model and demand control are designed through supply chain pricing for perishable products to increase the overall profit of the chain. The demand in this chain is considered to be price-dependent, in fact, the model has the ability to manage and control demand through price leverage. There are a number of potential locations for creating production, distribution and retail outlets, which allows the model to choose the best location for building centers. technology through RFID waves is presented and the cost of this technology is included in the model. The distinction of this research from others is considering different states for product corruption, price-dependent demand and the use of radio frequency identification technology. The main aim of this research is to maximize profits in the supply chain of perishable products. Other goals of this research include the optimal management of demand, inventory, location and pricing with respect to product corruption. The results of model sensitivity analysis show the efficiency of the proposed model.

Problem Definition

In this paper, a four-level, multi-product and multi-period supply chain is considered. Products in this chain are considered to be perishable. Fig. 1 illustrates supply chain flows. The rate of product corruption in each distributor and retailer can be different for each product in each period. In this model, the date (period) of the receipt of the product at the preservation centers is taken directly (inventory variable index) and this can be used to evaluate the age of the products in the preservation centers.

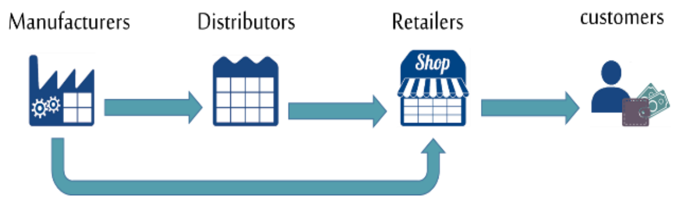

Fig. 1. supply chain flows

The remainder of this paper is organized as follows: In Section 2, the literature review is provided. In Section 3, the formulation of the general model is explained. In Section 4, implementation and evaluation are presented. In Section 5, conclusion is outlined.

Literature Review

An important issue that leads to increased corporate profits in a competitive environment is the design of an efficient supply chain network. Location decisions are in strategic decision making and inventory control is in the set of operational/tactical decision-making sets. Gzara et al. [13] have stated that traditionally these decisions are made individually. In order to achieve effective supply chain structure, location and inventory issues must be developed, Simultaneously.

Daskin et al. [14] proposed a nonlinear integer programming model for an inventory problem and proposed a Lagrangian liberation method for solving it.

They designed a supply chain for the blood products needed by Chicago hospitals and considered the product's corruptive limits in their model and analyzed the sensitivity of the results with changes in important parameters.

Shen et al. [15] examined a location and inventory problem involving one supplier and several retailers and considered demand in their study. Their model considers the selection of some customers as distribution centers, which receive the goods from the supplier and send them directly to other points of demand.

The purpose of their model is to determine the number of distribution centers, their location and the allocation of customers to distribution centers. The order size that each distribution center distributes to the upstream suppliers of the chain is dependent on the customers who have been assigned to the distribution center.

Ouyang et al. [16] reviewed an inventory control model for instant perishable products by purchasing credit and fixed demand. The purpose of this paper is to determine the optimal warehouse re-filling policy to minimize total inventory-related costs. Finally, according to the results of the numerical example, several solutions to reduce annual inventory-related costs have been proposed.

Miranda and Garrido [17] linked inventory control decisions to the facility locating problem. A mixed integer nonlinear programming model that implemented a solution with Lagrange liberation and other common practices are presented by them.

Atamturk et al. [18] presented a non-linear integer programming model for a location-inventory problem and considered two capacity constraints. They solved this problem by a method based on Lagrange liberation and its other sub-methods.

Vidyarthi et al. [19] designed a multi-product inventory-distribution system with uncertain demand. The purposes were to determine the location of the factory and distribution centers, to allocate retailers to the distribution centers, and the amount of transportation from the factory to distribution centers and warehouses. They modeled the problem as an integer nonlinear programming problem.

A model in which the customer's daily demand is uncertain and the time that product arrives from supplier to distributor is depended is presented by Park and Sung [20]. In this paper, distribution centers follow the periodic review inventory policy.

Shahabi et al. [21] continued the work of Park et al In order to develop it. They considered the retailer's demand, dependency and provided a mathematical programming model for this problem and presented an external approximation solution to solve it.

Amorim et al. [22] presented a model for two types of perishable products. The first group belongs to products that have a certain lifespan (e.g., blood products) and the second category refers to goods which have an indefinite lifespan (e.g., crops). They modeled this problem as an integer nonlinear programming problem.

Piewthongngam et al. [23] presented a model for the production and distribution of perishable goods. In the model, several factories as production centers, several farms as demand centers, several types of products and several time periods are considered. The amount of demand for each point is determined in two ways. The first step is to determine the amount of demand in each phase of the planning horizon, and the next step is to estimate the amount of demand for periods after the planning horizon. In each of the above cases, the initial estimate of demand is determined according to the existing guidelines and in the next steps, depending on the amount of consumption in each group and the responsibility of that group, the amount of demand is corrected. The proposed model is nonlinear and solves with the original algorithm.

Shahabi et al. [24] studied a location-inventory issue within the supply chain, including suppliers, hubs, warehouses and retailers. The goal was to minimize the location, inventory and transportation costs. They raised this issue as a mixed-integer non-linear programming and then modified it as a mixed integer second order cone programming and their results showed that complex problems can be solved by modifying the formula and using common solvers.

Coelho and Laporte [25] presented an integrated production-distribution model for perishable products. three policies of sending older products, submitting newer products and optimized sending of product modeling is applied by them to inventory. Their model is solved by a branch and bound algorithm.

Van Elzakker et al. [26] presented an integrated inventory-location model for perishable products. The problem was considered in four cases, regardless of age factor, regarding the age of products directly, regarding the age of products indirectly, calculating the age of the products in combination with the previous scenarios, in the form of four mixed-integer linear programming mathematical models with the goal of minimizing the total cost of System presented.

Berman et al. [27] studied a location-inventory model with time-sensitive demand for assigning the customer to the facility, they focused on two mechanisms: a directed allocation in which operators of facilities steer customer to the facilities and customer choice, in which customers assign themselves to the facilities. their facilities. They compared location-inventory issues with direct allocation and customer choice and provided two innovative algorithms for these models and showed the accuracy of these algorithms.

Kaya and Urek [28] modeled the location-inventory-pricing problem in a supply chain through decision-making on the location of facilities, inventory control and pricing, simultaneously, in order to maximize overall profits in their designed supply chain network. They proposed a hybrid meta-heuristic algorithm including Tabu Search algorithms, simulated-annealing and genetic algorithm to solve the proposed model.

Hiassat et al. [29] presented a location-inventory-routing model for perishable products. The model specifies the number of places needed to build warehouses, the inventory levels of each retailer and the routes traveled by each vehicle. The proposed model adds location decisions to the problem of inventory routing to make the model more realistic and practical. The proposed model is non-linear and solved by the genetic algorithm.

