A Freight Planning and Carrier Selection Robust Programming Model: A Case of Study

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Abstract: Design/methodology/approach
Trade and transportation are two related issues that affect each other, and planning freight-carrying vehicles to deliver products to markets is a challenging logistics issue which is currently under extensive studies. To have a better decision-making, a bi-objective mathematical programming model should be addressed. It is critical for decision-makers to minimize the travel costs while considering the desired product quality in the destination to maximize the customers' satisfaction. In the scientific research, uncertainty is natural currency. Uncertainty is normal in the real world, but to decision-makers, it sounds like ineffective. As a result, to have a robust decision, a robust possibilistic programming model is proposed. This paper is aimed to plan and allocate the product to proper carrier with appropriate vehicle in the specified route considering its percent reduced quality, under uncertainty. To solve the problem, use has been made of the mathematical modeling and the model has been implemented on a real case to validate it. Tomatoes, oranges, and potatoes have been considered in three high-traffic routes and the model has been solved once without and once with uncertainty in the demand. Numerical results have shown that the proposed model reduces the total cost and, hence, reduces the cost price of the finished product, and prevents its reduced quality when carried by proper vehicles. Effects of the model's key parameters on the cost price have also been checked through some sensitivity analyses.

Keywords: Freight Planning; Carrier Selection; Mathematical programming model; Robust possibilistic programming; Uncertainty

1. Introduction

A network system that consists of moving goods, services and or information from origin to destination can be defined as a supply chain [22]. The transportation role in the SC is to transfer the raw material and semi-finished/finished products and distribute and deliver them to the customer. Considering the day-increasing volume of demand in the world, transportation plays a vital role and large production companies are no more able to do all their responsibilities alone. Therefore, they oursource their transportation tasks to the related organizations and companies. But, the latter do not usually have their own transportation means; they conduct a tender and distribute the existing freight among the qualified selected carriers after aggregating the total demand based on their own required features such as reputation, credit, and the carriers' vehicle variety.

Products are highly variable in nature, require special mode for their transportation, and their demand for each route is determined considering the origin and destination (e.g., flammable material need to be carried with special vehicles or agricultural products have special conditions and should not be spoiled on a long trip to their destination). This study addresses the agricultural products to be carried from the source (cultivation site) to the sink (demand site).

According to the reports published by news agencies, a major reason for agricultural products' rising prices in recent years is the disruption in their displacement and transportation trend due to improper management. In Iran, neither the transportation vehicles are few nor is producing agricultural products a problem because the soil is fertile and the climatic conditions are good. The delay in delivering the product to the customer is merely due to improper transportation management that can be greatly solved by proper planning. This process can now be described, according to the carriers' various demands, by defining some parameters in the form of a mathematical model in each section of which a saving of even 1% can highly reduce the costs.

It is worth noting that moving goods from one place to another is often a complicated process because of its dynamism. Trying more and more to meet different needs of the real world applied issues makes the problem more complicated. For instance, including the existing constraints in the transportation planning problem increases its complexity significantly because the problem becomes non-deterministic and variable; in other words, changing the problem's objectives, nature, or other factors over time, i.e. its related uncertainties, may cause a change in its optimality. If such uncertainties are considered in the optimization process, the problem will become dynamic for which we need solutions that will not lose their optimality under uncertain conditions. These are called "sustainable solutions" which are in fact those that show a good performance under the worst conditions; "robust" and "resistant" are other terms used instead of "sustainable".

Different models have been proposed regarding the product transportation operations, appropriate routes, and selecting proper carriers and their expectation levels for which simulation plays an important role at different stages.

Simulation not only validates the models' correct performance, but also helps the producers and owners of products to make decisions and assess their policies.

According to what was stated, this study is aimed to reach optimal decisions in transportation operations considering a proper vehicle type and the freight it transfers on a specified route. Customers' demands and percent reduced quality of the product along the route are uncertainties added so that the owners can transfer their products to their desired destinations at the lowest cost. The structure of present study was illustrated in Fig. 1.

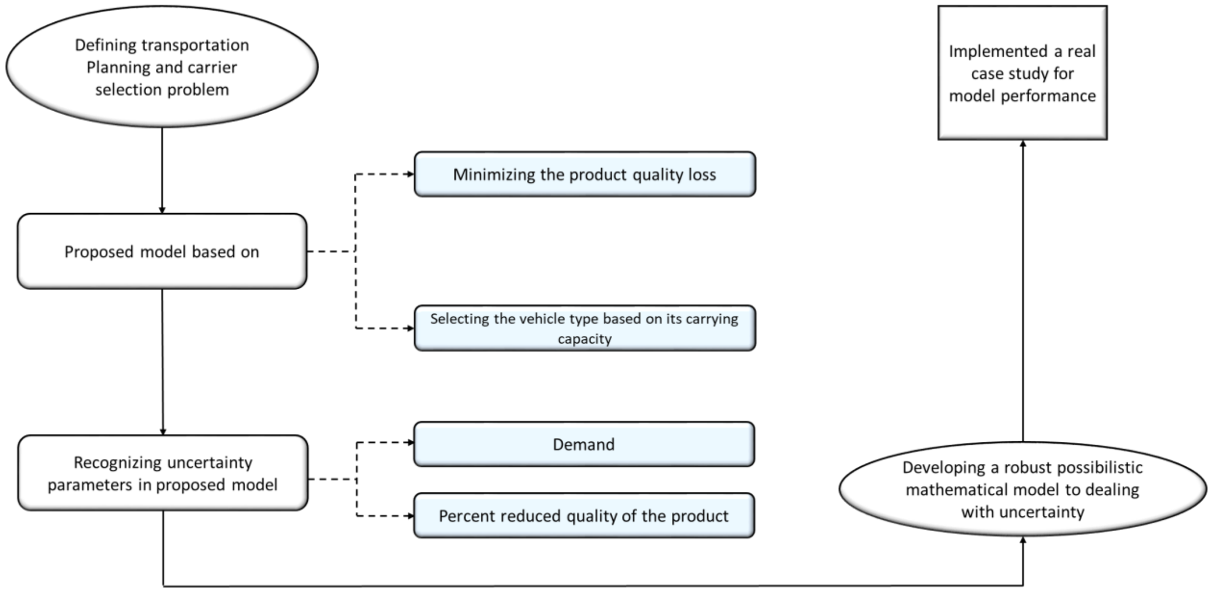

Figure 1- the tructure of this study

The rest of this paper has been so organized as to study and review the literature in Section 2, define the sets, parameters, variables, and problem modeling in Section 3, present and solve a case study in Section 4, do the sensitivity analyses and numerical studies in Section 5, and present the conclusions and suggestions for future studies in Section 6.

2- Literature review

This section will briefly study the research on product transportation planning whose importance is increasing. In the next paragraph, we explained the importance of the issue and using the third party planning to select the best carrier.

The transportation sector consists of the product owner, forwarders, and carriers; logistic services that need high precision (packaging, warehousing, distribution and inventory management, origin-to-destination goods transfer planning and management with proper carriers at lower cost and time) are provided by forwarders or the third party (3PL). The more are these companies in touch with the product owners and take the transfer responsibility of more diverse products, the more complex this process will become. Each owner has a different product in a different route that should reach the destination in a given time period and some products have specific transfer conditions for which a proper vehicle should be selected. On the other hand, the carriers have limited number of vehicles and operate on specific routes depending on their conditions. If they fail to properly manage these processes, not only they themselves and the product owner will incur extra costs, but also the environmental damage will be intensified. The increased use of road infrastructures has also had such consequences as increased accidents leading to economic, social, and psychological effects on the families, increased road maintenance/repair, and so on [3]; this is why carriers are after optimizing their processes as much as they can. The third parties' planning to select the best carrier is a tactical decision usually made annually or every 6 months.

