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Honey global supply chain network design using fuzzy optimization approach

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Abstract

From the past, honey has been known as a healthy product for human life. Iran has a suitable climate for beekeeping and is among the high-ranked countries in honey production. However, due to failure to comply with quality issues, export of honey from Iran is associated with many problems. According to this issue, this paper presents a robust possibilistic optimization network design model for honey global supply chain regarding global issues (e.g. Incoterms) and quality problems. The proposed network design model considers the product quality and its effect on the amount of demand. Numerical results from the robust model compared with the deterministic model show that the proposed robust model provides appropriate solutions with low risk for the decision makers.

Keywords: Agricultural products, honey supply chain, supply chain network design, robust probabilistic programming.

1- Introduction

A supply chain (SC) includes all sectors that play role, either directly or indirectly, in meeting customer's needs. The SC contains not only the producer and the supplier, but it also includes transportation, warehouses, retailers, and customers (Chopra &Meindl, 2007).SC management is a series of approaches to integrate the SC members with the objective of reduction of the system cost and enhancing the level of service to the customers. Nowadays, companies are facing many challenges to achieve their goals due to the reasons such market changes, customer's different requirements, globalization of economic. The SC design and integrated management will not only solve these problems, but it can also create long-term competitive advantage for the company (Meixell & Gargeya, 2005).Supply chain network design(SCND) as a strategic decision, has more impact on the reduction of costs compared to tactical and operational decisions. As strategic decisions are made before the tactical and operational ones, they play a constraining role for the latter decisions (Meepetchdee& Shah, 2007).

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The globalization of economic and emergence of the international companies have caused more attention to global supply chain network design. In the last decades of 19^{th} century, interesting in international SCs have extended rapidly, specifically in the automobile, computer, and clothing industries In a global SC, the members are scattered all around the world and SC management is not limited to the internal environment of only one country(Syam, 1997). The global SC management is a combination of three key processes: 1) global sourcing (management and communication with international suppliers), 2) global production (production activities distributed throughout the world), and 3) global distribution (sale management and international distribution channels) (Caniato et al., 2013).

An agricultural supply chain (ASC) involves different agricultural activities (cultivation, irrigation, and harvesting), initial products processing, quality control tests, packaging, storing, distributing, and marketing (Iakovou et al., 2012). What making different between ASC and other kind of SCs is the importance of agricultural product’s quality which highly affect human health (Salin, 1998). Also unpredictable variations in ASCs parameters like climatic conditions have made the management of these SCs more difficult. Considering the importance of the health aspects of agricultural products and the high risk of the flowing corruption in chain, the coordination between parties involved in chain become more important.

Some factors of ASCs such diversity in consuming types of agriculture products, corruption risks of them and rapid changes in parameters like product final price increases the importance of the effective strategies for ASCs management (Ahumada & Villalobos, 2008).On the other hand, Concerns regarding the supply of the world’s growing population food and considering the reductions in the agricultural resources has caused more attention to ASCs at the international level. International parameters like taxes, exchange rate, products’ insurance, and transportation conditions increase the problem complexity (Tsolakis et al., 2014).

Apart from risks in global SCs, there are more opportunities today to have SC facilities in different countries. In today’s world economy, consumers tend to buy the best product at the lowest price no matter where it has been produce (Canel&Khumawala, 1996). In addition, advancements in technologies and developments in the information infrastructures have made it possible for the companies to locate their different SC facilities in different parts of the world. In an international SCs, the parties are often unaware of the business rules in each other’s countries and this can result in disputes, legal claims, and waste of money and time. On the other hand, transportation from one country to another as part of a SC can face perils. To solve such these problems, the International Chamber of Commerce published a set of rules, first in 1936 called “Incoterms” (International Commercial Terms), with the objective of interpreting the terms most common in the Global trade to prevent their multiple interpretations. Incoterms solves problems regarding goods transportation from the seller to the buyer and deals with such problems as transportation, import, export, body responsible for the payments and to take the risks at different stages. Some of the rules provided in “Incoterms” are: EXWRule, FCA Rule, CPT Rule, CIP Rule, FAS Rule, FOB Rule, and CIF Rule. Since the last two terms have been used in this paper, their brief descriptions are as follows:

A) The FOB Rule: this rule is specific just to marine transportation. According to FOB the seller must load the goods at the specified origin port and after export clearance, delivers it to the buyer or carrier as the buyer’s agent on the deck. In this rule the risks and costs up to the delivery on the deck are all on the seller. after that, the risks and costs including transportation from the origin port to the destination port, unloading at the destination port, obtaining import licenses, paying import duties and internal transportation in the destination country are all on the buyer. In this Rule, the buyer takes no responsibilities regarding the transportation insurance, but since the risks are on him after the carrier loading, it is reasonable to insure the load against probable risks.

B) The CIF Rule: In this rule, the delivery point is the carrier deck Like FOB where the seller delivers the goods to the buyer or carrier as the buyer’s agent, but the seller must pay all of the cost for transformation and insurance but he has no responsibilities for the risks of products failure and these risk are on the buyer.

Another issue in the global supply chain network design that has attracted more attention recently is the transfer pricing. Transfer price definite as the price of the product bought by a company branch from other branch of that company in other country (Perron et al., 2010); in general, transfer price is to regulate the price of the products and services transferred between two branches of one company. Since multinational companies branches are established in different countries, transfer pricing is a powerful tool that can transfer the income to the branches in countries with lower taxes and hence cause an increased profit for the company (Shunko&Gavarnie ., 2007). There are three common methods for transfer pricing in the literature that in this paper, the upper and lower bound method is used. In this method, an acceptable interval for price determined based on the cost price, market price, and negotiations and then the optimum transfer price is found by the model in this interval.

The main contributions of this paper are as follows: **1)** Designing global honey supply chain network based on the quality levels of product, **2)** Consideration of global parameters particularly Incoterms in transferring products between countries, **3)** Applying transfer price as a variable in the model dependent on quality level, **4)** Supposing uncertainty demand and tax rate and using posibilistic theory to modeling uncertainty.

The remaining of this paper is structured as follows: Section 2 briefly reviews the relevant literature on global supply chain network design. In Section 3, the deterministic model presented after problem definition. Section 4, provides the posibilistic robust design of the network. In Section 5, the robust form of the model has been solved based on the Hypothetical data and results have been reported. Section 6 deals with interpreting the numerical results and finally in Section 7, managerial Conclusions and also gaps for more research are reported.

2- Literature review

Early studies on the global facility location problem have been done by Hodder and Jucker (1985) who have proposed a mixed-integer programming model for facility location in the global environment .The global parameters considered in their work are exchange rate, customs tariffs and taxes. The exchange rate and price of final product are supposed as parameters with uncertainty and scenario –programming is used to model these uncertainties. The objective function in addition to optimize the average performance, reduce the differences between the values of the objective function for different scenarios. After this work, many researches were focused on the global supply chain network design that among them the almost recent one is Hammami and Frein (2014). They studied the problem of redesign of a national SC of to a global one with presenting a mixed-integer optimization model for the maximization of the company profit. The national SC includes suppliers, producers, and distributers, and the network redesign is to add foreign suppliers, producers, and distributers to meet the company's needs in the international markets. The model decisions for the maximization of the company's profit after tax deduction are capacity planning, selecting foreign suppliers, and transfer pricing.

Most of the papers reviewed in our work, have considered one-echelon SC including Manufacturing sites and retailers. Only Munson and Rosenblatt,(1997), Sheu and Lin (2012) and Hammami and Frein (2013, 2014) have addressed two-echelon SCs including production, distribution centers and retailers. Munson and Rosenblatt (1997) have proposed a deterministic, single-period, mixed-integer model that selects suppliers and production centers with their allocated demands. An important assumption of model is that the company should buy a specified rate of its manufacturing components from the domestic suppliers and at most one production center can be located in each country.

Among reviewed papers, only Hammami and Frein (2013, 2014) have considered the multi-product SC; in Hammami and Frein (2013), raw material, medium product, and final product have been considered as separate products. In reviewed papers, Canel and Khumawala,(1996), Goh et al. (2007), and Hammami and Frein (2014) have used multi-period models for supply chain network design. Goh et al. (2007) have presented a two-objective model for the global supply chain network design problem that specifies the locations of the facilities and the amounts of products transported from facilities to retailer's centers. In their work, demands, taxes, customs tariffs, and exchange rate are assumed uncertain; one objective function maximizes the profit after tax deduction and the other minimizes the risks in the SC.

Hodder and Juker (1985), Munson and Rosenblatt (1997), and Hammami and Frein (2013) have assumed unlimited facility capacity while Canel and Khumawala (1996) is the only paper that has modeled the problem with both limited and unlimited capacities. In their work, a multi-period, mixed-integer model has been proposed. The model objective is to maximize profit after tax deduction. They considered investment, construction, transportation, storage and shortages costs in model. The problem is deterministic and includes exchange rate, taxes, tariffs, and direct export motivations as global factors. The applicability of the model also has been shown in a chemical industry case study.