Soto-Silva et al. [30] presented an integrated location-inventory model for horticultural products and fruit. In this model, there are three modes of purchase model, sales model and integrated sales model. In all models, the goal is to minimize the total cost of the system. In the first model, the optimal purchase price is determined by each supplier. In the second model, the optimal allocation of products takes place in the existing warehouses and cold stores. Finally, the integrated model also determines the optimal amount of purchases and optimal allocation to the cold stores.

Mohammed and Wang. [31] provided a location-inventory model for perishable products. Their model is a three-level supply chain for perishable commodities (meat). The first level of the chain includes livestock farms which are the centers of production in the network. Healthy livestock is carried to the second level of the chain, slaughterhouses, to be slaughtered and slaughterhouses are considered as distribution centers. After the killing of cattle, meat is sent as the final product to retailers who are assumed to have demand points in this model. The aim of the research is to find the optimal location of production centers and distributions through the potential points available and the optimal amount of products transferred between different centers.

Savadkoohi et al. [32] Have developed a location-inventory model for the drug supply chain. In their model, strategic decisions (opening of production and distribution centers) and tactical decisions (material flow in the chain and amount of inventory) are made to minimize the total cost of the chain. They tested it in a real case study to validate and analyze the model they presented.

Dai et al. [33] developed an inventory location model for a supply chain of perishable products. In their model constraints are set for greenhouse gas emissions. The model is a mixed integer nonlinear programming (MINLP) and is proposed to solve the hybrid genetic algorithm (HGA) and the hybrid harmony search (HHS) to minimize supply chain costs.

Yavari and Geraeli [34] designed a green closed-loop supply chain for perishable products. Their designed supply chains are multi-product, multi-period and include suppliers, manufacturers, warehouses, retailers and collection centers. Demand, the rate of return and the quality of returned products are considered to be uncertain. Their model is mixed-integer linear programming (MILP). Minimizing the supply chain costs and environmental pollutants are the objectives of this model. The results show that products' lifetime and levels of uncertainty have different effects on objectives.

Rohmer et al. [35] designed an inventory routing model for the supply chain of perishable products. In their studied supply chain, the products are transferred from supplier to warehouse, if necessary, the products are stored in the warehouse and then delivered to the customers from the warehouse. The objective of their model is to minimize transportation and storage costs. The designed model is mixed-integer linear programming (MILP) And the neighborhood search algorithm is used to solve the model.

Aghsami et al. [36] proposed an integrated Markovian queueing-inventory model with a single retailer and single supplier problem with imperfect quality and destructive testing acceptance Sampling.

Kaya et al. [37] investigated a model to determine the best s, S inventory management levels in e-groceries under some rules. Here, s and S represent, re-order and order-up-to levels for replenishment of products.

Taleizadeh et al. [38] presented a sustainable inventory system with price-sensitive demand and carbon emissions under partial trade credit and partial backordering.

Soleymanfar et al. [39] developed a new model to determine optimum sustainable economic order quantity (EOQ) and economic production quantity (EPQ) values for multiple products of a supply chain with two echelons, consisting of a retailer and a supplier, considering product return policy.

Arabi et al. [40] Maximizing total profit as an economic aspect, minimizing sound pollution as a social aspect, and minimizing dust pollution as an environmental aspect of sustainability are considered simultaneously in this paper for the first time. The results show the great potential of installing quarries in the center of Iran geographically.

Zafari and Shishebori [41] The study introduces a multi-objective three-stage location-routing problem in designing an efficient and timely distribution plan in the response phase of a possible earthquake. The objective functions of the proposed problem include minimizing the unsatisfied demands, minimizing the arriving times, and minimizing the relief operations costs.

Bakhtiari et al. [42] proposed a location-routing problem with simultaneous pickup and delivery under a hard time window that has a heterogeneous and limited depot and vehicle capacities and a multi-variety of products and uncertain traveling time that considering all of these constraints together make the problem closer to real practical world’s problems. results in the Robust model show that increasing the confidence level has led to an increase in the value of the objective function of the robust counterpart model.

Mixed Integer Non-linear Programming Model

In this model, we consider a multi-product and multi-period supply chain with perishable items. This supply chain consists of manufacturers, distributors, retailers and customers. The rate of product corruption in each distributor and retailer can be different for each product in each period. The main purpose of the model is to design a supply chain for perishable products, in such a way that the chain's profit becomes maximized. For this purpose, the model simultaneously tries to increase revenues and reduce the total cost of the chain. To achieve this goal, the model determines the location, inventory, price and demand variables in a way that the objective function of model approaches the optimality.

The assumptions, used symbols and the model is presented in the following sections.

Assumptions

In this paper, the following assumptions are considered for the desired problem:

- The model has four levels, including manufacturers, distributors, retailers and customers.
- The planning horizon has several periods.
- The product distributed in the chain is perishable.
- The system is intended for several product types.
- Product demand in each period depends on the price of the product in the same period.
- The number and location of facilities at the beginning of the planning horizon for the entire planning horizon should be selected from potential locations.
- The only manufacturer, in some situation, can supply its products directly to the retailer to prevent corruption.
- Only distributors and retailers can store products.
- Manufacturers and customers are not allowed to store products.
- Distributors and retailers can store their products for a specified period of time.
- The rate of corruption in distributors is lower than that of retailers.
- The delivery time of the product is very short in comparison with the duration of the planning period and can be discarded.
- Manufacturers have limitations in production.
- Distributors and retailers have storage limits.
- The number of manufacturers, distributors, and retailers is limited.

Sets

F set of manufacturers (1... *f*... *F*)
W set of distributors (1... *w*... *W*)
D set of retailers (1... *d*... *D*)
C set of customers (1... *c*...*C*)
U set of products (1... *u*... *U*)
T set of periods (1... *t*... *T*)
J set of the number of permitted product storage periods in the distributor *(1... j... J)*
K set of the number of authorized storage periods at the retail store *(1... k... K)*

Parameters

$\boldsymbol{F_f}$ fixed cost of running the manufacturer *f*.
$\boldsymbol{F_w}$ fixed cost of running the distributor *w*.
$\boldsymbol{F_d}$ fixed cost of running the retailer *d*.
$\boldsymbol{MFC_{fut}}$ cost of producing related to manufacturer *f* for each unit of product *u* during period *t*.
$\boldsymbol{Tc_{ut}}$ cost of transporting each unit of product *u* in period *t*.
$\boldsymbol{WH_{wut}}$ preservation cost related to distributor *w* for each unit of product u in period *t*.
$\boldsymbol{DH_{dut}}$ preservation cost related to retailer *d* for each unit of product *u* in period *t*.
$\boldsymbol{FEC_{wut}}$ cost of corruption related to distributor *w* for each unit of product *u* in period *t*.
$\boldsymbol{FEC_{dut}}$ cost of corruption related to retailer *d* for each unit of product *u* in period *t*.
$\boldsymbol{RFID\ SC}$ cost of installing RFID system in each facility.
$\boldsymbol{RFID\ TC}$ cost of installing an RFID tag on any product produced.
$\boldsymbol{DS_{fw}}$ distance between manufacturer *f* and distributor *w*.
$\boldsymbol{DS_{fd}}$ distance between manufacturer *f* and retailer *d*.
$\boldsymbol{DS_{wd}}$ distance between distributor *w* and retailer *d*.
$\boldsymbol{DS_{dc}}$ distance between retailer *d* and customer *c*.