For starting the review, we search the starting point of the transportation and distribution issue in this paragraph that is the main title of the present study. The transportation and distribution issue was first introduced by Canterwidge in 1939. In 1941, a mathematical formula (called the Hitchcock problem) was proposed that is used standardly today and in 1947, Copman did some research in this field [4]. Shefii & Caplice were the first to address logistics and vehicle selection issues in product transportation through mathematical modeling. Their model obtains the optimum number of vehicles and proper means of transportation during the bid process [1]. Since uncertainties play a very important role in optimization and are recently used in many papers, the proposed model too has considered fuzzy demand and product quality reduction.

The uncertain nature of some parameters in these problems caused the authors are pushed to apply uncertainty approaches. The studies that consider the uncertainty in these problems are reviewed in these two paragraphs. Using real data and demand uncertainty in a paper entitled "A Robust Practical Transportation Planning", Morales proposed an efficient planning/management model that gained popularity among carriers because it saved much of the fleet costs and equipment [5]. He then used the robust optimization technique that controls fixed routes under severe conditions. Considering uncertainty in ships' arrival, unloading, and loading time, Kazemi et al. developed a planning model of assigning berths at container terminals that reduced the departure time and maintained the planning robustness under uncertain conditions. Considering uncertain demand [6], Tikeny et al. modeled and solved an integrated mathematical model for capacitated single-hub locating in the aircraft industry [7]. It was formulated as a stochastic, two-phase, integer, programming model for the solution which a GA-exact evolutionary algorithm was proposed. Liu et al. developed an emergency relief logistics model under uncertain disaster time and demand and solved a numerical example to check its applicability [11]. Cappanera et al. wrote an essay on the optimization planning model of the home for the elderly considering uncertain demand [12]. Saeedi et al. presented a robust optimization model for uncertain loading of a chiller and solved it with the GAMS software [13]. In a paper on "Fuzzy Uncertainties in the Logistic Equation", Cecconello et al. used the population density as an uncertain fuzzy variable to obtain more reliable results in their modeling [18]. Ahmadian Behrooz has developed a model on the uncertain demand management in the natural gas transmission network and has used an algorithm developed based on chance constraints [13]. In a paper entitled "A Reliable Multi-stage Hybrid Load Transport Model", Fotouhi & Nathan developed a robust mix integer model with uncertain supply and demand in specified time periods and different routes [16]. They implemented it in small and large networks and showed that time can be divided into different periods to reduce the transportation costs. They developed an algorithm to solve the model which also controls the worst case and has a constraint to enforce heavy fines for late deliveries.

In continuous, the studies are categorized based on uncertainty parameters consideration. Most optimization papers have considered only uncertain demand, but the model in this paper considers uncertainty both in demand and percent reduced quality as well as in. As regards the percent reduced quality of products carried with different vehicles, Seifi et al. presented a 2005-2014 review review paper on hybrid freight transport wherein they evaluated the travel time for perishable goods and concluded that any development in the transportation models would greatly save the related costs [17]. Considering time interval constraints, Hadian et al. addressed the vehicle routing problem for the transportation/distribution of perishable goods and reduced fuel consumption. Then using the CPLEX solver and GAMS software in a case study, they solved and validated their proposed model. Considering transportation issues [8], Etemadnia et al. studied the locating of places for collecting and distributing fruit and vegetables, Since the population growth increases the need for the food stuff, authorities are after better SC management and planning to not only provide the people with timely product delivery, but also reduce the total network costs (transportation, construction of distribution sites, etc.) [15].

The next category of papers has been reviewed base on the objective functions. Each of the mentioned papers has somehow considered, in its model, the percent reduced quality of products with specific expiry dates. The present paper has specified this change in the objective function with a coefficient that is multiplied by the product price. This means that the product owner should incur more cost if a product spoils, and since we are after minimizing the transportation costs, we need to select a vehicle that can deliver the most products at the lowest cost and the least decay.

Another issue considered in this article is selecting the vehicle type that is somehow related to the percent reduced quality because it affects the product carrying capacity. For instance, some vehicles are refrigerated and can keep perishable materials (agricultural products, vegetables, etc.) for a longer time, but have less capacity and can displace smaller quantities of goods.

Since the proper vehicle selection is a decision that affects the travel demand, Mahsa Taghavi et al. studied it for passenger transportation, checked its interaction with the starting time of non-working trips, and modeled it by the multiple logit model [9]. Keyvanfar et al. [24] have proposed a model with three considered objectives that are minimizing the total logistics costs, maximizing the rate of demand satisfaction and maximizing the quality of delivery and also Zou et al [25] have presented an attempt to realize the optimization of cascading failure process of urban transit network based on Load-Capacity model, for better evaluating and improving the operation of transit network.

A review of all the related papers concludes that most of them have, for simplicity, neglected many of the real-world issues in their modeling. Some have done the modeling based on how the carrier looks at the issue and some have done the same based on the product owner's point of view. For instance, some have maximized the carrier's profit, some have minimized the transportation cost and time, some have studied the vehicle's environmental effects (social issue), and some have considered random parameters (e.g. demand); however, there is no model that can simulate the desired environment fully with all the views integrated.

Fig. 2 shows a set of 85 terms found from a review of various transportation-related studies used under such different topics as the objective function, focus, deficiency, and so on [26].