In most of the reviewed papers, the problem has been modeled with deterministic parameters; few have modeled the real world uncertainties. Jamalnia et al. (2014) have used the fuzzy approach while Hodder and Juker (1985), Hodder and Dinser (1986), and Goh et al. (2007) have used the probabilistic programming method in dealing with uncertainties. Hooder and Dincer (1986) have studied the production centers location problem considering financial decisions. In their work, the effects of financial help from government for large companies are evaluated. The model objective is to maximize the profit after tax deduction under uncertain price and exchange rate. The model uses of the exchange rate, taxes, and customs tariffs as the global parameters and determines, in addition to the facilities locations and the material flow between them, the most appropriate pattern of financing from among the proposed patterns.

Price, demand, exchange rate, tax, and tariff are the parameters that have been assumed uncertain in reviewed papers. Hodder and Juker (1985), Hodder and Dinser (1986), and Goh et al. (2007) have considered uncertain exchange rate. Also, Goh et al. (2007) and Jamalniaet al. (2014) have addressed uncertain demand. In Hodder and Juker (1985) and Hodder and Dinser (1986) the price is assumed uncertain. The model proposed by Goh et al. (2007) is the only one that considers both the tax and tariff as uncertain parameters. Jamalnia et al. (2014) have modeled the problem with uncertain objectives.

The global SC parameters are either quantitative (exchange rate, tax, tariff, and transportation insurance) or qualitative (country's political situation, global survival and competition, state regulations, cultural, and social). In reviewed papers, the quantitative parameters have been of more interest to the researchers. The only papers that have considered qualitative parameters are Jamalnia et al. (2014) and Badri (1999); the former has considered the cultural and social situations of the foreign countries while the latter has addressed the welfare level of countries people in the modeling.

Related to the increased distance between the producer and the final consumer in the global SC, and while quality plays an important role in the customer satisfaction, none of the studied papers has addressed the issue of quality in global supply chain network design. Considering the customer demand based on the product quality can prevent company's capital losses and will help better planning for capital allocation. In most of the reviewed papers, the transfer price has been considered as a parameter while determining the optimum transfer price highly affects the profit maximization after the SC tax deduction. Considering the great distances in the global SC, inventory is quite an important issue for meeting the customers' demands. This has not been addressed appropriately in the papers reviewed; we have considered this as a variable for the distribution centers. None of the papers has considered insurance while in reality this is quite vital for the reduction of the risks due to failures in products transportation.

In this paper a novel global supply chain for honey has designed. An important assumption in this supply chain is regarding the price and demand of honey as a function of quality. The constraints in international trade also are considered by using Incoterms as variables in model. Due to variation occurred in real word in such chains, demand and exchange rate assumed as uncertain parameters and fuzzy method used to model these parameters. For lessening the risks of applicability of the model, the robust theory is used.

3- Problem statement and model formulation

Human kind has long paid particular attention towards natural products like honey. During the time form past to present, scientific advances have not only approved its value, but have also shown new dimensions of its benefits. In addition to food usages, honey is used in different industries like pharmaceutics. A unique feature of this product is its quality which highly affects its usage. Honey is marketed in different quality levels and the price of each level depends on this level of quality. Considering quality in the honey global supply chain is quite important because customers all around the word pay more attention to the quality of foreign products.

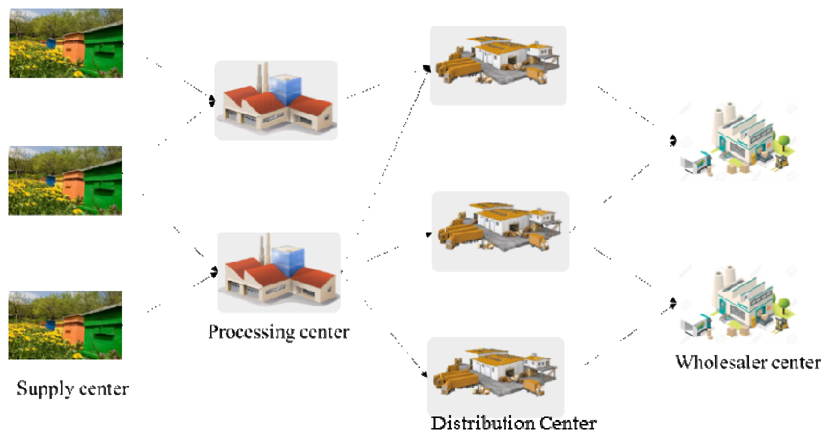
The supply chain of honey that is discussed in this paper includes active sectors in the honey processing and exporting. As shown in figure1, this sectors are supply centers, processing center, distribution centers and wholesaler centers. Among these centers, processing and suppliers are located in one country and Distributers and wholesalers scattered all around the word. The processing company buys its required honey from the honey producers as suppliers in supply chain. To select these suppliers, some quality parameters are introduced related to the features of the supply centers. The value of each parameter is found at the beginning of each period through the inspections by the company from the supply centers and then entered in the model as a parameter. There are two upper and lower bounds defined for the total value of quality parameters related to each supply center; centers with this total above the upper bound, receive an "Excellent Quality"(EQ) certificate and those with this total between the lower and upper bounds receive a "Good Quality"(GQ) certificate; each certificate is valid for only one time period. When buying honey from centers with the EQ certificate, the company does not check the product, but the checking is carried out for centers with the GQ certificate which increases the company's inspection costs. The purchased honey is turned into final products in the company's processing centers. Activities have done in these centers includes Separating impurities of honey, blending, quality categorizing and packaging. The distribution centers are the company's agents all around the word. At the end of the SC, the honey wholesale centers in the foreign countries are considered as the final customers; demands of these centers have been assumed based on the honey quality. In the problem, the company wants to choose some countries as location of distribution centers. In other words, since customers are scattered in different countries, the company would like to know considering criteria such the exchange rate, taxes, tariffs, and customs duties, which location, from among all the potential ones in different countries, is most suitable for locating a distribution center.

When some potential locations are selected to establish distribution centers, it is necessary to sign the transportation-delivery contracts. By transportation-delivery contract we mean the Incoterms Rules and since in this research the connection between the processing and foreign distribution centers is assumed only through the sea, FOB and CIF contracts are used. If the foreign distribution center is established and the FOB contract is selected between the processing and foreign distribution centers, then the costs of the goods transportation from the processing center to the origin port are on the processing center and after that they are up to the distribution center. But, if the contract is of the CIF type, the costs of the transportation from the production center to the domestic port (from where goods are transported to the foreign distribution center), transportation between the two ports, and insurance are on the processing center. The only costs that are up to the distribution center are those of the transportation from the port (distribution center) to the distribution center. The proposed model is capable of selecting the optimal contract considering different tax rates in the origin and destination countries. Another important issue raised in global SCs is the costs related to the import duties that are to be paid by importers to the customs offices of their own countries. Since in most countries the import duties are computed based on the goods' CIF value, this method is used in this paper. CIF value is equal to sum of the goods price and the costs of transportation and international insurance.

The model assumptions are as follows:

- The SC is global and its different centers are scattered in more than one country (the suppliers and processing centers are in one country and the potential distribution centers and wholesalers in all around the word).
- The number and location of the suppliers, processing centers and customers are pre-determined.
- The number and location of the distribution centers should determined by the model.
- The SCN is multi-product.
- The proposed model is multi-period.

- The customer centers are single-sourced meaning that only one distribution center can meet each wholesaler's demand.
- The processing and distribution centers are capable of storing products.
- The product can be sent between consecutive centers only.
- The wholesalers demand in each period can only met in that period and cannot transferred to future time periods.
- The raw material/product inventory in the processing and distribution centers can be transferred from one period to another.
- The connection between the processing and foreign distribution centers in this research is by the marine mode.
- The contracts used in this research are of the FOB and CIF types because these are the ones used in marine transportation.
- The import duties in the potential countries for setting up distribution centers are calculated based on the product CIF value.
- The raw material and product inventory management system is FIFO.
- The dollar, the international currency accepted by all countries, is the currency considered for all inter-country payments and recipients.
- The base currency is that of the distribution center's country.