$\boldsymbol{FC_{fut}}$ maximum production capacity related to manufacturer *f* for each type of product *u* in period *t*.
$\boldsymbol{WC_{wut}}$ maximum storage capacity related to distributor *w* for each unit of product *u* in period *t*.
$\boldsymbol{DC_{dut}}$ maximum storage capacity related to retailer *d* for each unit of product *u* in period *t*.
$\boldsymbol{Dp_{cut}}$ maximum demand of customer *c* for product *u* in period *t.*

$\boldsymbol{NSAW_{wut}}$ health rate related to distributor *w* for product type *u* in period *t.*
$\boldsymbol{NSAD_{dut}}$ health rate related to retailer store *d* product *u* in period *t.*
$\boldsymbol{NFEW_{wut}}$ corruption rate related to distributor *w* for product *u* in period *t.*
$\boldsymbol{NFED_{dut}}$ corruption rate related to retailer store *d* for product *u* in period *t.*
$\boldsymbol{ZVT_{cut}}$ coefficient of reduction in demand versus the rise in the price related to customer *c* for product *u* during period *t.*
$\boldsymbol{M}$ large number.

Binary decision variables

$\boldsymbol{L_f}$ if manufacturer f is chosen to be present in the chain, it takes one, otherwise it will get zero.
$\boldsymbol{L_w}$ if the w distributor is chosen to be present in the chain, it takes one, otherwise it will get zero.
$\boldsymbol{L_d}$ if retailer *d* chosen be present in a chain, it takes one, otherwise it gets zero.
$\boldsymbol{Li_{fw}}$ if the connection between the manufacturer *f* and the distributor *w* takes one, otherwise it takes zero.
$\boldsymbol{Li_{fd}}$ if the connection between the manufacturer *f* and the retailer *d* takes place, it takes one, otherwise it will be zero.
$\boldsymbol{Li_{wd}}$ if the connection between the distributor *w* and the retailer *d* takes place, it takes one, otherwise it will be zero.
$\boldsymbol{Li_{dc}}$ if the connection between retailer *d* and customer *c* takes a value of one, otherwise it will be zero.

Decision variables

$\boldsymbol{P_{ut}}$ price of each product unit *u* in period *t*
$\boldsymbol{D_{cut}}$ demand of Customer *c* for product *u* in period *t*
$\boldsymbol{A_{fut}}$ amount of product *u* produced by the manufacturer *f* during period *t*
$\boldsymbol{Q_{fwut}}$ quantity of product *u* transferred between producer *f* and distributor w in period *t*
$\boldsymbol{Q_{fdut}}$ quantity of transferred product *u* between manufacturer *f* and retailer *d* in period *t.*
$\boldsymbol{Q_{wdut}}$ quantity of product *u* transferred between distributor *w* and retailer *d* during period *t.*
$\boldsymbol{Q_{dcut}}$ The amount of product *u* transferred between retailer *d* and customer *c* during period *t.*
$\boldsymbol{R_{uw(t-j)t}}$ inventory of product *u* related to distributor *w* from period *(t-j)* at the beginning of period *t.*
$\boldsymbol{R_{du(t-k)t}}$ amount of product inventory *u* from period *(t-k)* at retailer *d* at the beginning of period *t.*
$\boldsymbol{I_{wu(t-j)t}}$ amount of product inventory *u* from period *(t-j)* at distributor *w* at the end of period *t.*
$\boldsymbol{I_{du(t-k)t}}$ amount of product inventory *u* from period *(t-k)* at retailer *d* at the end of period *t.*
$\boldsymbol{Dl_{wu(t-j)t}}$ amount of withdrawal from the product inventory *u* from period *(t-j)* at distributor *w* in period *t.*
$\boldsymbol{Dl_{du(t-k)t}}$ The amount of withdrawal from the product inventory *u* from period *(t-k)* at retailer *d* in period *t.*

The purpose of the proposed model is to maximize profits and it can be computed through relation (1). The objective function is the result of the difference between the revenue and the total cost of the chain. Eqs. 2 and 3 compute the total revenue and the total cost of the chain, respectively. The total cost includes fixed costs, production, transportation, preservation, product corruption, and identification through frequency waves costs, respectively, through Eqs. 4-9 is calculated.

$$\max Z = REV - TOC \tag{1}$$

$$REV = \sum_{c}\sum_{u}\sum_{t}(P_{ut} \times D_{cut}) \tag{2}$$

$$TOC = FC + MC + TC + HC + PC + RFC \tag{3}$$

$$FC = \sum_{f}(F_f \times L_f) + \sum_{w}(F_w \times L_w) + \sum_{d}(F_d \times L_d) \tag{4}$$

$$MC = \sum_{f}\sum_{u}\sum_{t}(A_{fut} \times MFC_{fut}) \tag{5}$$

$$\begin{aligned} TC = {} & \sum_{f}\sum_{w}\sum_{u}\sum_{t}(Q_{fwut} \times Tc_{ut} \times DS_{fw}) + \sum_{f}\sum_{d}\sum_{u}\sum_{t}(Q_{fdut} \times Tc_{ut} \times DS_{fd}) + \sum_{w}\sum_{d}\sum_{u}\sum_{t}(Q_{wdut} \times Tc_{ut} \times DS_{wd}) \\ & + \sum_{d}\sum_{c}\sum_{u}\sum_{t}(Q_{dcut} \times Tc_{ut} \times DS_{dc}) \end{aligned} \tag{6}$$

$$HC = \sum_{w}\sum_{u}\sum_{t}\sum_{j}(R_{wut(t-j)} \times WH_{wut}) + \sum_{d}\sum_{u}\sum_{t}\sum_{k}(R_{dut(t-k)} \times DH_{dut}) \tag{7}$$

$$\begin{aligned} PC = {} & \sum_{w}\sum_{u}\sum_{t}(I_{wutt} \times FEC_{wut} \times NFEW_{wut}) + \sum_{w}\sum_{u}\sum_{t}\sum_{j}(I_{wut(t-j)} \times FEC_{wut} \times NFEW_{wut}) \\ & + \sum_{d}\sum_{u}\sum_{t}(I_{dutt} \times FEC_{dut} \times NFED_{dut}) + \sum_{d}\sum_{u}\sum_{t}\sum_{k}(I_{dut(t-k)} \times FEC_{dut} \times NFED_{dut}) \end{aligned} \tag{8}$$

$$RFC = \left(\sum_{f} L_f \times RFID\ SC + \sum_{w} L_w \times RFID\ SC + \sum_{d} L_d \times RFID\ SC\right) + \left(\sum_{f}\sum_{u}\sum_{t}(A_{fut} \times RFID\ TC)\right) \tag{9}$$