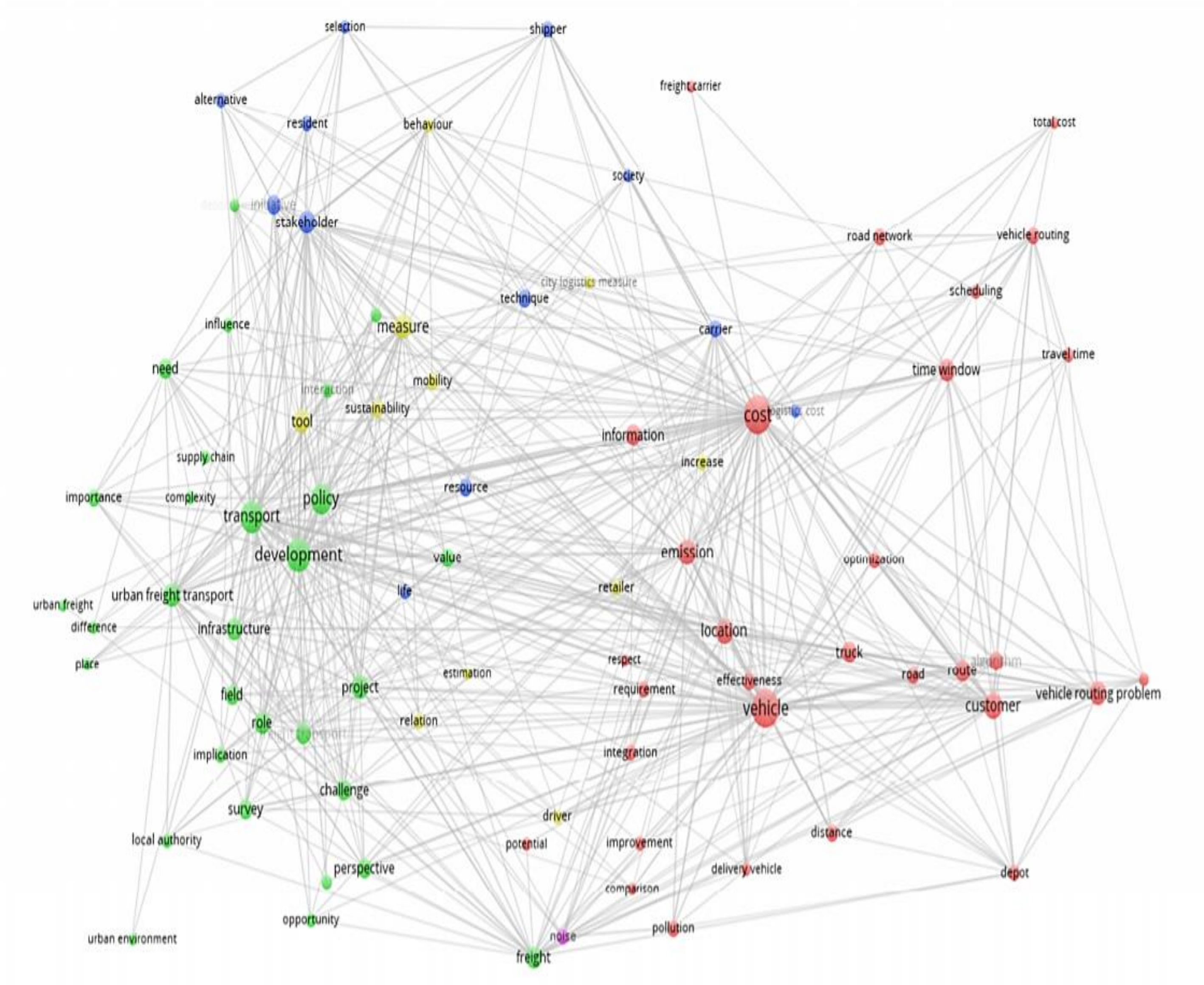

Figure 2- Map of the intensity of the relationship between words

Table 1- A summary of the transportation planning literature

Reference	Loss of quality percentage	selection			Objective Function						Uncertainty Issue		Case Study
		Route	Transportation mode	Carrier	Delay cost	Non serving orders cost	Operational cost	Fixed cost	Profit	Value of time	Cost of variability in transportation time	Demand	
Crainic, Ferland et al. [23]					✓		✓						Canada
Agarwal and Ergun [19]							✓		✓				-
Mu-Chen Chen et [2]	✓		✓				✓						
Andersen and Christiansen [20]					✓		✓	✓	✓	✓	✓		-
Anghinolfi, Paolucci et al. [21]						✓	✓						-
Ayar and Yaman [31]							✓						-
Sh. Hadian et al. [8]	✓		✓							✓			Iran
Jan Havenga et al. [27]					✓			✓	✓				South Africa
Vasco Sanchez Rodrigues et al. [28]				✓			✓		✓		✓		-
Hyun-Chan Kim et al. [29]			✓	✓						✓			New Zealand
M. DOUGLAS VOSS et al. 30]				✓	✓					✓			-
Yue Ge et al. [32]		✓								✓			-
Tian, W. and C. Cao [33]			✓				✓					✓	-
S.-P. Guo. [34]		✓	✓				✓			✓			
Current study	✓		✓	✓			✓					✓	Iran

According to Table 1, the main contributions of this paper are:

- Addressing an integrated model to formulate the transportation planning problems and carrier selection decisions, simultaneously.
- Dealing with uncertainty to determine robust solutions by developing a robust possibilistic mathematical model.
- Studying vehicle mode selection to provide the best product quality during the transportation procedures.
- Solving the model based on the real-world data of agri-food supply network to validate the proposed model.
- Selecting the vehicle type based on its carrying capacity

3- Problem modeling

The transportation of products is an extensive and complex industry. The attention of the paper is on carrier selection and freight transportation planning, which is on transportation operations that are mainly considered with the movements of products over relatively long paths between cities. Products may be displaced by pickups and trucks.

A complicated network of cities (e.g. ports and end-of-lines) connected by physical (e.g. tracks) links. Freight has to be displaced between given spots of this network. Besides its specific origin, destination, and product physical characteristics (weight, volume, etc.), each consignment may present any number of particular service requirements in terms of the type of vehicle. A profit or cost also usually accompanies a specific demand. The carrier displaces the freight by services performed by a large number of vehicles that move, usually on specified routes and sometimes following individually or grouped in convoys such as pickups or assemblies of several trucks.

Next to this issue, in transportation the agri-foods it's necessary delivery time. The quality of agri-food is sensitive to the time of transport because it has the probability of perishable. In other words, the passage of time causes reduced quality of agricultural products. Therefore, it is needful considered modality products in such networks. A view of this network is shown in Fig 3.

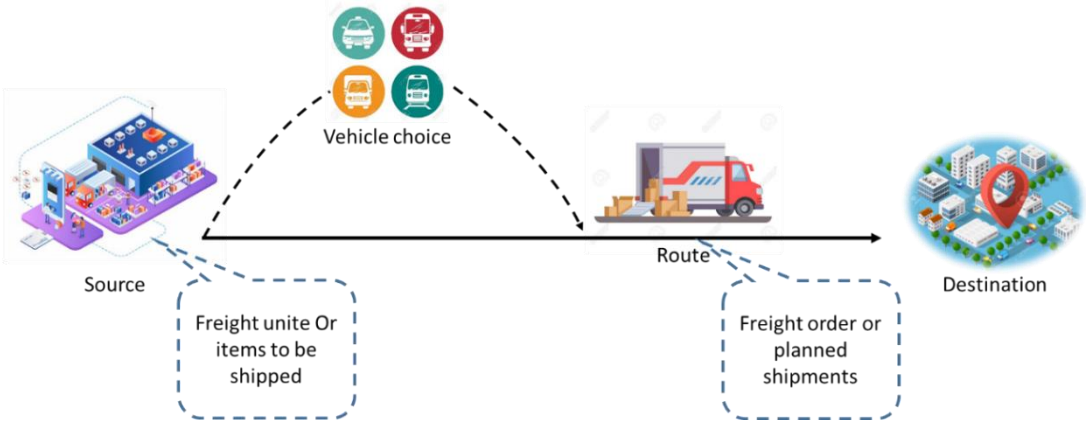

Figure 3-The cycle of transportation planning from origin to destination

3-1- Assumptions for problem formulation

Assumptions made to formulate the model considered in this paper are

- Multi products is procured.
- Carriers lies in a specified range.
- Single period has been considered for planning approach.
- Each carrier can displace only goods in its set of routes.
- For each lines, there are specific carriers with specific transportation mode.
- There is an intermediary company that works with several carriers.

3-2- Problem sets and indices

All the used symbols (input parameters, indices, and variables) are given in the Table (2) below:

Table 2- parameters, variables, and sets description

Sets	Description
$i \in I$	**Carriers in network**
$j \in J$	**lanes**
$p \in P$	**products**
$k \in K$	**Types of vehicle**
Decision variables	
$q_{i,j}^{p,k}$	**Quantity of product p that carrier i in lane j with vehicle type k transport**
$X_{i,j}^{p,k}$	**Number of type k vehicle for carrier i in lane j, product type p**

Parameters	
$alfa_j^{p,k}$	**percent reduced quality of product p in lane j with type k vehicle**
Pr^p	**Product price for per product**
D_j^p	**Demand for per lane per product**
M_i^k	**Maximum number of vehicle for per carrier per vehicle**
$R_{i,j}^k$	**Transportation cost for per carrier per lane per vehicle**
$Ca^{p,k}$	**Vehicle capacity for per product per vehicle**

3-3- The problem model

Eq.1 shows the objective function. In this paper, it minimizes the freight transportation costs considering the percent reduced quality of the product over time; naturally, the more is the time elapsed in the route, the more will become the value of this parameter.

$$Min\ Z_1 = \sum_{i\in I}\sum_{j\in J}\sum_{p\in P}\sum_{k\in K} q_{i,j}^{p,k}\, alfa_j^{p,k}\, Pr^p + \sum_{i\in I}\sum_{j\in J}\sum_{p\in P}\sum_{k\in K} X_{i,j}^{p,k} R_{i,j}^k \qquad (1)$$

Subject to:

$$\sum_{i\in I}\sum_{k\in K} q_{i,j}^{p,k} \geq D_j^p \qquad \forall j,p \qquad (2)$$

$$X_{ij}^{pk} = 0 \qquad \forall i,k,j \in J//Ji \qquad (3)$$

$$\sum_{j\in J}\sum_{p\in P} X_{i,j}^{p,k} \leq M_i^k \qquad \forall i\,,k \qquad (4)$$

$$X_{ij}^{pk} \geq q_{ij}^{pk}/Ca^{pk} \qquad \forall i,j,p,k \qquad (5)$$

$$q_{ij}^{pk} \geq 0\ \ ,\ \ X_{ij}^{pk} \geq 0 \qquad \forall i \qquad (6)$$

Constraint (2) ensures that the demand is fully met (in each route, there is a demand for each product that should be met).Constraint (3) ensures that each carrier should pass only certain routes. Constraint (4) shows the upper bound of the number of vehicles per carrier (each carrier owns a limited number of available vehicles). Constraint (5) yields the number of vehicles (it is equal to the weight of the transported freight divided by the capacity of each vehicle). Constraint (6) ensures that q and x are positive.