- **Figure 1.** Schematic view of the honey export network

Sets:

I Set of supply centers $i \in I$

J Set of processing centers $j \in J$

K Set of foreign distribution centers $k \in K$

L Set of wholesale centers $l \in L$

P Set of types of final products p∈ P

R Set of all the raw honey types bought from the supplier $r \in R$

T Set of the time periods $t \in T$

Q Set of the quality parameters $q \in Q$

Parameters:

In_{kt} inventory cost per unit product in distribution center k in time period t

p_{1pklt} Sale price of product p from distribution center k to wholesalerl at quality level 1in time period t

p_{2pklt} Sale price of product p from distribution center k to wholesaler l at quality level 2 in time period t

tr_{kt} Income tax rate for distribution center k in time period t

tr_{jt} Income tax rate for processing center j in time period t

f_k Fixed cost of setting up distribution center k

ti_{kt} Import customs tariff for distribution center k in time period t

$tc1_{jk}$ Transportation cost from production center j to the origin port for loading

$tc2_{jk}$ Transportation cost from the origin port to the port of distribution center k

$tc3_{jk}$ Transportation cost from the port of distribution center k to this center in transferring from processing center j

E_t Exchange rate in time period t

b_t Insurance cost of the product loadin time period t

hc_{jt} inventory cost of a unit product in processing center j in time period t

pc_{pjt} Processing cost for product p in processing center j in time period t

hc'_{jt} inventory cost of one unit raw material in processing center j in time period t

tc_{ij} Transportation cost of one unit raw material from supply center i to processing center j

p_{rijt} Purchase price of raw material r from supply center i for processing center j in time period t

q_{iqt} Quality parameter q for supply center i in time period t

Qh High quality rank

Qa Average quality rank

c_{rp} Coefficient of turning raw material r into product p

tc_{kl} Cost of sending unit of product from distribution k to wholesaler l

$Qc1$ Inspection cost per unit of raw material

$Qc2$ Periodic inspection cost of supply centers

$Tf1min$ Lower bound for transfer price of quality 1 product under FOB contract

$Tf1max$ Upper bound for transfer price of quality 1 product under FOB contract

$Tf2min$ Lower bound for transfer price of quality 2 product under FOB contract

$Tf2max$ Upper bound for transfer price of quality 2 product under FOB contract

$Tc1max$ Upper bound for transfer price of quality 1 product under CIF contract

$Tc1min$ Lower bound for transfer price of quality 1 product under CIF contract

$Tc2min$ Lower bound for transfer price of quality 2 product under CIF contract

$Tc2max$ Upper bound for transfer price of quality 2 product under CIF contract

Decision variables:

d_k Binary variable: 1 if distribution center k is set up, and 0 otherwise

ys_{ijt} Binary variable: 1 if supply center i is allocated to processing center j in time period t, and 0 otherwise

yf_{jkt} Binary variable: 1 if transportation contract between processing center j and distribution center k with mode m in time period t is FOB, and 0 otherwise

yc_{jkt} Binary variable: 1 if transportation contract between processing center j and distribution center k with mode m in time period t is CIF, and 0 otherwise

y_{klt} Binary variable: 1 if wholesaler l is allocated to processing center j in time period t, and 0 otherwise

Sa_{it} Binary variable: 1 if total quality rating of supply center i in time period t is more than upper bound of quality, and 0 otherwise

Sh_{it} Binary variable: 1 if total quality rating of supply center i in time period t is between upper and lower bounds of quality, and 0 otherwise

z_{kt}^{+} Profit of distribution center k in time period t before tax payment

z_{kt}^{-} Loss of distribution center k in time period t before tax payment

z_{jt}^{+} Profit of processing center j in time period t before tax payment

z_{jt}^{-} Loss of processing center j in time period t before tax payment

Tf_{1pjkt} Transfer price of product p at quality level 1 transferred from processing center j to distribution center k in time period t under FOB contract

Tf_{2pjkt} Transfer price of product p at quality level 2 transferred from processing center j to distribution center k in time period t under FOB contract

Tc_{1pjkt} Transfer price of product p at quality level 1 transferred from processing center j to distribution center k in time period t under CIF contract

Tc_{2pjkt} Transfer price of product p at quality level 2 transferred from processing center j to distribution center k in time period t under CIF contract

x_{ijrt} Amount of raw material r transferred from supply center i to processing center j in time period t

x_{1jkpt} Amount of product p at quality level 1 transferred from processing center j to distribution center k in time period t

x_{2jkpt} Amount of product p at quality level 2 transferred from processing center j to distribution center k in time period t

x_{1klpt} Amount of product p at quality level 1 transferred from distribution center k to wholesaler l in time period t

x_{2klpt} Amount of product p at quality level 2 transferred from distribution center k to wholesaler l in time period t

I_{jrt} Inventory of raw material r in processing center j in time period t

I_{1kpt} Inventory of product p at quality level 1 in distribution center k in time period t

I_{2kpt} Inventory of product p at quality level 2 in distribution center k in time period t

I_{1jpt} Inventory of product p at quality level 1 in processing center j in time period t

I_{2jpt} Inventory of product p at quality level 2 in processing center j in time period t

The model objective function is the maximization of profit for the processing and foreign distribution centers after tax deduction. The model constraints includes establishment and allocation constraints, meeting wholesaler's demand, selecting transportation and delivery contracts, determining the optimum transfer price, and types of variables.

$$Max\sum_{k}\sum_{t}(1-tr_{kt})(z_{kt}^{+}-z_{kt}^{-})+\sum_{j}\sum_{t}(1-tr_{jt})(z_{jt}^{+}-z_{jt}^{-}) \tag{1}$$

$$
\begin{aligned}
& z^{+}_{jt} - z^{-}_{jt} = (\sum_p \sum_k x_{1jkpt}.Tf_{1jkpt}.yf_{jkt} + \sum_p \sum_k x_{2jkpt}.Tf_{2jkpt}.yf_{jkt} + \\
& \sum_p \sum_k x_{2jkpt}.Tc_{2jkpt}.yc_{jkt} + \sum_p \sum_k x_{1jkpt}.Tc_{1jkpt}.yc_{jkt}).E_t \\
& -\sum_r \sum_j x_{ijrt}(p_{rijt} + tc_{ij}) - \sum_r \frac{(I_{jrt} + I_{jrt-1}).hc'_{jt}}{2} - \sum_p \frac{(I_{1jpt} + I_{1jpt-1}).hc_{jt}}{2} - \\
& \sum_p \frac{(I_{2jpt} + I_{2jpt-1}).hc_{jt}}{2} - \sum_i Sa_{it}(\sum_r x_{ijrt}.\mathrm{Qc1}) + Qc2 - \sum_i Sh_{it}.\mathrm{Qc}\,2 - \\
& \sum_k yf_{jkt}.Tc1_{jk}.(\sum_p x_{1jkplt} + \sum_p x_{2jkplt}) - \sum_k yc_{jkt}.(Tc1_{jk} + Tc2_{jk} + b_t).(\sum_p x_{1jkplt} + \sum_p x_{2jkplt})
\end{aligned}
\qquad \forall j,t \qquad (2)
$$

$$
\begin{aligned}
& z^{+}_{kt} - z^{-}_{kt} = \sum_l \sum_p x_{1klpt}.p_{1klpt}.E_t + \sum_l \sum_p x_{2klpt}.p_{2klpt}.E_t - \\
& f_k.d_k - In_{kt}\left[\frac{(I_{1kpt} + I_{1kpt-1})}{2} + \frac{(I_{2kpt} + I_{2kpt-1})}{2}\right].E_t \\
& -\sum_j \sum_p Tf_{1jkpt}.yf_{jkt}.x_{1jkpt}.E_t - \sum_j \sum_p Tf_{2jkpt}.yf_{jkt}.x_{2jkpt}.E_t - \\
& \sum_j \sum_p Tc_{1jkpt}.yc_{jkt}.x_{1jkpt}.E_t - \sum_j \sum_p Tc_{2jkpt}.yc_{jkt}.x_{2jkpt}.E_t - \\
& \sum_j \sum_p Tc2_{jkpt}.yc_{jkt}.(x_{1jkpt} + x_{2jkpt}).E_t - \\
& \sum_j \sum_p yf_{jkt}.(x_{1jkpt} + x_{2jkpt}).(b_t + Tc2_{jkt} + Tc3_{jkt}) - \\
& \sum_j \sum_p yc_{jkt}.(x_{1jkpt} + x_{2jkpt}).(Tc3_{jkt}) - \\
& \sum_j \sum_p ti_{kt}.yf_{jkt}.(Tf_{1jkpt} + b_t + Tc2_{jkt} + Tc3_{jkt}).x_{1jkpt} - \\
& \sum_j \sum_p ti_{kt}.yf_{jkt}.(Tf_{1jkpt} + b_t + Tc2_{jkt} + Tc3_{jkt}).x_{2jkpt} - \\
& \sum_j \sum_p ti_{kt}.yc_{jkt}.Tc3_{jkt}.x_{1jkpt} - \sum_j \sum_p ti_{kt}.yc_{jkt}.Tc3_{jkt}.x_{1jkpt}
\end{aligned}
\qquad \forall k,t \qquad (3)
$$

$$
Qa.Sa_{it} \le \sum_q q_{iqt} \qquad \forall i,t \qquad (4)
$$

$$
Qh.Sh_{it} \le \sum_q q_{iqt} \qquad \forall i,t \qquad (5)
$$

$$ys_{ijt} \le Sa_{it} + Sh_{it} \qquad \forall i, j, t \qquad (6)$$

$$Sa_{it} \le Sh_{it} \qquad \forall i, t \qquad (7)$$

$$x_{ijrt} \le ys_{ijt}.M \qquad \forall i, j, t \qquad (8)$$

$$I_{1kpt} = I_{1kpt-1} + \sum_{j} x_{1jkpt} - \sum_{j} x_{1klpt} \qquad \forall k, p, t \qquad (9)$$

$$I_{2kpt} = I_{2kpt-1} + \sum_{j} x_{2jkpt} - \sum_{j} x_{2klpt} \qquad \forall k, p, t \qquad (10)$$