Subject to:

$$D_{cut} = Dp_{cut} - (ZVT_{cut} \times p_{ut}) \qquad \forall c, u, t \tag{10}$$

$$A_{fut} = \sum_{w} Q_{fwut} + \sum_{d} Q_{fdut} \qquad \forall f, u, t \tag{11}$$

$$\sum_{f} Q_{fwut} + \sum_{j} R_{wut(t-j)} \geq \sum_{d} Q_{wdut} + I_{wutt} + \sum_{j} I_{wut(t-j)} \qquad \forall w, u, t \tag{12}$$

$$\sum_{f} Q_{fdut} + \sum_{w} Q_{wdut} + \sum_{k} R_{dut(t-k)} \geq \sum_{c} Q_{dcut} + I_{dutt} + \sum_{k} I_{dut(t-k)} \qquad \forall d, u, t \tag{13}$$

$$\sum_{d} Q_{dcut} = D_{cut} \qquad \forall c, u, t \tag{14}$$

$$A_{fut} \leq FC_{fut} \times L_f \qquad \forall f, u, t \tag{15}$$

$$\sum_{f} Q_{fwut} + \sum_{j} R_{wut(t-j)} \leq WC_{wut} \times L_w \qquad \forall w, u, t \tag{16}$$

$$\sum_{w} Q_{wdut} + \sum_{f} Q_{fdut} + \sum_{k} R_{dut(t-k)} \leq DC_{dut} \times L_d \qquad \forall d, u, t \tag{17}$$

$$Li_{fw} \leq \sum_{u}\sum_{t} Q_{fwut} \qquad \forall f, w \tag{18}$$

$$\sum_{u}\sum_{t} Q_{fwut} \leq M \times Li_{fw} \qquad \forall f, w \tag{19}$$

$$Li_{fd} \leq \sum_{u}\sum_{t} Q_{fdut} \qquad \forall f, d \tag{20}$$

$$\sum_{u}\sum_{t} Q_{fdut} \leq M \times Li_{fd} \qquad \forall f, d \tag{21}$$

$$Li_{wd} \leq \sum_{u}\sum_{t} Q_{wdut} \qquad \forall w, d \tag{22}$$

$$\sum_{u}\sum_{t} Q_{wdut} \leq M \times Li_{wd} \qquad \forall w, d \tag{23}$$

$$Li_{dc} \leq \sum_{u}\sum_{t} Q_{dcut} \qquad \forall d, c \tag{24}$$

$$\sum_{u}\sum_{t} Q_{dcut} \leq M \times Li_{dc} \qquad \forall d, c \tag{25}$$

$$R_{wut(t-j)} = I_{wu(t-1)(t-j)} \times NSAW_{wut} \qquad \forall w, u, t, j \tag{26}$$

$$\sum_{f} Q_{fwut} - Dl_{wutt} = I_{wutt} \qquad \forall w, u, t \tag{27}$$

$$R_{wut(t-j)} - Dl_{wut(t-j)} = I_{wut(t-j)} \qquad \forall w، u، t، j \quad (28)$$

$$Dl_{wutt} + \sum_{j} Dl_{wut(t-j)} = \sum_{d} Q_{wdut} \qquad \forall w، u، t \quad (29)$$

$$R_{dut(t-k)} = I_{du(t-1)(t-k)} \times NSAD_{dut} \qquad \forall d، u، t، k \quad (30)$$

$$\sum_{w} Q_{wdut} + \sum_{f} Q_{fdut} - Dl_{dutt} = I_{dutt} \qquad \forall d، u، t \quad (31)$$

$$R_{dut(t-k)} - Dl_{dut(t-k)} = I_{dut(t-k)} \qquad \forall d، u، t، k \quad (32)$$

$$Dl_{dutt} + \sum_{k} Dl_{dut(t-k)} = \sum_{c} Q_{dcut} \qquad \forall d، u، t \quad (33)$$

Pricing can be used as a tool for controlling and managing demand and thereby controlling production in the chain, in this way, the profit of the chain can be maximized by satisfying the desired level of demand.

Each customer has a definite demand and the demand for each of them is dependent on the price offered by the chain for that customer, but despite the competitive conditions of market and demand growth as well as limited production capacities, it does not appear to be necessary to meet all the demands by the producers.

Therefore, the producers must be able to control the level of demand by applying leverage and consequently his(their) productions, so by determining the appropriate price, the estimated rate of demand can be sought, which leads to the maximum revenue and profit and the minimum cost of the chain. In order to simplify the model and make the model more efficient, the numbers of satisfied requests will be assumed to be a linear function of the price of each market in each period.

The general function of demand estimation is Eq. 10 ($D_{cut} = Dp_{cut} - (ZVT_{cut} \times p_{ut})$) in which a coefficient ZVT_{cut} or rate of demand reduction is positive with increasing numerical price and Dp_{cut} is the maximum demand of the customer. In this function, price is considered as the problem variable and price determination is one of the objectives of the problem.

Eqs. 11-14 are designed to create a balance between the input and output rates of each Chain's center. Eq. 11 controls the amount of production and distribution of the product in the manufacturer, and states that the production of each manufacturer *f* of each product *u* in each period *t* must be equal to the quantity of product *u* which is transferred to the distributors *w* and retailers *d*. Eq. 12 states that in each period *t* the amount of product *u* received from the manufacturer *f* plus the amount of inventory (from previous periods) at the beginning of the same period at the distributor w must be greater than the inventory at the end of the same period and the product sent to the retailer d Be at that time.

Eq. 13 also holds the same for retailers. Eq. 14 states that the amount of product sent from retailer d to customer c must be equal to the value of met demand of customer c.

Eqs. 15-17 ensure that the capacity of the manufacturer, distributor and retailer is met. Eq. 15 ensures that the production of each active manufacturer f in the chain of product u in each period t must be less than the capacity of the manufacturer f of the product u in the same period t.

Eq. 16 states that for each period t the product amount u received from the manufacturer f plus the amount of product inventory (from past periods) at the beginning of the same period in the distributor *w*, with the condition that the distributor is active in the chain, should be less than the distributor's capacity w for the product u in the same period t.

As in the previous Eq. 17, in each period t, the amount of product u received from the manufacturer f plus the amount of product u received from the distributor w and the amount of inventory (from past periods) at the beginning of the same period in the retailer store d with the condition that the retailer is active in the chain should be less than the retailer d capacity of the product u in the same period t.