3-4- The robust possibilistic mathematical model

Inuiguchi and Sakawa (1996) used min-max approach and it was the first effort towards RP in the area of fuzzy mathematical programming. Robust programming (RP) theory provides risk-averse methods to cope with uncertainties in optimization problems. A clear and comprehensive definition for ‘robust solution’ is defined below: robustness denotes that problem results should not be significantly sensitive to its input parameters. “A robust to an optimization problem is said to be robust if it has both feasibility robustness and optimality robustness. Feasibility robustness means that the solution should remain feasible for (almost) all possible value of uncertain parameters and optimality robustness means that the value of objective function for the solution should remain close to optimal value or have minimum deviation from the optimal value for (almost) all possible value of uncertain parameters. Robust possibilistic programming model The presented realistic RP formulation is a flexible version of hard worst case approach which tries to minimize worst value of exchange rates in objective function nevertheless it does not satisfy all the constraints with uncertain parameters’ in their extreme worst case values. It is not cost effective to consider all uncertain parameters in their extreme values (e.g., demand) unless in cases that even small perturbation from the expected performance could result in catastrophic outcomes (e.g., military and emergency cases). Realistic formulation has considered some violation for demand constraints since it can become shortage in some levels. The realistic programming approach considers a reasonable trade-off between the robustness (optimality robustness), cost of robustness (feasibility robustness) as it tries to produce solutions feasible for almost every possible value of uncertain parameters. It also seeks to produce solutions with least deviation from optimum objective function values. The realistic RP approach covers the range between worst case and average case. Furthermore, the degree of feasibility and optimality robustness can be controlled. The realistic programming approach considers a reasonable trade-off between the robustness (optimality robustness), cost of robustness (feasibility robustness) as it tries to produce solutions feasible for almost every possible value of uncertain parameters. It also seeks to produce solutions with least deviation from optimum objective function values. The realistic RP approach covers the range between worst case and average case. Furthermore, the degree of feasibility and optimality robustness can be controlled (Pishvaee et al., 2012) [10].

The available data of uncertainty parameters have not the precise distribution function for using stochastic approaches because they have deep uncertainty as a result we need a robust optimization model to deal with uncertainty parameters. On the other hand, the high-cost investment has forced us in order to use a realistic approach that one of them is robust possibilistic programming (Pishvaee et al., 2012) [10].

RPP II is a realistic robust possibilistic programming model with the following general form:

$$\text{Min} \quad \mathrm{Z} = \mathrm{fy} + \mathrm{cx}$$

$$S.T: \quad Ax \geq d,$$

$$Bx = 0,$$

$$Sx \leq Ny,$$

$$Tx \leq 1,$$

$$y \in \{0,1\}, \qquad x \geq 0$$

For facing uncertainty parameters N in constraint $Sx \leq Ny$, we used necessity measurement in fuzzy theory. Also, the amount of error from the value determined by necessity measure is shown in the objective function using penalty for violation in the form of $\pi(\beta N_1 + (1-\beta)N_2 - N_1)$. This trend can also be repeated for the demand parameter (d). For example:

$$Nec\{Sx \leq \tilde{N}y\} \geq \beta \Leftrightarrow Sx \leq (\beta N_1 + (1-\beta)N_2)\,\mathrm{y},$$

In RPP II:

$$Min\ E[Z] + \gamma\big((Z_{max}) - E(Z)\big) + \delta(d_4 - (1-\alpha)d_3 - \alpha d_4) + \pi(\beta N_1 + (1-\beta)N_2 - N_1)y$$

$$S.T: \quad Ax \geq (1-\alpha)d_3 + \alpha d_4\,,$$

$$Bx = 0,$$

$$Sx \leq (\beta N_1 + (1-\beta)N_2)\,\mathrm{y},$$

$$Tx \leq 1,$$

$$y \in \{0,1\}, \qquad x \geq 0, \qquad\qquad 0.5 < \alpha, \beta \leq 1$$

Where $E[Z]$ is the expected value of the objective function and Z_{max} is the maximum objective value. Considering this general form, we intend to implement the RPP II for the deterministic model (described in the previous section) under such uncertain parameters as the demand and percent reduced quality $(alfa_j^{p,k}, D_j^p)$. Assuming trapezoidal form for $(\widetilde{alfa_j^{p,k}}, \widetilde{D_j^p})$ uncertain parameters, they can be shown with 4 values:

$$\widetilde{D_j^p} = (D_{j(1)}^p, D_{j(2)}^p, D_{j(3)}^p, D_{j(4)}^p)$$

$$\widetilde{alfa_j^{p,k}} = (alfa_{j(1)}^{p,k}, alfa_{j(2)}^{p,k}, alfa_{j(3)}^{p,k}, alfa_{j(4)}^{p,k})$$

Table 3- Parameters added to the model considering uncertain conditions

New parameters	Description
$\boldsymbol{\gamma}$	Importance factor (penalty for the deviation of the maximum value from the average)
$\boldsymbol{\delta}$	Penalty for demand constraint violation
New decision variables	
$\boldsymbol{a_j^p}$	Minimum chance constraint reliability (related to the demand constraint)

In the possibilistic model, we need new parameters and variables defined in the Table 3. According to the RPP II model, since the objective function in the possibilistic problem should include costs, deviation of the maximum cost from the average, and constraint violation fines, it will be in the form of Eq. (7):

$$Min\ Z = [E(Z_1) + \gamma\big((Z_1)_{max} - E(Z_1)\big) + \delta \sum_j (D_{j(4)}^p - (1 - M_j^p)D_{j(3)}^p - M_j^p D_{j(4)}^p)\ ] \quad (7)$$

$$\text{E(Z}_1\text{)}= \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{p\in P}\big(q_{ij}^{pk}\big)\ \left(\frac{alfa_j^{\ p,k(1)}+alfa_j^{\ p,k(2)}+alfa_j^{\ p,k(3)}+alfa_j^{\ p,k(4)}}{4}\right)Pr^p \times y_{ij}^{pk} + \times y_{ij}^{pk} \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{p\in P} X_{ij}^{pk}\ R_{ij}^k \quad (8)$$

$$Z_{1max}=\sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{p\in P}\big(q_{ij}^{pk}\big)\ alfa_j^{\ p,k(4)}Pr^p \times y_{ij}^{pk} + \sum_{i\in I}\sum_{j\in J}\sum_{k\in K}\sum_{p\in P} X_{ij}^{pk}\ R_{ij}^k \times y_{ij}^{pk} \quad (9)$$

Eq. (8) shows the average cost wherein the uncertain coefficient of percent reduced quality is the average of four values related to its trapezoidal representation. Eq. (9) too shows the maximum cost wherein the coefficient of percent reduced quality has been replaced with the fourth digit (highest value related to the trapezoidal representation).