$$I_{1jpt} = I_{1jpt-1} + \sum_{j} x_{ijrt}.Sa_{it}.c_{rp} - \sum_{j} x_{1jkpt} \qquad \forall j, p, t \qquad (11)$$

$$I_{2jpt} = I_{2jpt-1} + \sum_{j} x_{ijrt}.Sh_{it}.c_{rp} - \sum_{j} x_{2jkpt} \qquad \forall j, p, t \qquad (12)$$

$$yf_{jkt} + yc_{jkt} \le d_k \qquad \forall j, k, t \qquad (13)$$

$$x_{1jkpt} \le (yf_{jkt} + yc_{jkt}).M \qquad \forall j, k, p, t \qquad (14)$$

$$x_{2jkpt} \le (yf_{jkt} + yc_{jkt}).M \qquad \forall j, k, p, t \qquad (15)$$

$$x_{1klpt} \le y_{klt}.M \qquad \forall l, k, p, t \qquad (16)$$

$$x_{2klpt} \le y_{klt}.M \qquad \forall l, k, p, t \qquad (17)$$

$$y_{klt} \le d_k \qquad \forall l, k, t \qquad (18)$$

$$\sum_{k} x_{1klpt} \le D_{1lpt} \qquad \forall l, k, p, t \qquad (19)$$

$$\sum_k x_{2klpt} \le D_{2lpt} \qquad \forall l,k,p,t \qquad (20)$$

$$Tf_{1\min} \le Tf_{1jkpt} \le Tf_{1\max} \qquad \forall p,j,k,t, \qquad (21)$$
$$Tf_{2\min} \le Tf_{2jkpt} \le Tf_{2\max}$$
$$Tc_{1\min} \le Tc_{1jkpt} \le Tc_{1\max}$$
$$Tc_{2\min} \le Tc_{2jkpt} \le Tc_{2\max}$$

$$x_{ijrt}, x_{1jkpt}, x_{2jkpt}, x_{1klpt}, x_{2klpt} \ge 0 \qquad \forall j,k,t,p,l \qquad (22)$$
$$I_{1kpt}, I_{2kpt}, I_{1jpt}, I_{2jpt} \ge 0$$
$$z_{kt}^{+}, z_{kt}^{-}, z_{jt}^{+}, z_{jt}^{-} \ge 0$$
$$Tf_{1pjkt}, Tf_{2pjkt} \ge 0$$
$$d_k, ys_{ijt}, Sa_{it}, Sh_{it} \in \{0,1\}$$

Equation (1) is the objective function that maximizes the profit of the processing and distribution centers after tax deduction. Equation (2) computes processing centers' profit before tax deduction. Equation (3) calculates distribution centers' profit before tax deduction. Equations (4) and (5) determine the quality level of the supply centers in each time period. Equation (6) states that supply centers allocation to processing centers is possible only when supply centers achieve the desired quality level of the company. Equation (7) specifies the relation between the variables of supply centers' quality levels. Eq. (8) states that the honey transfer is possible only when a supply center has been allocated to a processing center. Equations (9) and (10) balance the flow of the distribution centers considering their inventory. Equations (11) and (12) balance the flow of the processing centers. Equation (13) states that the distribution center must established to sign the product transfer contracts between processing center and distribution center. Equations (14) and (15) state that the product flow between the processing and distribution centers exists only when a contract (FOB or CIF) has been signed. Equations (16) and (17) state that the flow between distributions centers and wholesalers exist only when the wholesalers are allocated to distribution center. Equation (18) states that allocation of wholesalers to distribution centers is possible only when the distribution center set up. Equation (19) and (20) take care of the demand limitations. Equation (21) specifies the upper and lower bounds of the transfer price. And, finally, the set of Equations (22) consider the model variables type in the problem.

4- Robust posibilistic programming model

The SCs, specifically at the global level, are facing high Risks due to their dynamic and complex nature which can considerably affect their performance. Increased influence of uncertainty on the SC design can be intensified by long time horizon. This fact makes the uncertainty notion more important. In this research, the exchange rate and demand parameters have been assumed uncertain. Data uncertainty is either stochastic or cognitive; the former is due to the stochastic nature of the parameters and the latter is because of insufficient or lacking historical data. If the problem parameters are **1)** available, **2)** sufficient, **3)** reliable, and **4)** their future behavior follows the patterns, then the stochastic programming will be used to model uncertainty; otherwise, fuzzy programming is used to model the uncertainty.

Because of the industries' dynamic nature, instability of patterns and lack of sufficient data about the parameters precise determination of their values is quite difficult, if not sometimes impossible. Also, to estimate the probability distribution function, historical data are important. In addition to the availability of sufficient data, the expert knowledge for the exact estimation of uncertain parameters is needed. Under uncertainties with lack of exact data, the probabilistic programming can be an appropriate approach. In the present study, data uncertainties are of the cognitive type (programming time period is long and hence the historical data are either lacking or insufficient) and therefore fuzzy theory and probabilistic programming approach have been used. In the probabilistic programming problems, one possibility distribution function is considered for each uncertain parameter. These functions indicate the possibility of the occurrence of different values for each parameter. Due to the lack of historical data, expert opinion is used for the determination of the type of the distribution function.

To change the fuzzy mathematical model into the deterministic one, the chance constraint programming approach has been used. This method enables the decision maker to control the confidence level of the constraints satisfaction. This approach was first developed by Yager (1981) and then expanded by Dubois and Prade (1987) and Hilpern (1992). Using Probabilistic programming, demand and exchange rate are assumed to have trapezoidal possibility distribution. Considering this assumption, equations (2), (3),(19), (20) of the main model change into equations (23)-(26). The fuzzy model is as follows.

$$Max \sum_k \sum_t (1-tr_{kt})(z_{kt}^+ - z_{kt}^-) + \sum_j \sum_t (1-tr_{jt})(z_{jt}^+ - z_{jt}^-)$$

s.t:

Equations (4)-(18) and equations (21)-(22):

$$\begin{aligned}
z_{jt}^+ - z_{jt}^- = (&\sum_p \sum_k x_{1jkpt}.Tf_{1jkpt}.yf_{jkt} + \sum_p \sum_k x_{2jkpt}.Tf_{2jkpt}.yf_{jkt} + \\
&\sum_p \sum_k x_{2jkpt}.Tc_{2jkpt}.yc_{jkt} + \sum_p \sum_k x_{1jkpt}.Tc_{1jkpt}.yc_{jkt}).E[E_t] \\
&-\sum_r \sum_j x_{ijrt}(p_{rijt} + tc_{ij}) - \sum_r \frac{(I_{jrt} + I_{jrt-1}).hc'_{jt}}{2} - \\
&\sum_p \frac{(I_{1jpt} + I_{1jpt-1}).hc_{jt}}{2} - \sum_p \frac{(I_{2jpt} + I_{2jpt-1}).hc_{jt}}{2} - \\
&\sum_i Sa_{it}(\sum_r x_{ijrt}.\mathrm{Qc1}) + Qc2 - \sum_i Sh_{it}.\mathrm{Qc}2 - \sum_k yf_{jkt}.Tc1_{jk}.(\sum_p x_{1jkplt} + \sum_p x_{2jkplt}) - \\
&\sum_k yc_{jkt}.(Tc1_{jk} + Tc2_{jk} + b_t).(\sum_p x_{1jkplt} + \sum_p x_{2jkplt})
\end{aligned} \quad \forall j,t \qquad (23)$$

$$z_{kt}^{+} - z_{kt}^{-} = \sum_{l}\sum_{p} x_{1klpt}.p_{1klpt}.E[E_t] + \sum_{l}\sum_{p} x_{2klpt}.p_{2klpt}.E[E_t] - \qquad \forall k,t \qquad (24)$$

$$f_k.d_k - In_{kt}\left[\frac{(I_{1kpt}+I_{1kpt-1})}{2}+\frac{(I_{2kpt}+I_{2kpt-1})}{2}\right].E[E_t]$$

$$-(\sum_{j}\sum_{p} Tf_{1jkpt}.yf_{jkt}.x_{1jkpt}.-\sum_{j}\sum_{p} Tf_{2jkpt}.yf_{mjkt}.x_{2jkpt}$$

$$-\sum_{j}\sum_{p} Tc_{1jkpt}.yc_{jkt}.x_{1jkpt} - \sum_{j}\sum_{p} Tc_{2jkpt}.yc_{mjkt}.x_{2jkpt}$$

$$\sum_{j}\sum_{p} Tc2_{jkpt}.yc_{jkt}.(x_{1jkpt}+x_{2jkpt})).E[E_t] -$$

$$\sum_{j}\sum_{p} yf_{jkt}.(x_{1jkpt}+x_{2jkpt}).(b_t + Tc2_{jkt} + Tc3_{jkt}) -$$

$$\sum_{j}\sum_{p} yc_{jkt}.(x_{1jkpt}+x_{2jkpt}).(Tc3_{jkt}) -$$

$$\sum_{j}\sum_{p} ti_{kt}.yf_{jkt}.(Tf_{1jkpt} + b_t + Tc2_{jkt} + Tc3_{jkt}).x_{1jkpt} -$$

$$\sum_{j}\sum_{p} ti_{kt}.yf_{jkt}.(Tf_{1jkpt} + b_t + Tc2_{jkt} + Tc3_{jkt}).x_{2jkpt} -$$

$$\sum_{j}\sum_{p} ti_{kt}.yc_{jkt}.Tc3_{jkt}.x_{1jkpt} - \sum_{j}\sum_{p} ti_{kt}.yc_{jkt}.Tc3_{jkt}.x_{1jkpt}$$

$$Nec\{\sum_{k} x_{1klpt} \le D_{1lpt}\} \ge \alpha \qquad \forall l,k,p,t \qquad (25)$$

$$Nec\{\sum_{k} x_{2klpt} \le D_{2lpt}\} \ge \alpha \qquad \forall l,k,p,t \qquad (26)$$