Eqs. 18-25 relate to the structural constraints of the supply chain network. Eqs. (18) and (19) are in fact one equation that has been converted into two parts in order to take a standard form.

This restriction is originally $Li_{fw} \leq \sum_u \sum_t Q_{fwut} \leq M \times Li_{fw}$. In this equation, M is a very large number. When the binary variable Li_{fw} gets zero, the two sides of this equation are zero, and in fact no product will be exchanged between the manufacturer f and the w distributor. But when the binary variable Li_{fw} takes one, the manufacturer f and the distributor w can Exchange product together from one unit to M. And so Eqs. 20 and 21 for the relationship between the manufacturer f and the retailer d, the restrictions (22) and (23) for the relationship between the distributor w and the retailer d, finally, Eqs. 24 and 25 for the relationship between retailer d and customer c.

Eqs. 26-29 state how inventory is hold in the distributor. Eq. 26 states how much of products at the end of the previous period *(t-1)* in the distributor *w* can be safely transferred to the beginning of this period *t*. Eq. 27 shows that the inventory of products at the end of the period which received in the same period is equal to the sum of products received from manufacturer in period *t* minus the withdrawal rate of these products in period *t*.

Eq. 28 shows that inventory at the end of the period is equal to the difference between the amount of inventory at the beginning of the period and the amount of withdrawal from inventory at that period. Eq. 28 states that in period t, the total impressions from the product u in the distributor w of the products from periods (t-j) through t must be equal to the total product u sent from this distributor to the total of d retailers that received products during this period.

Eqs. 30-33 represent how inventory is held in retail stores. Eq. 30 states how much of the inventory at the end of the previous period (t-1) in retailer d can be safely transferred to the beginning of this period t. Eq. 31 shows that the inventory at the end of the period from the products which received in the same period is equal to the sum of products received from manufacturers and distributors in period t minus the withdrawal of these products in period t.

Eq. 32 shows that inventory at the end of the period is equal to the difference between the amount of inventory at the beginning of the period and the amount of withdrawal from that inventory. Eq. 33 states that in period t, the total impressions from the product u in the retail store d of the products from periods *(t-k)* through *t* must be equal to the total product *u* sent from the retailer to the total customer *c* during the period *t*.

Model Linearization

As is clear, due to the multiplication of two continuous variables, relation (2) is in nonlinear state. Therefore, researchers have proposed to linearize this nonlinear state. Vidal and Goetschalckx, [40] linearized this nonlinear state, in a three-step as below.

Step 1: For each of the continuous variables of Eq. 2, an upper limit and a lower limit are determined in accordance with the constraints of the expressed model. the variables D_{cut} and p_{ut} are positive and continuous, the lower limit of both variables is zero. Given the constraint (10), the upper limit of the variables is Dp_{cut} and $\frac{Dp_{cut}}{ZVT_{cut}}$. Eqs. 34 and 35 show this.

$$0 \leq p_{ut} \leq \frac{Dp_{cut}}{ZVT_{cut}} \qquad \forall c، u، t \tag{34}$$

$$0 \leq D_{cut} \leq Dp_{cut} \qquad \forall c، u، t \tag{35}$$

Step 2: The result of the multiplication of the two continuous variables associated with relation (2) in each other is equal to another continuous variable(X_{cut}), and in the model instead of the product of the two continuous variables, this variable is replaced.

$$P_{ut} \times D_{cut} = X_{cut} \qquad \forall c، u، t \tag{36}$$

Step 3: Limits (37) and (38) are added to the constraints of the original model.

$$0 \le X_{cut} \le \frac{Dp_{cut} \times D_{cut}}{ZVT_{cut}} \qquad \forall c، u، t \qquad (37)$$

$$0 \le X_{cut} \le Dp_{cut} \times P_{ut} \qquad \forall c، u، t \qquad (38)$$

Implenetation and Evaluation

To evaluate the model's efficiency, the random parameters in the interval defined in Table 1 are used.

Table 1. Model Parameters

Parameter	Amount	Parameter	Amount
$\boldsymbol{F_f}$	100,000,000-120,000,000	DS_{fw}	100-500
$\boldsymbol{F_w}$	10,000,000-12,000,000	DS_{fd}	1000-2000
$\boldsymbol{F_d}$	5,000,000-6,000,000	DS_{wd}	500-1000
$\boldsymbol{MFC_{fut}}$	2000-2500	DS_{dc}	100-200
$\boldsymbol{Tc_{ut}}$	3-4	FC_{fut}	4000-6000
$\boldsymbol{WH_{wut}}$	2000-3000	WC_{wut}	3000-3500
$\boldsymbol{DH_{dut}}$	1000,2000	DC_{dut}	2500-3000
$\boldsymbol{FEC_{wut}}$	1000-1500	Dp_{cut}	2000-3000
$\boldsymbol{FEC_{dut}}$	1000-1500	$NSAW_{wut}$	0.9
$\boldsymbol{RFID\ SC}$	2,000,000	$NSAD_{dut}$	0.6
$\boldsymbol{RFID\ TC}$	25	$NFEW_{wut}$	0.1
$\boldsymbol{ZVT_{cut}}$	0.1	$NFED_{dut}$	0.4
		M	1000000000

In this section, with a set of problems created in different dimensions, the proposed model and analysis its results are implemented. Issues created for model testing These issues are solved in the GAMS environment on a computer with hardware specifications, 2.53 GHz core i5 processor and GB 8 memory running on Windows 7-64bit.

Sixteen randomly generated problems are designed in different dimensions and their specifications are shown in Table 2. In this table, T represents the number of periods of planning horizon, U denotes the number of product variations and F, W, D, C represent the potential number of manufacturers, distributors, retailers and customers. *J*, *K* represents the number of authorized holdings of inventory at distributors, retailers.

Table 2. Dimensions of Designed Issues

Issue no.	*k*	*j*	*T*	*U*	*C*	*D*	*W*	*F*
1	2	4	6	2	5	3	3	2
2	2	4	6	3	7	5	3	4
3	3	6	12	2	9	8	5	6
4	6	9	18	3	12	10	7	8
5	3	6	12	4	5	10	9	11
6	3	6	12	1	32	10	9	11
7	3	6	12	2	14	11	10	10
8	3	6	12	3	15	11	12	10
9	6	12	24	1	18	13	12	11
10	6	12	18	2	18	12	13	11
11	3	6	12	2	19	13	12	12
12	3	6	12	2	20	14	11	12
13	3	6	15	1	23	15	10	13
14	3	6	12	1	25	16	14	13
15	3	6	12	1	30	15	15	15
16	3	6	9	2	36	17	15	16

In Table 3, Z represents the objective function of the problem and the total profit of the chain. REV represents the total revenue of the chain. TOC is the total cost of the whole chain. The numbers in Table 3 are all multiples of 10^8.