Next, the constraints that have been changed or added to the model are explained.

$$\sum_{i\in I}\sum_{k\in K} q_{ij}^{pk}\ \le\ \big(1 - a_j^p\big)D_{j(3)}^p + a_j^p D_{j(4)}^p \qquad \forall j,p$$

$$0.5 \le\ a_j^p\ \le 1 \qquad \forall j,p$$

4- Numerical results

In the numerical example, it is assumed that the problem has the following three routes:

Route 1- Shahsavar-Tehran (about 250 km; taking almost 5 hours to cover)

Route 2- Tehran-Arak (about 280 km; taking almost 3.5 hours to cover)

Route 3- Mashhad-Sari (the longest; about 730 km; taking almost 8.5 hours to cover)

Table 4-number of vehicles for each carriers

Transport company	K1 =type I	K2 =type II
A: Fatemi Transport	120	**100**
B: Zamirnezhad Transport	180	**140**
C: Keshavarz Transport	40	**170**

Products are displaced by 3 carriers as follows each of which has a limited number of vehicles shown in Table 4. It is also assumed that carrier 1 (Fatemi Transport) and carrier 3 (Keshavarz Transport) do not displace products on respectively Route 2 (Tehran-Arak) and Route 1 (Shahsavar-Tehran). Considering the origins and routes mentioned above, effort has been made in this case study to select products cultivated more in the routes' origins and sent to other cities incapable of producing them. Table 5 shows the demand for these products in the specified routes. Table 6 shows the fare rates for different carriers (found through research) depending on their policies, routes, and type of the selected vehicle for product transportation.

Table 5- Numerical examples of demand from each product per route in tonne

Route types	**P1= orange (tonne)**	**P2= potato (tonne)**	**P3= tomato (tonne)**
Route1 (Shahsavar-Tehran)	300	0	**340**
Route2 (Tehran- Arak)	200	200	**200**
Route3 (Mashhad-Sari)	0	300	**400**

Table 6- Numerical examples of transportation cost for each vehicles and carriers in dollars

Fatemi transport			
Vehicle types	**Route 1**	**Route 2**	**Route 3**
Type I	380000	0	**450000**
Type II	600000	0	**660000**
Zamirnezhad transport			
Type I	360000	360000	**440000**
Type II	610000	570000	**670000**
Keshavarz transport			
Type I	0	360000	**450000**
Type II	0	580000	**660000**

As shown, the fare for Tehran-Arak Route is more than that for Shahsavar-Tehran. The reason, according to the interviews with these carriers, is that when a freight vehicle leaves Tehran (the capital) for a smaller city, it is very likely that it will return empty whereas when it leaves a small city for Tehran, it is most likely that it can carry another product on the way back (or on another route) due to a large freight variety in Tehran; since the latter is more profitable, its fare is less.

Price of the products sold in the fruit and vegetable markets is much more than that sold by farmers to dealers because: 1) the latter by the product wholesale and 2) a noticeable amount of the product spoils in the way due to improper planning of goods and non-refrigerated vehicles; hence, dealers increase their prices to maintain their profits. This paper has taken the farmers' price (Table 7) for the buyers' optimal conditions.

Obviously, the capacity of the vehicles for each company will remain the same. However, depends on transported product types, capacities will be different. Only in the numerical example, capacity of the vehicle assumed to be equal (table 8).

Table 7-The price of each type of products

	Orange (per tonne-dollar)	**Potato(per tonne-dollar)**	**Tomato (per tonne-dollar)**
Product price	1000	1500	**3500**

Table 8-Capacity of each type of vehicle

	Type I (tonne)	**Type II (tonne)**
Vehicle capacity	20	**40**

The vehicle/product type and route/weather conditions cause some product to spoil (or begin to) in the way. Since the buyers are willing to maximize their profit, they prefer to carry their products with appropriate vehicles to lessen the amount of products that lose their quality. Accordingly, the percent reduced quality has been defined in the objective function by alpha (Table 9) that varies based on the mentioned causes.

A point worth noting is that although the travel time has not been defined separately, it has been included in alpha; its value is different for different carriers (but same vehicle and route) because the driver speed affects the travel time which in turn affects alpha.

Both the deterministic and possibilistic models of this paper have been coded and implemented by the CPLEX Software.

Table 9-Data samples for the percentage of product quality (alpha) on different routes with types of vehicles

Route 1 (Shahsavar- Tehran)		
Product	**Vehicle Type**	
	Type I	**Type Ii**
Orange	5.2	**4.13**
Potato	6.2	**9.3**
Tomato	2.1	**3.15**
Route 2 (Tehran-Arak)		
Orange	2.18	**6.3**
Potato	6.2	**5.03**
Tomato	5.4	**6.1**
Route 3 (Mashhad-Sari)		
Orange	5.3	**9.103**
Potato	5.03	**6.1**
Tomato	5.2	**6.04**

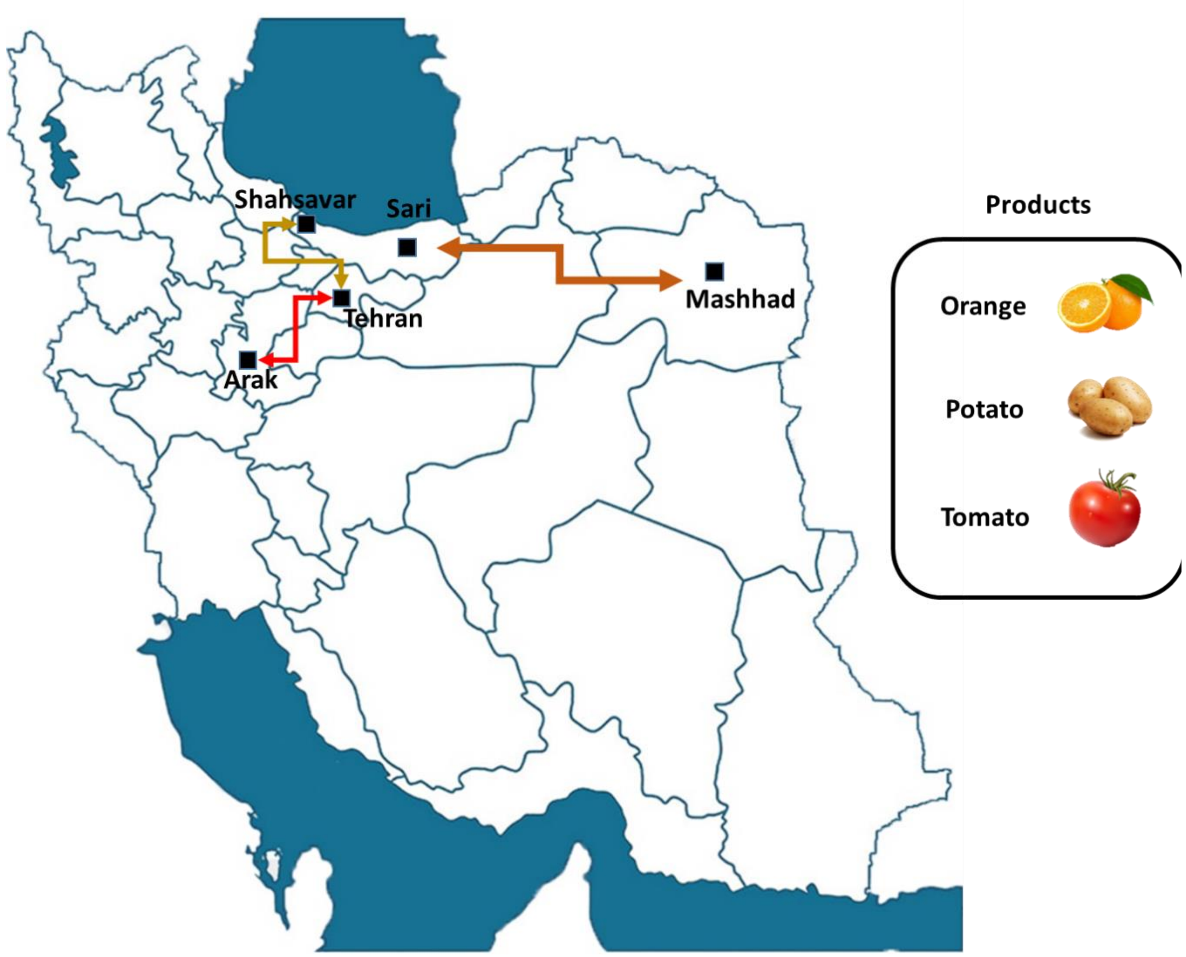

Figure 4-The map of proposed agri-food supply chain network

4-1- Results of the Deterministic and Possibilistic Models

Fig. 4 briefly shows the problem's numerical examples to be explained here in detail.