For model defuzzication average amount of exchange rate is used, also for demand, the definition of the NEC measure applied. By these assumptions, the model is changed as follows.

$$Max \sum_{k}\sum_{t}(1-tr_{kt})(z_{kt}^{+}-z_{kt}^{-}) + \sum_{j}\sum_{t}(1-tr_{jt})(z_{jt}^{+}-z_{jt}^{-}) \qquad (27)$$

st:

Equations (4)- (18) and equations (21)- (22):

$$z_{kt}^{+}-z_{kt}^{-}=\sum_{l}\sum_{p}x_{1klpt}.p_{1klpt}.E_{t}+\sum_{l}\sum_{p}x_{2klpt}.p_{2klpt}.[\frac{E_1+E_2+E_3+E_4}{4}]- \qquad \forall k,t \qquad (28)$$

$$f_k.d_k-In_{kt}\left[\frac{(I_{1kpt}+I_{1kpt-1})}{2}+\frac{(I_{2kpt}+I_{2kpt-1})}{2}\right].[\frac{E_1+E_2+E_3+E_4}{4}]$$

$$-(\sum_{j}\sum_{p}Tf_{1jkpt}.yf_{jkt}.x_{1jkpt}-\sum_{j}\sum_{p}Tf_{2jkpt}.yf_{jkt}.x_{2jkpt}$$

$$-\sum_{j}\sum_{p}Tc_{1jkpt}.yc_{jkt}.x_{1jkpt}-\sum_{j}\sum_{p}Tc_{2jkpt}.yc_{jkt}.x_{2jkpt}).[\frac{E_1+E_2+E_3+E_4}{4}]-$$

$$\sum_{j}\sum_{p}Tc2_{jkpt}.yc_{jkt}.(x_{1jkpt}+x_{2jkpt}).[\frac{E_1+E_2+E_3+E_4}{4}]-$$

$$\sum_{j}\sum_{p}yf_{jkt}.(x_{1jkpt}+x_{2jkpt}).(b_t+Tc2_{jkt}+Tc3_{jkt})-$$

$$\sum_{j}\sum_{p}yc_{jkt}.(x_{1jkpt}+x_{2jkpt}).(Tc3_{jkt})-\sum_{j}\sum_{p}ti_{kt}.yf_{jkt}.(Tf_{1jkpt}+b_t+Tc2_{jkt}+Tc3_{jkt}).x_{1jkpt}-$$

$$\sum_{j}\sum_{p}ti_{kt}.yf_{jkt}.(Tf_{1jkpt}+b_t+Tc2_{jkt}+Tc3_{jkt}).x_{2jkpt}-$$

$$\sum_{j}\sum_{p}ti_{kt}.yc_{jkt}.Tc3_{jkt}.x_{1jkpt}-\sum_{j}\sum_{p}ti_{kt}.yc_{jkt}.Tc3_{jkt}.x_{1jkpt}$$

$$\sum_{k}x_{1klpt}\le\frac{1}{2}.(1+\alpha).D^{3}{}_{1lpt}+\frac{1}{2}.(1-\alpha).D^{4}{}_{1lpt} \qquad \forall l,k,p,t \qquad (29)$$

$$\sum_{k}x_{2klpt}\le\frac{1}{2}.(1+\alpha).D^{3}{}_{2lpt}+\frac{1}{2}.(1-\alpha).D^{4}{}_{2lpt} \qquad \forall l,k,p,t \qquad (30)$$

There are three main disadvantages in this approach: **1)** an increase in the number of constraints with uncertain parameters considerably increases the number of tests required to achieve appropriate confidence levels for the decision makers and hence increases the time required, **2)** there is no guarantee that the final selected confidence level is optimal, and **3)** it is probable that there might be deviations in the constraints with uncertainties which can result in their infeasibility. To eliminate these drawbacks, a robust probabilistic programming model has been proposed as follows.

A robust decision is can resist against uncertainties and its implementation bring about the minimum fluctuations. Robust optimization programming is a risk-averse approach for dealing with optimization problems under uncertain conditions (Pishvaee et al., 2012). For the first time in 1973, Sevister developed a pessimistic method to deal with linear programming models. Mulvey et al. (1995) developed a more flexible robust model, on the basis of a scenario-based stochastic programming, which was a turning point in the related literature and other models were presented later on its basis. Some years afterwards, Ben-Tal and Nemirovski (2000) took a considerable step forward in enhancing the robust programming theory by developing Sevister's model for uncertain linear programming problems with convex uncertainty sets.

Next, Bertsimas and Sim (2004) proposed, based on Sevister’s model, a pessimistic model with less conservatism. Also, Leung et al. (2007) have presented some developed forms of Mulvey’s model.

In a robust model, the worst value of the objective function occurs when its uncertain parameters have their worst possible values; therefore, in our case, the worst objective function value is when the exchange rate has its worst possible value. Since the objective function is of the maximization type, in the terms with positive sign for exchange rate, the worst value occurs in E^1 and in terms with negative sign for exchange rate it occurs in E^4. Considering these assumption, the robust probabilistic programming model will be as follows:

$$Max E[z] - \gamma(E[z] - z_{\min}) - \varphi[\frac{1}{2}(1+\alpha)D^3_{1lpt} + \frac{1}{2}(1-\alpha)D^4_{1lpt} - D^3_{1lpt}] - \varphi[\frac{1}{2}(1+\alpha)D^3_{2lpt} + \frac{1}{2}(1-\alpha)D^4_{2lpt} - D^3_{2lpt}] \quad (31)$$

St.

Equations (4)-(18) and equations (20)-(21) and equations (30)-(31)

$$E[z] = \sum_k \sum_t (1 - tr_{kt}).E(z^+_{kt} - z^-_{kt}) + \sum_j \sum_t (1 - tr_{jt}).E(z^+_{jt} - z^-_{jt}) \quad (32)$$

$$Z_{\min} = \sum_k \sum_t (1 - tr_{kt}).(z^+_{kt} - z^-_{kt})_{\min} + \sum_j \sum_t (1 - tr_{jt}).(z^+_{jt} - z^-_{jt})_{\min} \quad (33)$$

$$E(z^+_{jt} - z^-_{jt}) = (\sum_p \sum_k x_{1jkpt}.Tf_{1jkpt}.yf_{jkt} + \sum_p \sum_k x_{2jkpt}.Tf_{2jkpt}.yf_{jkt} + \quad \forall j,t \quad (34)$$
$$\sum_p \sum_k x_{2jkpt}.Tc_{2jkpt}.yc_{jkt} + \sum_p \sum_k x_{1jkpt}.Tc_{1jkpt}.yc_{jkt}).[\frac{E_1 + E_2 + E_3 + E_4}{4}] - \sum_r \sum_j x_{ijrt}(p_{rijt} + tc_{ij}) -$$
$$\sum_r \frac{(I_{jrt} + I_{jrt-1}).hc'_{jt}}{2} - \sum_p \frac{(I_{1jpt} + I_{1jpt-1}).hc_{jt}}{2} - \sum_p \frac{(I_{2jpt} + I_{2jpt-1}).hc_{jt}}{2} - \sum_i Sa_{it}(\sum_r x_{ijrt}.\mathrm{Qc}1) + Qc2 -$$
$$\sum_i Sh_{it}.\mathrm{Qc}\,2 - \sum_k yf_{jkt}.Tc1_{jk}.(\sum_p x_{1jkplt} + \sum_p x_{2jkplt}) - \sum_k yc_{jkt}(Tc1_{jk} + Tc2_{jk} + b_t).(\sum_p x_{1jkplt} + \sum_p x_{2jkplt})$$