Table 3. Output of model

Issue no.	*Z*	*REV*	*TOC*
1	4.3	8.93	4.63
2	9.86	16.1	6.23
3	18.5	32	13.5
4	59.62	95.2	35.6
5	22.1	35.4	13.3
6	27.7	51.6	23.9
7	29.8	51	21.2
8	48.3	79.3	31
9	37.9	64.9	27
10	58.9	96.7	37.8
11	39.4	67.2	27.9
12	42.4	70.8	28.4
13	28.2	49.2	21
14	23.8	41.4	17.6
15	27.9	50.9	23
16	54.9	95.9	41

In each repetition of the problem, an optimal answer is obtained, which has two types of variables: binary variables and continuous variables. Binary variables for designing the chain network and the selection of chain partners and continuous variables for planning production, distribution, inventory and also price and objective function variables. The supply chain network structure represents the companies that exist on the network and their relationship with other companies.

For example, in problem number 2, after solving the model and in the software output, the binary variables L and Li represent the supply chain structure. The variable L specifies which of the centers can be present in the supply chain structure. Each center where L is one is present in the supply chain structure, and if this variable is zero, they will be deprived of participation in the supply chain. In this example, the variable L for M4, W3, D1, D2 centers has a value of 1 and will be present in the network of the supply chain, and the remaining centers have zero and are not present in the network. This model does not decide on the presence of customers, but the members of the chain are obliged to respond to their requests.

The Li variable specifies the relationship between the chain members. The Li variable performs this by forming a matrix that includes the chain members (selected by the variable L) and all the customers of the chain. Each member of the chain in this matrix has its own row and column. Each strand has a value of 1, the rows and columns of that strand (chain members) are related to each other in the network structure. If the value of the strand is zero, then the two members have nothing to do with each other in the chain structure. The matrix below shows the output of the GAMS program for the Li variable in Problem 2.

$$\begin{array}{ccccccccccc} & w3 & d1 & d2 & c1 & c2 & c3 & c4 & c5 & c6 & c7 \\ m4 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ w3 & 0 & 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ d1 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 0 & 1 & 0 \\ d2 & 0 & 0 & 0 & 0 & 1 & 1 & 0 & 1 & 1 & 1 \end{array}$$

Fig. 2 shows the selected network in issue number 2 by the binary variables L and Li.

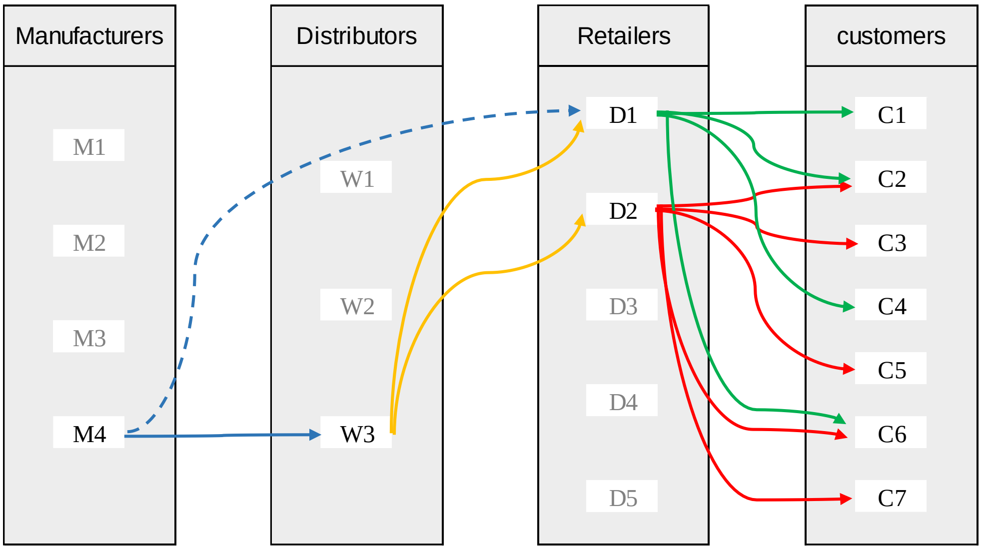

Fig. 2. selected Subnet

Sensitivity Analysis

Sensitivity analysis of demand reduction factor with increasing price

By increasing in the coefficient demand (reducing the rate of demand by increasing in prices) (ZVT_{cut}) in a period, the demanded amount to be provided by this chain should be reduced, as well as the total cost and total revenue of the chain will be reduced, resulting in overall profits of the chain also decreases. The results of this sensitivity analysis are presented in Table 4. In this table, the average price of a product type for the entire planning horizon is also calculated.

Fig. 3 shows any increases in *ZVT* causes decreases in total revenue and profit as well. changes in average prices according to an increase in *ZVT* is shown in Fig. 4. The increase in *ZVT* leads to a decrease in average price. Changes in demand according to increase in *ZVT* are seen in Fig. 5. Increases in *ZVT* leads to a decrease in total demand.

Table 4. Changes in demand reduction factor with increasing price

ZVT_{cut}	TOTAL DEMAND	AVERAGE PRICE	TOTAL REVENUE	TOTAL COST	TOTAL PROFIT
0.01	67098	127960.5	$9.61*10^9$	$7.6*10^8$	$8.85*10^9$
0.02	67098	72959.86	$4.8*10^9$	$7.6*10^8$	$4.04*10^9$
0.03	59572	48625.23	$3.09*10^9$	$7.11*10^8$	$2.48*10^9$
0.04	59585	36565.06	$2.32*10^9$	$7.1*10^8$	$1.71*10^9$
0.05	59597	29363.48	$1.86*10^9$	$6.1*10^8$	$1.25*10^9$
0.06	59605	24774.4	$1.55*10^9$	$6.1*10^8$	$9.37*10^8$
0.07	59495	21604.53	$1.32*10^9$	$6.09*10^8$	$7.16*10^8$
0.08	59122	19114.29	$1.16*10^9$	$6.06*10^8$	$5.5*10^8$
0.09	58652	17137.09	$1.03*10^9$	$6.04*10^8$	$4.22*10^8$
0.1	58224	19646.67	$9.21*10^8$	$6.1*10^8$	$3.2*10^8$
0.11	57377	17860.61	$8.33*10^8$	$6.09*10^8$	$2.36*10^8$
0.12	28962	16372.22	$4.97*10^8$	$3.08*10^8$	$1.89*10^8$
0.13	28962	15345.09	$4.59*10^8$	$3.08*10^8$	$1.51*10^8$
0.14	28962	14248.43	$4.26*10^8$	$3.08*10^8$	$1.18*10^8$
0.15	28962	13298	$3.97*10^8$	$3.08*10^8$	$8.96*10^7$
0.16	28962	12466.36	$3.73*10^8$	$3.08*10^8$	$6.47*10^7$
0.17	28962	11744.16	$3.51*10^8$	$3.08*10^8$	$4.28*10^7$
0.18	28788	11091.26	$3.3*10^8$	$3.07*10^8$	$2.33*10^7$
0.19	28542	10507.42	$3.11*10^8$	$3.05*10^8$	6049527