All the deterministic parameters are similar in both the possibilistic and deterministic models. The uncertain parameters (route demand and percent reduced quality) considered as trapezoidal fuzzy numbers, are calculated as follows:

Part I	$\mathbf{0.8 * deterministic\ quantity}$
Part II	$0.9 * \text{deterministic quantity}$
Part III	$1.1 * \text{deterministic quantity}$
Part IV	$1.2 * \text{deterministic quantity}$

Table 10 shows the values of other new parameters of the problem. The minimum chance constraint reliability for demand equaled 1 in all cases.

Table 10-new parameters for uncertainty problem

Quantity	**New parameters**
1	γ
2000	δ

5- Sensitivity analysis and numerical studies

Table 11 shows all the parameters entered the sensitivity analysis graph separately.

Table 11-All the parameters entered the sensitivity analysis

Parameters	Description
$alfa_j^{p,k}$	**percent reduced quality of product p in lane j with type k vehicle**
Pr^p	**Product price for per product**
D_j^p	**Demand for per lane per product**
M_i^k	**Maximum number of vehicle for per carrier per vehicle**
$R_{i,j}^k$	**Transportation cost for per carrier per lane per vehicle**
$Ca^{p,k}$	**Vehicle capacity for per product per vehicle**

5-1- Sensitivity analysis on product price:

As shown in Fig. 5, our proposed typical model is not very sensitive to the product price because when the latter is 20-fold, the total cost is nearly 8-fold, and when it drops by 40%, the total cost is reduced by only around 17%. In the model with uncertainty, the rise in the total cost is about 7.5 times (for a 20-fold product price rise); the model works like a normal function when the product price falls.

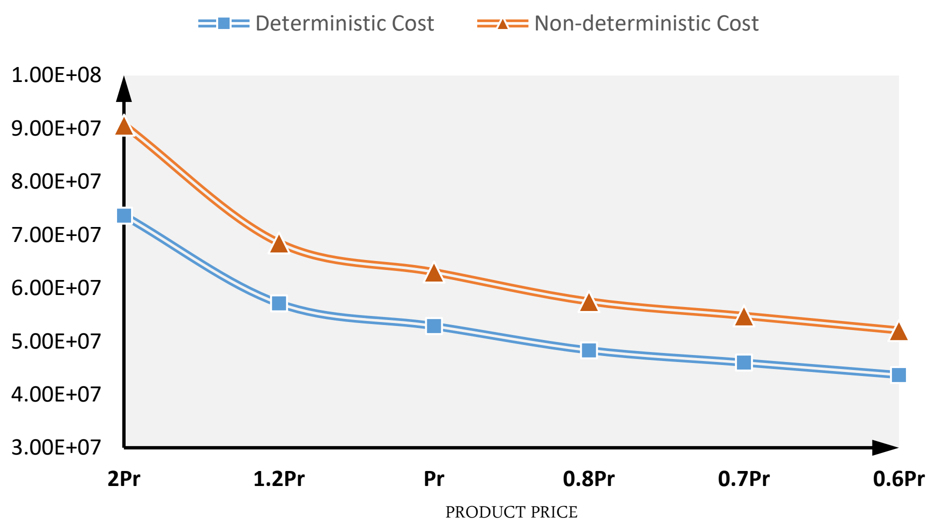

Figure 5-The cost function under product price fluctuation

5-2- Sensitivity analysis on transportation cost:

As expected, a decrease in the transportation costs has reduced the total cost in both models (Fig. 6); a 20% reduction in the former has reduced the total cost of the proposed typical model by 12% (less than 20%). Also Fig. 5 shows the model behavior considering uncertainty in the problem; here too, the decrease in the total cost is 12% for 20% reduction in the transportation costs, and a reduction of 30% in the latter reduces the total cost by 18 and 17% for the typical model and the one with uncertainty, respectively. This means that uncertainties reduce the tolerance in costs and prevent the model from large variations. However, a decrease in percent transportation costs does not equally reduce the total cost, and this difference is higher in higher percentages. Logically, high reductions in the transportation costs are not economical because the total cost is not reduced very much especially in the model with uncertainty.

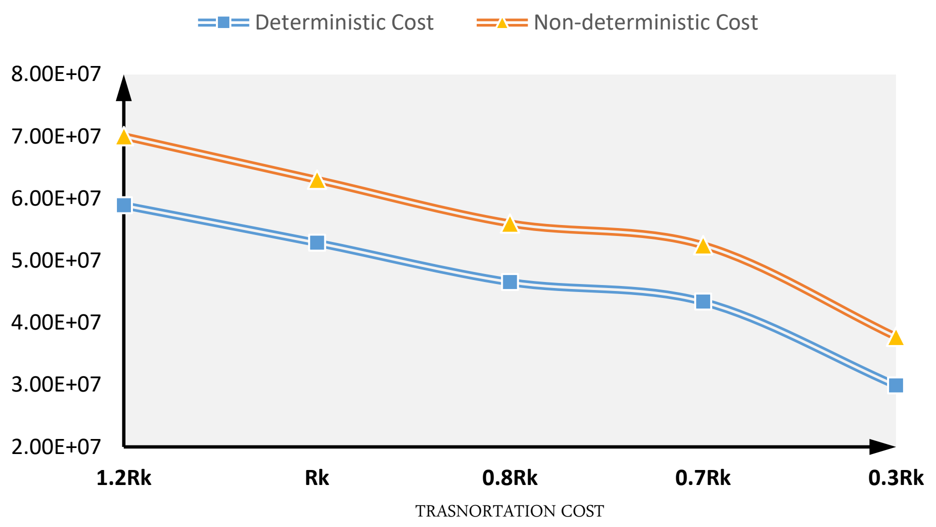

Figure 6-The cost function under transportation cost fluctuation

5-3- Sensitivity analysis on maximum number of each vehicle for each carrier:

As shown in Figs 7 and 8, in a typical objective function, a reduction of up to 10% in the number of vehicles will increase the costs; beyond 10%, the costs will remain unchanged. But, when the demand and percent reduced quality are uncertain, a 10% reduction in the number of vehicles will reduce the transportation costs and then there is an increase (exactly opposite).