$$E(z^+_{kt} - z^-_{kt}) = \sum_l \sum_p x_{1klpt}.p_{1klpt}.E_t + \sum_l \sum_p x_{2klpt}.p_{2klpt}.[\frac{E_1 + E_2 + E_3 + E_4}{4}] - \quad \forall k,t \quad (35)$$
$$f_k.d_k - In_{kt}\left[\frac{(I_{1kpt} + I_{1kpt-1})}{2} + \frac{(I_{2kpt} + I_{2kpt-1})}{2}\right].[\frac{E_1 + E_2 + E_3 + E_4}{4}] - (\sum_j \sum_p Tf_{1jkpt}.yf_{jkt}.x_{1jkpt} -$$
$$\sum_j \sum_p Tf_{2jkpt}.yf_{jkt}.x_{2jkpt} - \sum_j \sum_p \sum_m Tc_{1jkpt}.yc_{jkt}.x_{1jkpt} - \sum_j \sum_p Tc_{2jkpt}.yc_{jkt}.x_{2jkpt}).[\frac{E_1 + E_2 + E_3 + E_4}{4}] -$$
$$\sum_j \sum_p Tc2_{jkpt}.yc_{jkt}.(x_{1jkpt} + x_{2jkpt}).[\frac{E_1 + E_2 + E_3 + E_4}{4}] - \sum_j \sum_p yf_{jkt}.(x_{1jkpt} + x_{2jkpt}).(b_t + Tc2_{jkt} + Tc3_{jkt}) -$$
$$\sum_j \sum_p yc_{jkt}.(x_{1jkpt} + x_{2jkpt}).Tc3_{jkt} - \sum_j \sum_p ti_{kt}.yf_{jkt}.(Tf_{1jkpt} + b_t + Tc2_{jkt} + Tc3_{jkt}).x_{1jkpt} -$$
$$\sum_j \sum_p ti_{kt}.yf_{jkt}.(Tf_{1jkpt} + b_t + Tc2_{jkt} + Tc3_{jkt}).x_{2jkpt} - \sum_j \sum_p ti_{kt}.yc_{jkt}.Tc3_{jkt}.x_{1jkpt} - \sum_j \sum_p ti_{kt}.yc_{jkt}.Tc3_{jkt}.x_{1jkpt}$$

$$(z_{jt}^{+}-z_{jt}^{-})_{\min}=(\sum_{p}\sum_{m}\sum_{k}x_{1jkpt}.Tf_{1jkpt}.yf_{jkt}+\sum_{p}\sum_{k}x_{2jkpt}.Tf_{2jkpt}.yf_{jkt}+ \qquad \forall j,t \qquad (36)$$

$$\sum_{p}\sum_{k}x_{2jkpt}.Tc_{2jkpt}.yc_{jkt}+\sum_{p}\sum_{k}x_{1jkpt}.Tc_{1jkpt}.yc_{jkt}).E_{1}$$

$$-\sum_{r}\sum_{j}x_{ijrt}(p_{rijt}+tc_{ij})-\sum_{r}\frac{(I_{jrt}+I_{jrt-1}).hc'_{jt}}{2}-\sum_{p}\frac{(I_{1jpt}+I_{1jpt-1}).hc_{jt}}{2}-\sum_{p}\frac{(I_{2jpt}+I_{2jpt-1}).hc_{jt}}{2}-$$

$$\sum_{i}Sa_{it}(\sum_{r}x_{ijrt}.\mathrm{Qc1})+Qc2-\sum_{i}Sh_{it}.\mathrm{Qc}\,2-\sum_{k}\sum_{m}yf_{jkt}.Tc1_{jk}.(\sum_{p}x_{1jkplt}+\sum_{p}x_{2jkplt})-$$

$$\sum_{k}yc_{jkt}.(Tc1_{jk}+Tc2_{jkt}+b_{t}).(\sum_{p}x_{1jkplt}+\sum_{p}x_{2jkplt})$$

$$(z_{kt}^{+}-z_{kt}^{-})_{\min}=\sum_{l}\sum_{p}x_{1klpt}.p_{1klpt}.E_{t}+\sum_{l}\sum_{p}x_{2klpt}.p_{2klpt}.E_{1}- \qquad \forall k,t \qquad (37)$$

$$f_{k}.d_{k}-In_{kt}\left[\frac{(I_{1kpt}+I_{1kpt-1})}{2}+\frac{(I_{2kpt}+I_{2kpt-1})}{2}\right].E_{4}-(\sum_{j}\sum_{p}Tf_{1jkpt}.yf_{jkt}.x_{1jkpt}-\sum_{j}\sum_{p}Tf_{2jkpt}.yf_{jkt}.x_{2jkpt}-$$

$$\sum_{j}\sum_{p}Tc_{1jkpt}.yc_{jkt}.x_{1jkpt}-\sum_{j}\sum_{p}Tc_{2jkpt}.yc_{jkt}.x_{2jkpt}).E_{4}-\sum_{j}\sum_{p}Tc2_{jkpt}.yc_{jkt}.(x_{1jkpt}+x_{2jkpt}).E_{4}-$$

$$\sum_{j}\sum_{p}yf_{jkt}.(x_{1jkpt}+x_{2jkpt}).(b_{t}+Tc2_{jkt}+Tc3_{jkt})-\sum_{j}\sum_{p}yc_{jkt}.(x_{1jkpt}+x_{2jkpt}).(Tc3_{jkt})-$$

$$\sum_{j}\sum_{p}ti_{kt}.yf_{jkt}.(Tf_{1jkpt}+b_{t}+Tc2_{jkt}+Tc3_{jkt}).x_{1jkpt}-\sum_{j}\sum_{p}ti_{kt}.yf_{jkt}.(Tf_{1jkpt}+b_{t}+Tc2_{jkt}+Tc3_{jkt}).x_{2jkpt}-$$

$$\sum_{j}\sum_{p}ti_{kt}.yc_{jkt}.Tc3_{jkt}.x_{1jkpt}-\sum_{j}\sum_{p}ti_{kt}.yc_{jkt}.Tc3_{jkt}.x_{1jkpt}$$

4-1-Model linearization

Since in equations (2) and (3) three decision variables are multiplied, the model is nonlinear and should be linearized to achieve more desirable state. This is done by a two-step approach presented by change and change (2000).In the first linearization step, the auxiliary variable $u1_{jkpt}$ is defined as $u1_{jkpt}=x_{1jkpt}.yf_{jkt}$. This variable definition guarantees that if yf_{jkt} =0, then $u1_{jkpt}$=0. But, if yf_{jkt} =1, then $u1_{jkpt}=x_{1jkpt}$. Equations 40-42 carry out the linearization of x_{2jkpt} in the case of FOB contracts. Again, the first linearization step for x_{2jkpt} and x_{1jkpt} in the CIF contracts is done according to equations 43-49.

$$u1_{jkpt}\le x_{1jkpt} \qquad \forall k,j,p,t \qquad (38)$$

$$u1_{jkpt}\le M.yf_{jkt} \qquad \forall k,j,p,t \qquad (39)$$

$$u1_{jkpt}\ge x_{1jkpt}-M.yf_{jkt} \qquad \forall k,j,p,t \qquad (40)$$

$$u2_{jkpt}\le x_{2jkpt} \qquad \forall k,j,p,t \qquad (41)$$

$$u2_{jkpt}\le M.yf_{jkt} \qquad \forall k,j,p,t \qquad (42)$$

$$u2_{jkpt}\ge x_{2jkpt}-M.yf_{jkt} \qquad \forall k,j,p,t \qquad (43)$$

$$u3_{jkpt} \le x_{1jkpt} \qquad \forall k, j, p, t \qquad (44)$$

$$u3_{jkpt} \le M.yc_{jkt} \qquad \forall k, j, p, t \qquad (45)$$

$$u1_{jkpt} \ge x_{1jkpt} - M.yc_{jkt} \qquad \forall k, j, p, t \qquad (46)$$

$$u4_{jkpt} \le x_{2jkpt} \qquad \forall k, j, p, t \qquad (47)$$

$$u4_{jkpt} \le M.yc_{jkt} \qquad \forall k, j, p, t \qquad (48)$$

$$u4_{jkpt} \ge x_{2jkpt} - M.yc_{jkt} \qquad \forall k, j, p, t \qquad (49)$$

In the second step, the product of the two continuous variables U_1 and TF is linearized by defining the auxiliary variables $r1_{jkpt} = tf_{1jkpt}.u1_{jkpt}$, $r2_{jkpt} = tf_{2jkpt}.u2_{jkpt}$, $r3_{jkpt} = tc_{1jkpt}.u3_{jkpt}$ and $r4_{jkpt} = tc_{2jkpt}.u4_{jkpt}$; this method was first used by Vidal and Gutschalex (2001). The point worth noting in this method is that at least one of the two variables should have upper and lower bounds; here TF has this condition. Substituting the above equations in the set of equations (21), we will have the equations (50):

$$\begin{aligned} & Tf_{1\min}.u1_{jkpt} \le r1_{jkpt} \le Tf_{1\max}.u1_{jkpt} \\ & Tf_{2\min}.u2_{jkpt} \le Tf_{2jkpt} \le Tf_{2\max}.u2_{jkpt} \\ & Tc_{1\min}.u3_{jkpt} \le r3_{jkpt} \le Tc_{1\max}.u3_{jkpt} \\ & Tc_{2\min}.u4_{jkpt} \le r4_{jkpt} \le Tc_{2\max}.u4_{jkpt} \end{aligned} \qquad (50)$$

Again, in equations (11) and (12), two continuous and binary variables have been multiplied. To linearize these equations, we will use the first step of the above method by first defining the auxiliary variables $e1_{ijrt} = x_{ijrt}.sa_{it}$ and $e2_{ijrt} = x_{ijrt}.sh_{it}$ and adding the equations (51)-(52) to the model:

$$\begin{aligned} & e1_{ijrt} \le x_{ijrt} \\ & e1_{ijrt} \le sa_{it} \\ & e1_{ijrt} \ge x_{ijrt} - M.sa_{it} \end{aligned} \qquad (51)$$

$$\begin{aligned} & e2_{ijrt} \le x_{ijrt} \\ & e2_{ijrt} \le sh_{it} \\ & e3_{ijrt} \ge x_{ijrt} - M.sh_{it} \end{aligned} \qquad (52)$$

5- Numerical results

To solve the presented model the GAMS software is used. Assuming a hypothetical SC including six suppliers, one processing center, and five potential points for the distribution centers in five countries; the model has to select three of them. Parameters related to these centers and the flows between them have been hypothetically considered in the model which is then solved in five time periods. Considering the strategic decision horizon, each period in the model is six months. Tables 1-3 show respectively the problem dimensions, exchange rate with trapezoidal distribution (in dollar because of its international acceptance), tax rate on profit (for processing and potential distribution centers in foreign countries).

