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Location Problem”**

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2. ABSTRACT

The goal of this master thesis is solving a real life two-stage-capacitated warehouse location problem. The case study consists of seven gardens, eight markets and six potential warehouses. The company rents a warehouse to store fruits and dispatches them to the markets for a short period, eight months. The purpose is to reduce the total costs by considering three costs: 1. Transportation costs from gardens to warehouses 2. Fixed costs of warehouses 3. Transportation cost from warehouses to the markets. For solving the problem, we use two different heuristic methods, ADD and DROP. To find an exact solution of the underlying Mixed-Integer Programming (MIP), CPLEX is used. We use both heuristic and exact methods and compare their results. In the next step, we consider different scenarios to study how different assumptions with respect to certain key parameters affect the solution. These scenarios include: 1. Changing the capacities, it means that we face capacity issue and have to choose another warehouse. 2. Changing the fixed cost; in this scenario the company buys the warehouse or warehouses instead renting them. Therefore, the periodical fixed costs will be less thus the case study will be changed to a multi-commodity, multi-echelon case; because if we be able to choose more than one warehouse it makes sense to assign the market and garden to a warehouse which is near to both of them. 3. Considering demand probabilities of all markets over ten year; in this scenario demand changes over time. 4. In fourth scenario we use different random demands that occur with certain probabilities to compare the random demand to determined demand, we applied the average probability rate of third scenario for both determined demand and random demand; therefore we are able to compare the results and the selected warehouse under determined situation and stochastic situation.

Keywords: Supply chain, warehouse location problem, two-stage facility location problem, optimization, CPLEX, mixed integer programming, MIP, heuristics method, exact method ADD DROP method, capacitated warehouse, multi-commodity, single-commodity, single-echelon, multi-echelon, cold storage warehouse, uncertainty demand, stochastic data, random demand

1. Zusammenfassung

Ziel dieser Masterarbeit ist es, ein reales zweistufiges Lagerstandort Problem zu lösen. Die Fallstudie besteht aus sieben Gärten, acht Märkten und sechs potenziellen Lagern. Das Unternehmen mietet ein Lagerhaus, um Obst zu lagern, und es von dort während acht Monaten auf unterschiedliche Market zu schicken. Ziel ist es, die Gesamtkosten durch Berücksichtigung von drei Teilkosten zu senken: 1. Transportkosten von Gärten zu Lagern 2. Fixkosten von Lagern 3. Transportkosten von Lagern zu den Märkten. Zur Lösung des Problems verwenden wir zwei verschiedene heuristische Methoden, ADD und DROP. Für das zugrunde liegende MIP (Mixed-integer Programming) Problem wird CPLEX verwendet. Wir verwenden sowohl heuristische als auch exakte Methoden und vergleichen ihre Ergebnisse. Im nächsten Schritt untersuchen wir verschiedene Szenarien, indem wir die Parameter ändern, um zu sehen wie diese die Lösung beeinflussen und welches Lager das optimale ist. Diese Szenarien umfassen: 1. Ändern der Kapazitäten, sodass Kapazitätsprobleme auftreten und wir ein anderes Lager auswählen müssen. 2. Änderung der Fixkosten, in diesem Szenario kauft das Unternehmen das Lager, anstatt es zu mieten; daher werden die periodischen Fixkosten geringer ausfallen und die Fallstudie wird in eine Multi-Commodity-Multi-Warehouse Problem umgewandelt. Denn wenn wir mehr als ein Lager auswählen können, ist es sinnvoll, den Markt und den Garten einem Lager zuzuordnen, welches sich in der Nähe von beiden befindet. 3. Berücksichtigung der Nachfrage Wahrscheinlichkeit aller Märkte über zehn Jahre. 4. Im vierten Szenario verwenden wir eine Zufällige Nachfrage, die mit einer bestimmt Wahrscheinlichkeitsrate Eintritt. Am Ende der Schlussfolgerung verwenden wir die durchschnittliche Wahrscheinlichkeitsrate des dritten Szenarios sowohl für die ermittelte Nachfrage als auch für die zufällige Nachfrage, um die Ergebnisse und das ausgewählte Lager unter einer bestimmten Situation und einer stochastischen Situation zu vergleichen.

3. INTRODUCTION

In past decades, successful businesses have paid close attention to supply chain management to optimize and manage their logistics systems especially in production industries, one of the most important topics in SCM, supply chain management, is finding the best location for facilities and when the case is a double-stage the importance is doubled to find the best location of warehouse or warehouses that have less transportation costs from producing sites, to warehouses and from warehouses to the markets. At the same time, not just variable costs, transportation costs, but also fixed costs of warehouses should be considered and the aim is cutting down sum of both variable costs and fixed costs.

Therefore, in this paper, we try to reduce the total costs by considering the constraints and criteria factors in order to choose the best warehouse location among six potential locations.

For business not just satisfying all needs of customers is important but also cost reduction will bring benefits and profits. Attention to this field of study is backed to 1960 by solving the facility location problem with the perspective of reducing the costs.

Generally, all facility location problems consist of four parts: The first part determines the number of potential warehouses. Second part determining the transportation costs based on supplied products and needs between gardens to warehouses and from warehouses to the markets. The third part indicates the size and capacity of each of these distributor warehouses. The last part determines how we should assign the plants and markets to the warehouses. For this matter two methods are used, first we use heuristic methods as ADD/DROP and then MIP, mixed integer programming, by using CPLEX by following the main goal which is reducing the total costs in an effective way that meets the customers' needs.