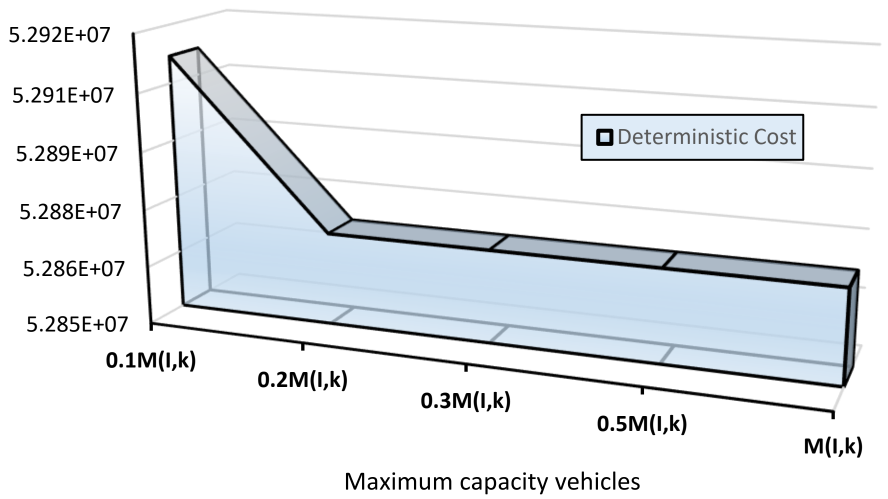

Figure 7-Deterministic cost function for each maximum number of vehicle

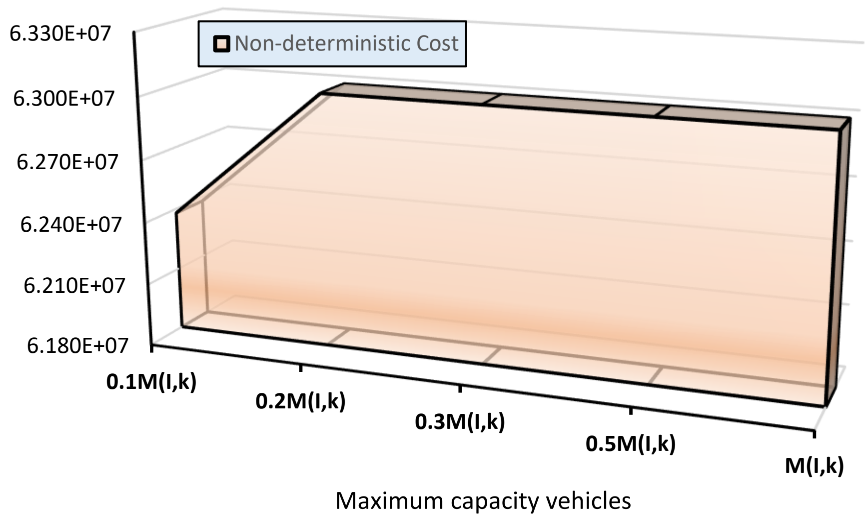

Figure 8-Non-deterministic cost function for each maximum number of vehicle

5-4- Sensitivity analysis on vehicle capacity:

Fig. 9 shows that a reduced vehicle capacity increases the cost price with a smooth slope in the range from 10 to 0.6 times and with a steep slope from 0.6 to 0.1 times; behavior of the two models is almost the same in this parameter. The important point in these two figures is that the more is the vehicle capacity, the closer is the value of the two models' objective functions, but a reduced capacity increases the value of the uncertainty function with a steeper slope because the demand function has uncertainty and meeting this demand incurs an extra cost.

The uncertain parameters (route demand and percent reduced quality) considered as trapezoidal fuzzy numbers, are calculated as follows:

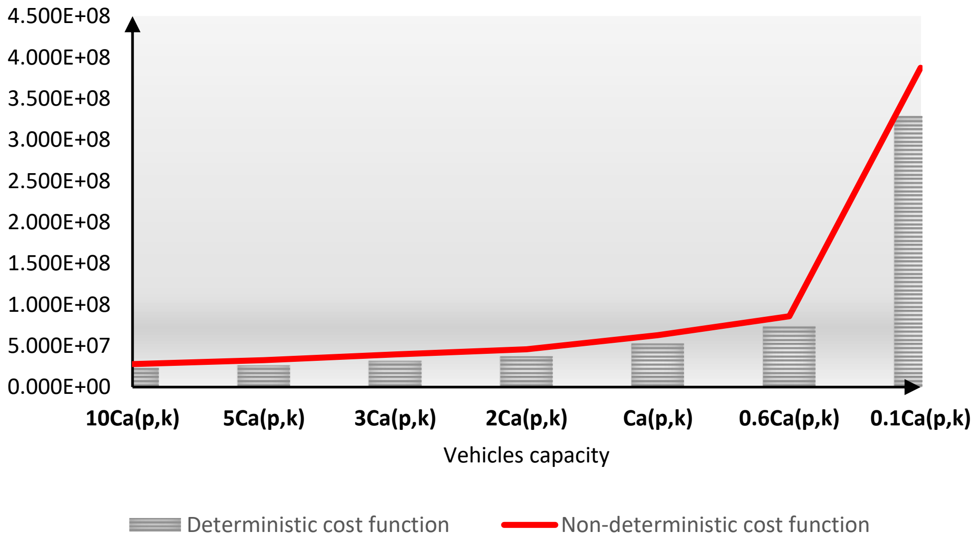

Figure 9- The cost function under vehicle capacity fluctuation

5-5- Sensitivity analysis on alpha (percent reduced quality):

In the models' objective functions, alpha is the coefficient of the reduced quality and Fig. 10 shows that an increase in its value can lead to the selection of a vehicle with higher transportation costs and minimum product quality. This means that the transportation costs will increase with an increase in alpha which is a fuzzy-trapezoidal parameter in our proposed model. When alpha increases by 1.5 times, the total cost in the models without and with uncertainty increases by 1.2 and 1.19 times, respectively which means the cost increase slope in the model with uncertainty is smoother. When alpha is halved, the total cost increases by about 0.78 times in the typical model and when it is doubled, the total cost increase is almost 0.65 times. In the model with uncertainty, the increase is about 0.77% times in the first case and about 0.64 times in the second case.

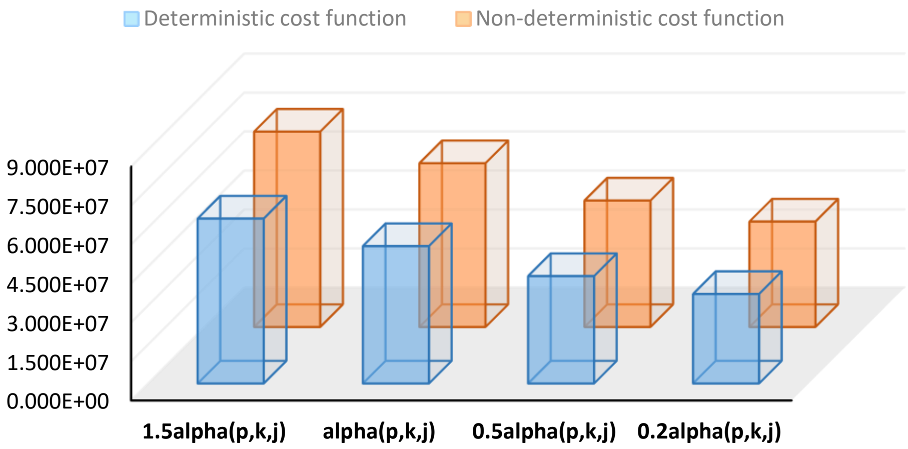

Figure 10- The cost function under alpha fluctuation

As mentioned earlier, alpha (percent reduced quality) is a fuzzy-trapezoidal uncertain parameter and the model has been solved with 0.1 intervals between the numbers. The next sensitivity analysis has been done with 0.2 intervals and Fig. 11 shows that this doubling reduced the total cost by about 111,000 dollars.

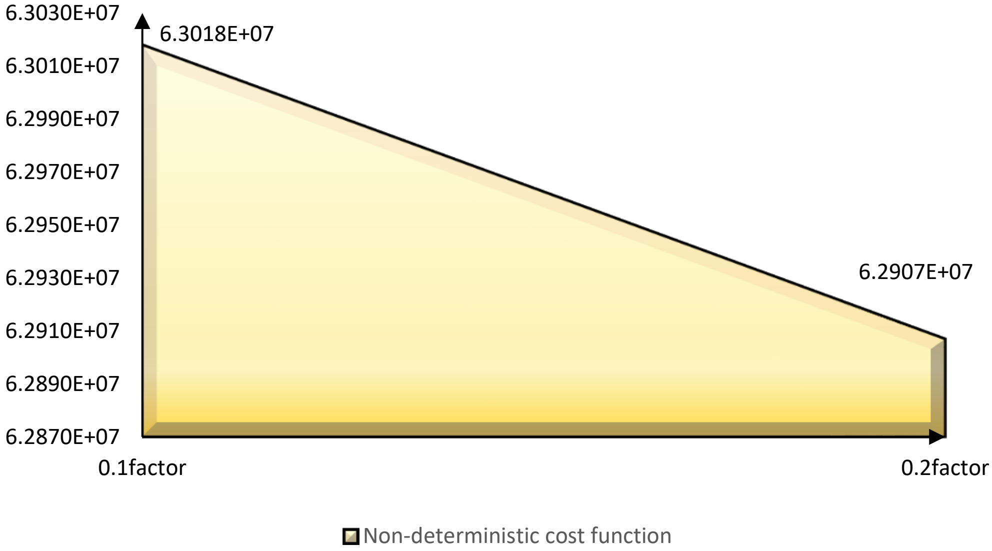

Figure 11-The cost function under alpha fluctuation on non-deterministic model

5-6- Sensitivity analysis on demand:

According to Fig. 12, doubling the demand increases the cost by 1.99 and 1.97 times in models without and with uncertainty, respectively. Halving the demand reduces the cost by 0.51% in the model without uncertainty, but increases it by 0.504 times in the model with uncertainty. Quadrupling the demand increases the cost by 3.986 and 3.92 times in models without and with uncertainty, respectively which means that demand variations cause less cost fluctuations in the latter case.