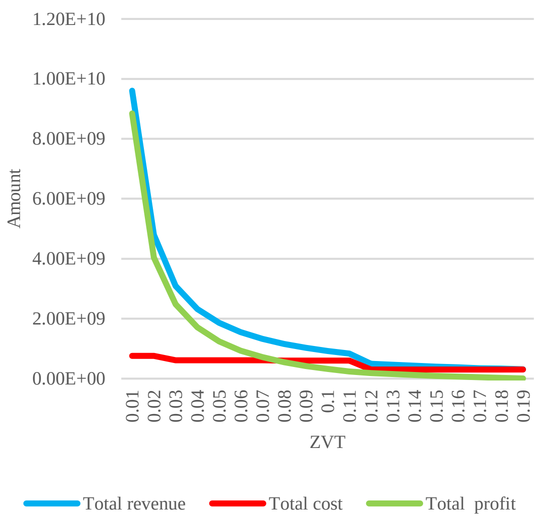

Fig. 3. Changes of total revenue, total cost and total profit according to increasing ZVT

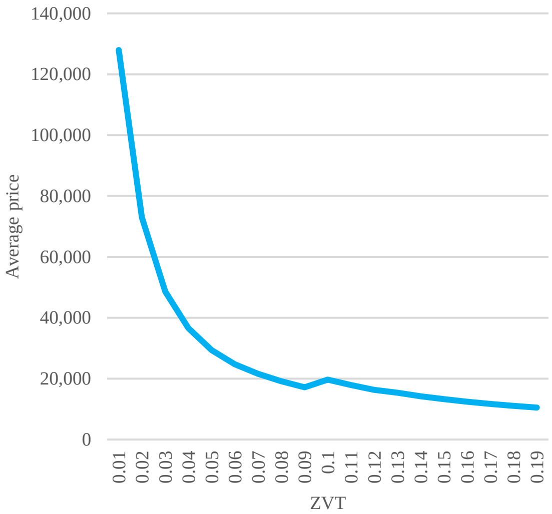

Fig. 4. Changes in average prices according to increasing ZVT

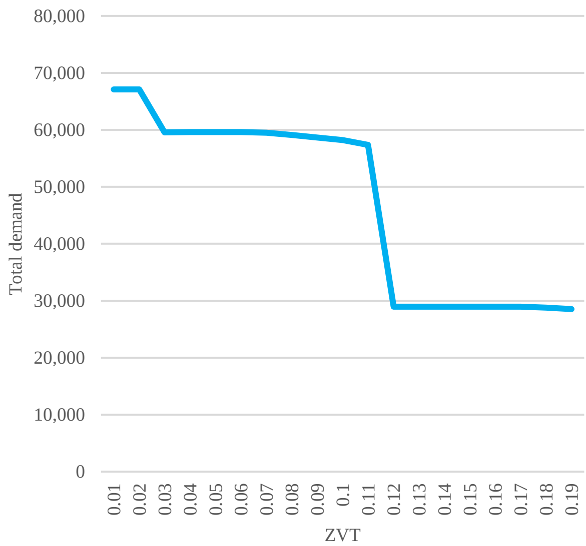

Fig. 5. Changes in Total demand according to increasing ZVT

Sensitivity analysis of the model to increase costs

The costs in this model are linear, so any kind of increase and decrease in cost linearly reduces or increases the chain's profit. In this section, by multiplying each of the costs, we will see the response of the profit function to this increase in costs. Increasing fixed costs, production, and transportation will have the greatest impact on the chain's profit and an increase in the cost of product corruption and its preservation will have the least impact on the chain's profit. Fig. 6 shows the effect of the increase in each cost with the constant of other costs and the level of overall profit reduction of the chain. In this section, costs are increased up to six times, and their impact on profit is presented as a graph.

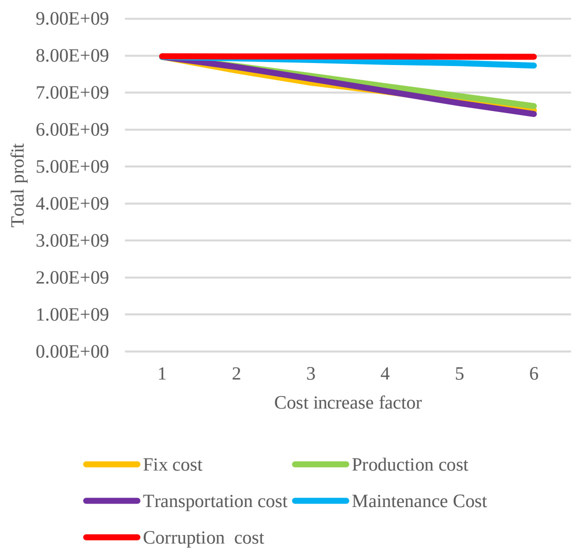

Fig. 6. The Impact of Increasing Costs on Profits

Sensitivity analysis of the model relative to the rate of corruption

In this section, the sensitivity of the model to the rate of corruption is analyzed. Accordingly, the model for a six-period planning horizon is set. As mentioned earlier, in this article, three types of corruption are examined. In the first type, the rate of corruption of products varies in different periods, this type of rate of corruption is very close to environmental realities because the environmental temperature, which is one of the main causes of product corruption, varies in different seasons and months of the year and this can be the most effective rate of product corruption. this type of corruption rate can be implemented in this model. In the second type, the rate of corruptibility is considered constant and in the third type, products are considered to be non-corruptible. Table 5 shows the rate of corruption in the three situations mentioned in different periods of planning horizons.

Table 5. Corruption rates in planning periods of horizon

Period	**Corruption rate Type 1**		**Corruption rate Type 2**		**Corruption rate Type 3**	
	Retailer	**Distributor**	**Retailer**	**Distributor**	**Retailer**	**Distributor**
1	0.6	0.4	0.5	0.2	0	0
2	0.7	0.2	0.5	0.2	0	0
3	0.5	0.3	0.5	0.2	0	0
4	0.6	0.4	0.5	0.2	0	0
5	0.4	0.2	0.5	0.2	0	0
6	0.3	0.1	0.5	0.2	0	0

Table 6. Model Results at Different Rates of Corruption

Corruption rate	Total inventory	Preservation cost	Total corrupted product	Corruption cost	Total cost of preservation and corruption
TYPE 1	9740	26038440	3862	4972553	31010993
TYPE 2	9959	26703830	2468	3053942	2975772
TYPE 3	13482	36192610	0	0	36192610

Maximum storage time is at the distributor for four periods and in the retailer for two periods. The model is implemented with the constant of all the parameters and the only change is in their rate of corruption which is performed in three types and its results are visible in Table 6. According to results, increase in total demand leads to an increase in total profit as well, shown in Fig. 7. According to the results of the corruption rate, the amount of inventory in the chain is affected. In the third corruption type, the model has the highest accumulation and inventory, this accumulation increases the total amount of preservation costs and corruption costs more than the two other types, which is visible in Fig. 8, while this type of corruption causes no cost of corruption. Therefore, the total cost of preservation and corruption is not necessarily dependent on the rate of product corruption.