Table 1. Problem dimensions

No of raw materials	No of product types	No of wholesalers	No of potential distribution points	No of processing centers	No of suppliers	No of time periods
6	5	10	5	1	6	5

Table 2. Exchange rate

Distribution Center	Exchange rate(for periods on dollar)
1	(3000,3200,3400,3600)
2	(3200,3400,3600,3800)
3	(3400,3600,3800,4000)
4	(3600,3800,4000,4200)
5	(3800,4000,4200,4400)

Table 3. Tax rate on profit

Center	Tax rate
Processing	0.25
Distribution 1	0.18
Distribution 2	0.32
Distribution 3	0.18
Distribution 4	0.20
Distribution 5	0.25

Model solution results have been reported in Tables 4-9. As shown, locations with lower tax rates and import rights are more appropriate for setting up distribution centers which means these two parameters have the highest impact on the selection of the potential points (compared with other influential parameters). Results also reveal that the purchase and storage of the raw materials in the warehouse of the processing center, and also purchase and storage of the final products in the distribution centers are more economical than buying them in each period because their storage costs are low. Distribution centers 1, 2, and 4 have been selected from among the five potential ones.

Table 4. Setting up distribution centers

Distribution center	K=1	K=2	K=3	K=4	K=5
Set-up	1	1	0	1	0

Table 5. Selecting FOB contract

Time period Distribution center	T=1	T=2	T=3	T=4	T=5
K=1	1	0	0	1	1
K=2	1	1	0	0	0
K=3	0	0	0	0	0
K=4	1	0	1	1	1
K=5	0	0	0	0	0

Table 6. Selecting CIF contract

Time period Distribution center	T=1	T=2	T=3	T=4	T=5
K=1	0	1	1	0	0
K=2	0	0	1	1	1
K=3	0	1	0	0	0
K=4	0	1	0	0	0
K=5	0	0	0	0	0

Table 7. Allocating distribution centers to wholesale

Distribution center	K=1					K=2					K=4				
Time Wholesaler	T=1	T=2	T=3	T=4	T=5	T=1	T=2	T=3	T=4	T=5	T=1	T=2	T=3	T=4	T=5
L=1	1	1	1	1	0	0	0	0	0	1	0	0	0	0	0
L=2	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
L=3	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
L=4	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
L=5	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0
L=6	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0
L=7	0	0	1	1	1	1	1	0	0	0	0	0	0	0	0
L=8	1	1	1	1	1	0	0	0	0	0	0	0	0	0	0
L=9	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
L=10	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1

Table 8. Optimum value of the transfer price for quality level 1

Dist. center	Products	T=1	T=2	T=3	T=4	T=5
K=1	P=1	0.5690	1.5262	1.8521	1.4625	1.2514
K=1	P=2	1.2521	1.0222	1.2323	1.0215	1.8350
K=1	P=3	0.9562	0.9452	1.5252	1.2511	1.2555
K=1	P=4	1.8525	2.2250	3.2323	1.2522	1.2521
K=2	P=1	1.2530	1.2530	1.2530	1.2360	1.2800
K=2	P=2	0.9520	0.8520	0.8510	1.2562	1.5251
K=2	P=3	0.9652	0.9513	0.9145	0.9251	0.9623
K=2	P=4	1.2525	1.3333	1.2666	1.8989	2.0232
K=4	P=1	1.2522	.25323	.25211	0.2323	0.9858
K=4	P=2	1.2562	1.3636	1.4525	1.9652	1.9596
K=4	P=3	0.9586	0.9851	1.0052	1.0236	0.9552
K=4	P=4	0.9253	0.9562	0.9362	0.9325	0.9256

Table 9. Optimum value of the transfer price for quality level 2

Distribution center	Product	T=1	T=2	T=3	T=4	T=5
K=1	P=1	1.2352	1.2	1.1251	1.0125	1.2
K=1	P=2	0.8	1.2532	1.1125	1.2563	1.7585
K=1	P=3	0.8965	1.2323	1.2511	1.256	1.3232
K=1	P=4	1.2222	1.3232	1.5252	1.2525	1.2531
K=2	P=1	1.2523	1.2523	1.2323	1.3333	1.2320
K=2	P=2	0.963	0.8563	0.85	0.8562	0.8563
K=2	P=3	0.8562	0.9633	0.9562	0.9251	0.9623
K=2	P=4	1.8520	1.2510	1.2363	1.2365	1.5425
K=4	P=1	1.2522	1.2965	1.2520	1.5525	0.9858
K=4	P=2	1.2562	1.3636	1.4525	1.9652	1.9596
K=4	P=3	0.9586	0.9851	1.0052	1.0236	0.9552
K=4	P=4	0.9253	0.9562	0.9362	0.9325	0.9256

6- Discussion

After solving the model, the effects of the tax rate on the objective function will be studied. For this purpose, the related parameter has been increased by 10% and decreased by 20% compared to the base value. Figure 2 shows the values of the integrated profit objective function under the influence of the tax on profit. As shown, the objective function value decreases with an increase in the tax on profit.

To study the effects of tax on the selection of FOB and CIF contracts, their lower and upper bound prices have been set equal. The model solution results under this assumption show that locations 2, 3, and 5 are selected for setting up distribution centers and the CIF is the optimum contract between the production and distribution centers. When the contracts’ price ranges are set equal, the income part in the objective function will be the same for both contracts and hence to maximize the objective function it is necessary to allocate the transportation and insurance costs (between the production and distribution ports) to the country with more tax because the pretax profit of the mentioned country will be less and therefore its after-tax profit will be increased. Accordingly, to maximize the profit, it is necessary that the production center should pay the transportation and insurance costs (between the two ports); therefore, the CIF contract is selected.

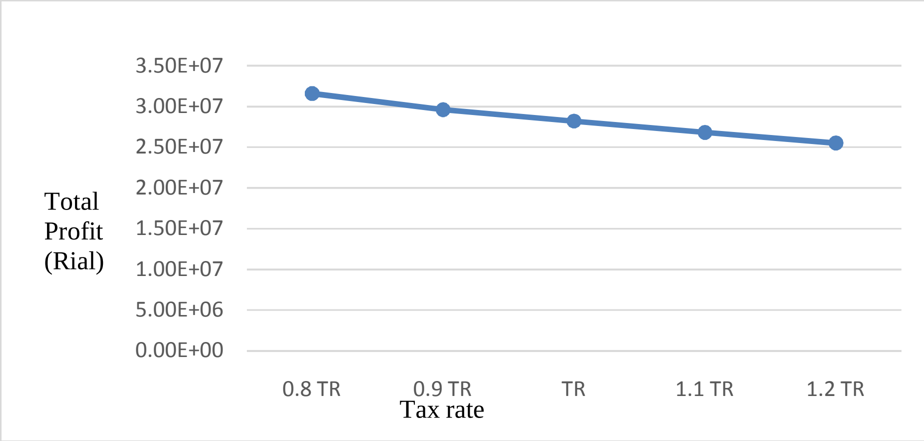


Figure 2. Effects of tax rate variations on the integrated profit

To analyze the performance of the proposed model, the probabilistic model was optimized considering a set confidence levels equal to 0.7, 0.8, and 0.9;their related objective function values are shown in Fig. 3. Results show that an increase in the least degree of feasibility will lead to a decrease in the objective function value due to more consumption of the resources. Next, 10 simulations were done randomly on the uncertain parameters under 7 different penalties shown in Table 13. For each simulation for an uncertain parameter with trapezoidal probabilistic distribution, a random number is produced uniformly between the beginning and end points of the probability distribution function. Then, the parameters produced in each simulation, and the optimum values of the variables specified by the probabilistic and robust probabilistic models under nominal data enter the model to check the outputs desirability and compare their results. Next, the optimum value of the objective function were calculated and compared under different penalties, average, and standard deviation of the robust probabilistic programming model (Figs. 4 and 5). The point quite obvious in Fig. 5 is that the standard deviation of the robust model is always better than that of the probabilistic model under different confidence levels. Another point worth noting is that the increase in penalties has increased the standard deviation, but the robust model’s superiority has been always maintained. In addition to the standard deviation, the average of the objective function too requires attention. As shown in Fig. 4, the values of the average of the objective functionof the robust model in the first two penalties are respectively less and equal to that of the probabilistic model at different confidence levels meaning that the robust model’s performance is not desirable compared to that of the probabilistic model. But, in the next series of penalties, the average value of the robust model is better than that of the probabilistic model meaning a better performance. When the amount of penalties or the decision makers’ risk aversion is high, using risk-averse models as robust probabilistic models is a more logical suggestion.