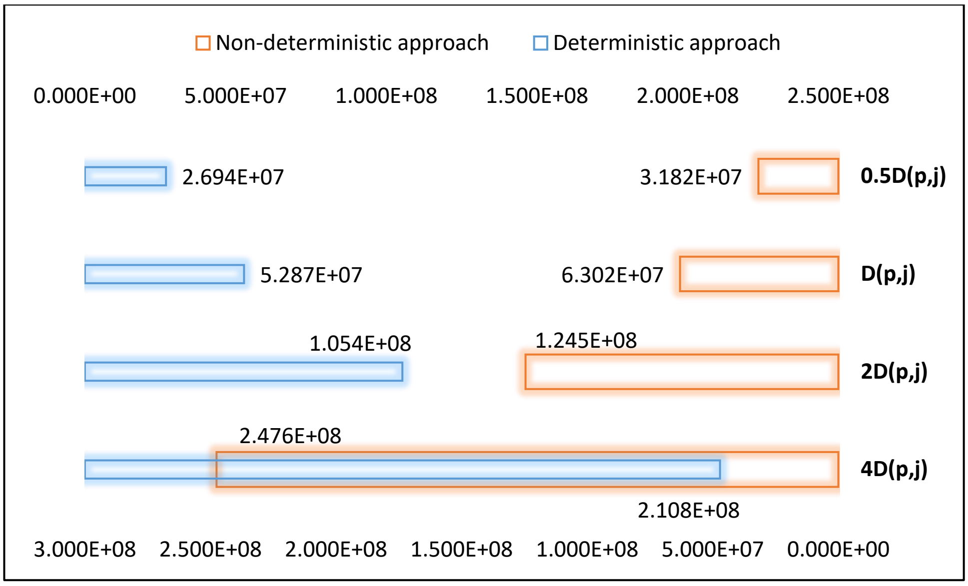

Figure 12- Sensitivity analysis on demand

5-7- Sensitivity analysis on gamma (γ)-values:

Fig. 13 shows the sensitivity analysis of the importance coefficient gamma (γ) for the model with uncertainty; the lower is its value, the lower is the transportation costs.

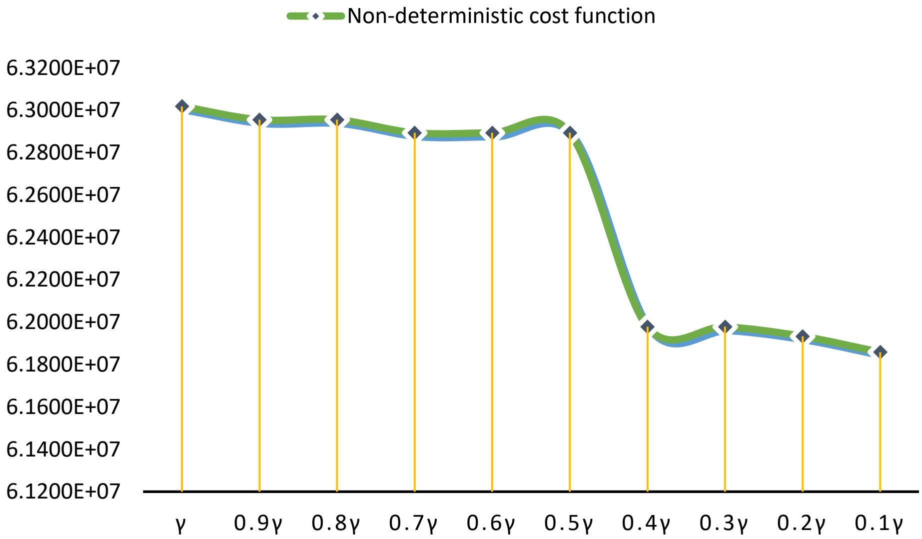

Figure 13- Sensitivity analysis on gamma (γ)

5-8- Sensitivity analysis on δ-values:

The demand constraint violation penalty is shown by delta (δ) in the model with uncertainty. According to Fig. 14, the cost remains unchanged for half δ-values (and less) meaning that if the penalty is small, the cost will not change; otherwise, the constraint violation will be costly. Hence, a penalty above a certain limit will highly affect the objective function.

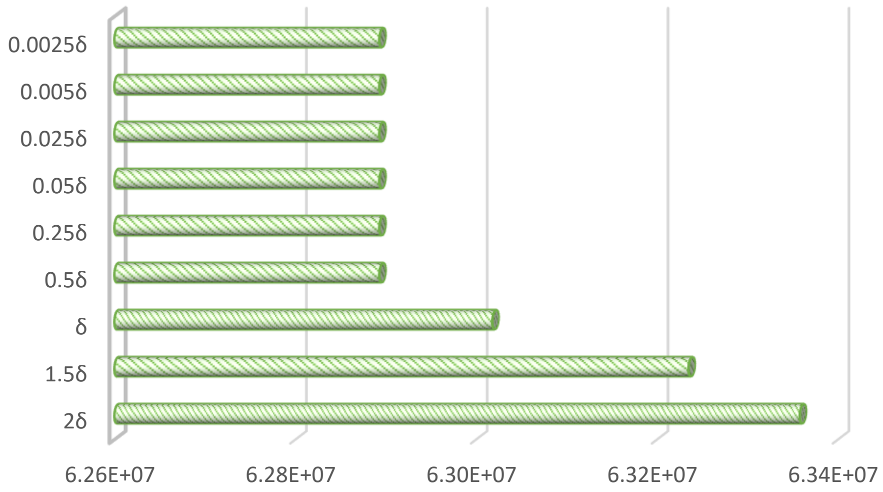

Figure 14- Sensitivity analysis on δ-values

6- Conclusions and Recommended Future Research

The real world is complicated and the complexity is due to the uncertainty in the form of ambiguity. For systems with low complexity, and, hence, low uncertainty, the closed form of the mathematical model provides a precise system definition. But for very complex systems where the numerical data are few, vague, and uncertain, the fuzzy theory is an approach to better understand the system behavior. Fuzzy modeling methods provide a proper framework to describe and address uncertainties when documents are insufficient or uncertain.

This paper presents a realistic robust possibilistic programming model wherein the demand and percent reduced quality (in displacements) are uncertain fuzzy-trapezoidal numbers, and the objective is to minimize the transportation costs while meeting the demand. Products are displaced via several routes in some which the carriers cannot, due to the vastness of the country, displace the products. This has been ensured by adding a constraint in the model bringing it closer to the real world. As expected, uncertain demand and percent reduced quality increased the objective function because there was a penalty; however, the tolerance in different conditions was lower than that of the model without uncertainty.

According to the sensitivity analyses performed on all parameters, models without and with uncertainty behaved nearly the same, but their behavior was totally opposite as regards the maximum number of vehicles owned by the carriers. In the former, the transportation costs increased with 10% of the maximum number of cars while in the latter, the cost increase was less; above 10%, the cost remained unchanged in both models. An increase in the interval between fuzzy-trapezoidal numbers reduced the total cost and doubling it reduced the total cost by about 111,000 dollars.

Considering the transportation time and environmental effects are suggested for future studies [35]. The transportation mode (e.g. railway) is another topic worth considering in the model; where possible, use can be made of an optimized railway system instead of roads to reduce the fuel consumption and environmental effects.

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