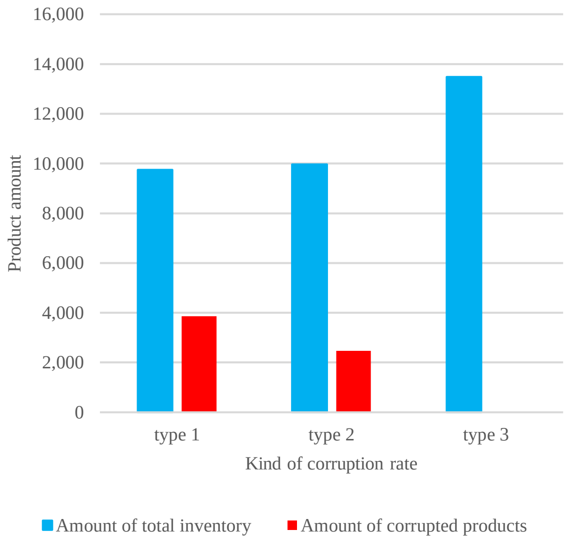

Fig. 7. Chart of inventory and product corruption in three types

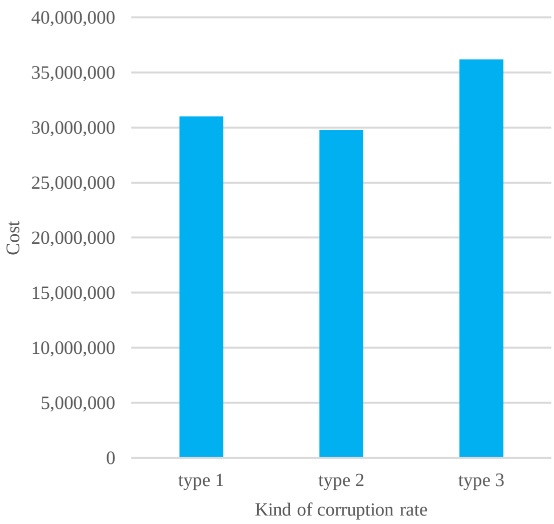

Fig. 8. Chart of total cost of preservation and corruption in three types of corruption

Sensitivity analysis of the model related to the increase of maximum customer demand

The increase in the maximum demand of a customer due to the effect on the final met demand, increases revenue and as a result, increases the total profit of supply chain, nonlinearly. Fig. 9 shows these changes. In this paper, a location-inventory model was introduced in a multi-product supply chain, taking into account the product's corruptibility and dependence of price on demand. The designed supply chain includes manufacturers, distributors, retailers and customers. manufacturers deliver their products to distributors or retailers. Distributors keep the product in their inventory, if needed, and deliver the rest of the product to retailers. Retailers receive the product from manufacturers, and distributors, then keep the product in inventory and send the remaining product to the customer according to the demand determined by the model for each customer in that period at the price specified in that period. meanwhile, a part of the product kept in inventory is corrupted due to the rate of corruption in that period and is removed from the supply chain.

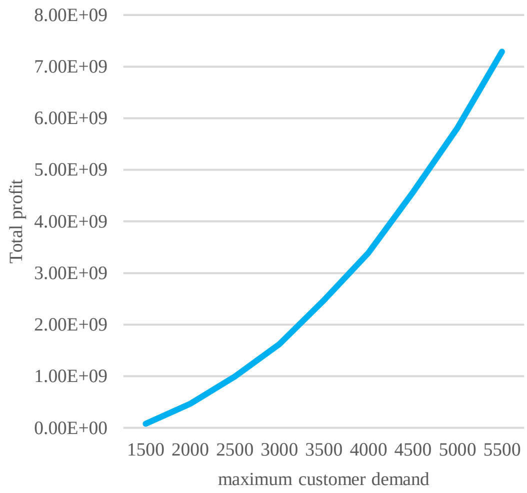

Fig. 9. Influence of increasing customer demand on chain profit
Conclusion

Conclusions

Today, new ideas and models are being introduced to improve supply chain performance. In the meantime, the integration approach has received much attention due to its ability to increase economic benefits and better demand response. In this research, an integrated location-inventory model for the supply chain of perishable products is presented. The rate of corruption is considered a three-dimensional parameter, so that the corruption rate can defined by each distributor and retailer in each period for each product, individually. Different corruption rates for each distributor and retailer affect the locational aspect of the model. In other words, the model in selecting centers for presence in the supply chain must consider both the distance between centers to reduce the cost of transport and the centers' corruption rate (quality of product retention in distributors and retailers) to reduce the corruption cost of product. This factor obviously demonstrates the need for consideration of location and inventory, simultaneously. Simple and linear models cannot account for the complex relationships between supply chain components. considering demand and price steadily, without taking any effect on them, drives the model away from reality. There are many factors affecting the quantity of demand and prices, the most important being the interaction of prices on demand and demand on prices. Price can be as an effective lever for managers and decision-makers to control customers' demand, but finding the optimal fit between price and demand in a way that maximizes chain profit is a complex task. According to the estimations made, this model is able to calculate the objective of maximizing the profit of this proportion, optimally, in each period, considering the demand dependence coefficient due to increasing prices. This computation adds to the complexity of the model due to the nonlinearity of the model, but increases the efficiency of the model in the real world. The designed supply chain is equipped with Radio Frequency Identification (RFID) system. The use of this technology enables supply chain managers to know at any time at which manufacturer a product is manufactured. at what time and for how long in maintenance centers (distributors and retailers) are stored and ultimately delivered to which customer. Implementation of this technology requires the installation of equipment in each supply chain center and the installation of labels on each product, and the cost of this implementation is taken into account in this model. After presenting the model, to evaluate its performance, several problems are defined in different dimensions and then sensitivity analysis is presented and the results of these analyses are described.

Regarding the literature review and in order to improve the efficiency and applicability of the model and to bring it as close as possible to reality, the following can be considered as a suggestion for future research:

- Application of heuristic and meta-heuristic algorithms for solving large-scale models.
- Application of different demand types such as inventory-related demand and so on.
- Importing quality factors for products into models and pricing products based on quality.
- Designing the model as a closed-loop model for the recycling or reproduction of products.

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