Table 10- Penalty values

No	1	2	3	4	5	6	7
penalty value	3000	5000	10000	20000	30000	40000	50000

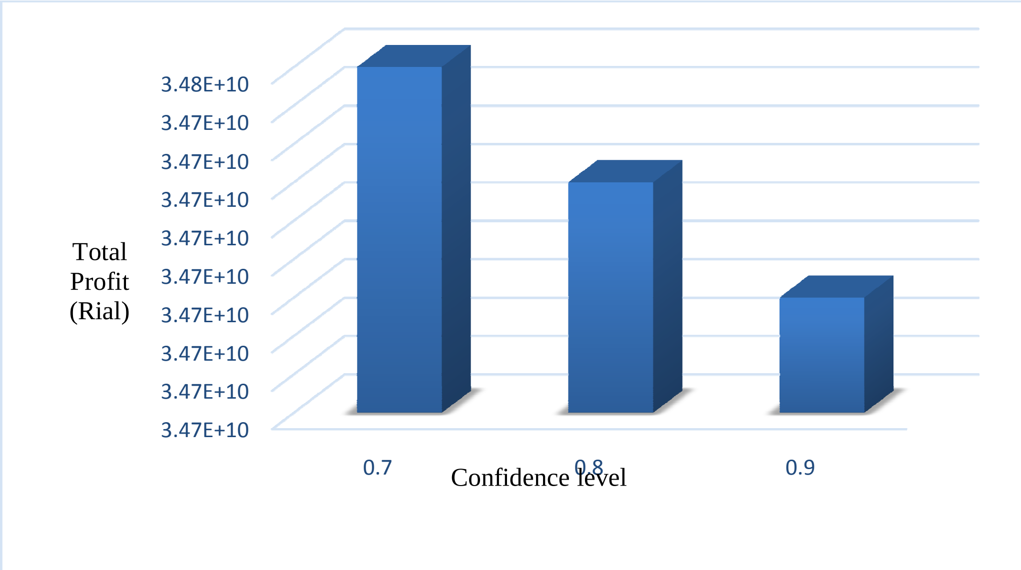


Figure 3. Different objective function values for different confidence levels

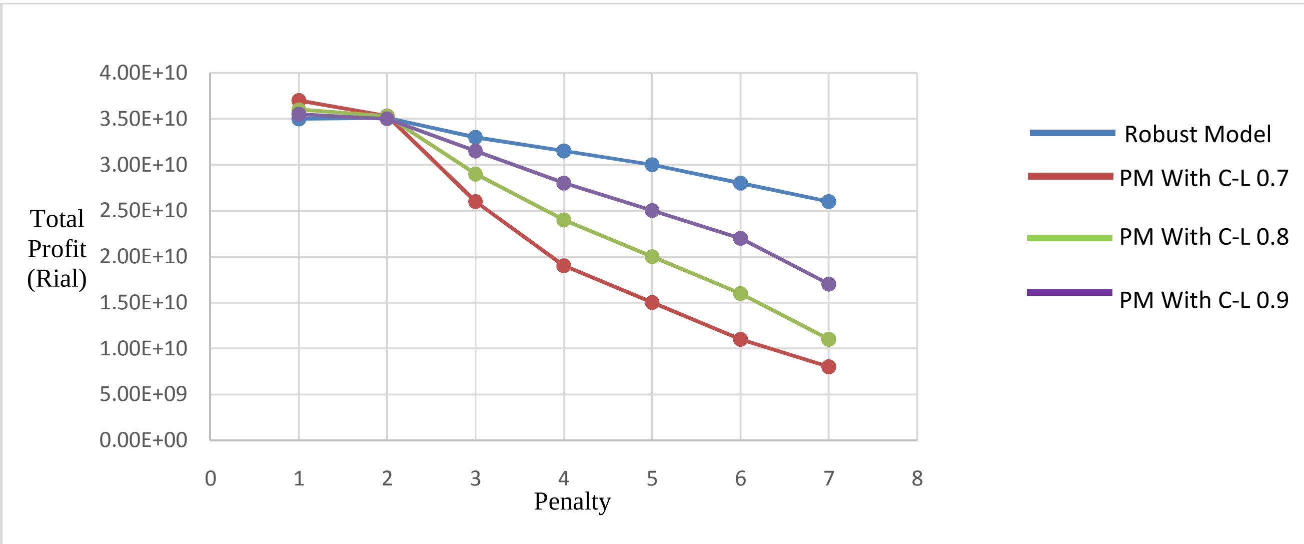


Figure 4. Average values of the objective function for different fine values

(PM: Possibilistaic Model, CL: Confidence Level)

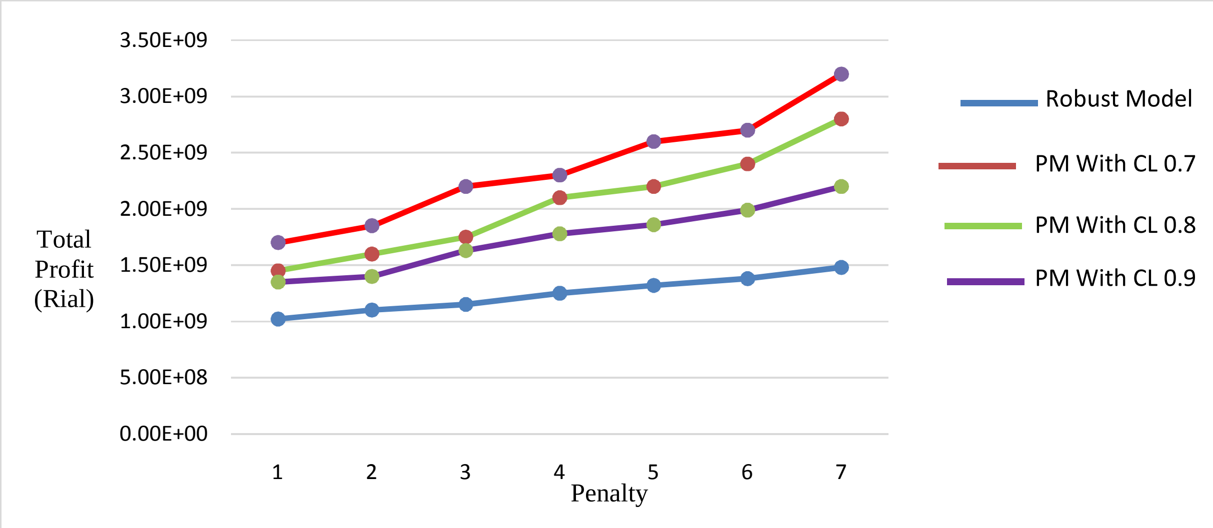


Figure 5. Standard deviation values for different fine values

7- Conclusion

Business globalization and emergence of the international companies are the reasons for more attention towards the global supply chain network design. Since decisions regarding network design have long term horizon, costly, and time consuming effects the optimum SCND is of great importance in decreasing the costs and increasing the profits of the international companies. In this research a MIP model has been proposed for the global SCND wherein the decisions about selecting best locations for distribution centers, allocating them to customers, selecting best transportation/delivery contracts between production and distribution centers, finding the optimum transfer price for products. It has been tried to consider international parameters as the exchange rate, tax rate, import tariffs, and transportation insurance to make the proposed model more realistic. In the proposed model, fuzzy numbers and probabilistic theory were used to address the uncertainty associated with the exchange rate and demand parameters. As the model results show, centers with lower tax rates and import rights are more appropriate for distribution centers meaning that these parameters have the highest effects on selecting the potential points for distribution centers compared to other parameters. Results also reveal that buying raw materials and final products and storing them respectively in the processing and distribution centers' warehouses is more economical than buying them in each time period due to their low storage costs.

Although the appearance of the global SCND dates back to many years ago, considering its importance in today's world, consistent research in this area is of utmost importance and deems quite necessary. Research opportunities enhancement of the existing global SCND models are numerous. One of them is the simultaneous consideration of qualitative and quantitative parameters in the model. Considering the global SC facility dispersion, addressing such other objectives as risk minimization can be another useful issue suggested for further research. Considering the drawbacks and shortcomings associated with probabilistic models, use of robust mathematical models can be of great help in making the models more realistic. Since real conditions are variable, the uncertainty assumptions in this research (for only exchange rate and demand) can be extended to other model parameters to make it more realistic. The contract forms used in this research for transportation/delivery between centers are FOB and CIF; using other really applicable forms of such contracts or selection of foreign suppliers can be other issues suggested for future studies.

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