Below there is a classification of location-routing problems based on different variables. Similar classifications are available in papers of Min et al. (1998), Klose (2005), Nagy and Salhi (2007), ReVelle (2008) and Melo (2009).

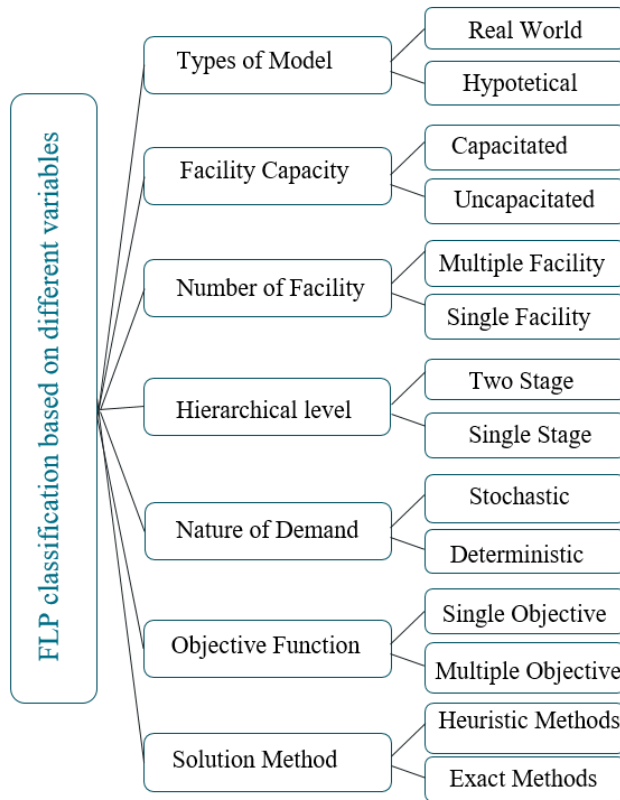


Figure 1. The classification of facility location problems

According to this classification our case study is based on a real world case and data, it is capacitated, if we consider the warehouse as the facility in the beginning. In the base case, under standard situation (without changing the parameters), we consider a single facility and in coming up scenarios the case will be multiple facilities. This paper follows a single objective, which is cost reduction and for solving that both heuristic methods and exact method will be examined. For the heuristic method, we solve the problem by ADD and DROP methods and as an exact method, we solve the case by using mixed integer programming & CPLEX.

3. 1. MOTIVATION

Working on a case study, which is related to the gardens, warehouses, supply chain management and cost reduction are so important for Iranians and Iranian companies and it has three main reasons as below:

1. Horticulture in Iran has a strong background and has a big share in Iran's GDP. And so many people in this way make a living.
2. Iran is 20 times bigger than Austria therefore an efficient supply chain model is important.
3. Due to the 1. Sanctions, 2. High rate of inflation and 3. Having the weakest currency in the world, cost reduction as much as possible is the goal of all businesses.

Thus, the goal is reducing the final cost by finding the best cold storage warehouse between pre-defined potential ones with considering the variable costs and the fixed costs.



Figure 2. Comparing Iran vastness to Europe

3. 2. PROBLEM DESCRIPTION

Pahnesar is a family company; the members are from Kondor, a village near Tehran. The main product of Kondor is cherry. It means for many years having the gardens of cherry and selling it to the other cities has been their traditional work and way of living. As they have expanded their business, they have decided to rent or buy other gardens in other cities of Iran. Their gardens consist of cherry, apple, apricot, nectarine, pear, kiwi and pomegranate. Then they rent a cold

storage warehouse or in a short form warehouse. To store and distribute the fruits to the other cities and markets.

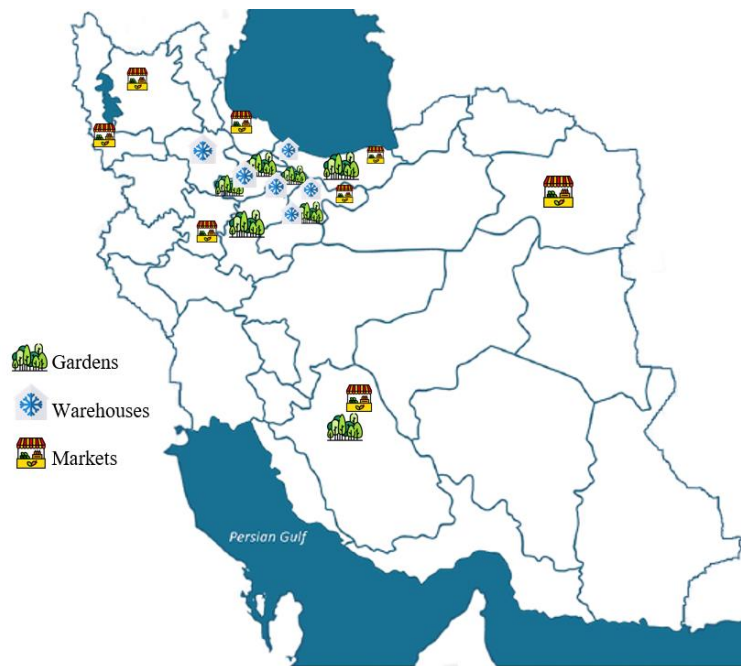


Figure 3. Location of gardens, warehouses and markets on the map of Iran

This is the map of Iran, as you can see around Tehran; capital of Iran we have more gardens warehouses and markets it has three reasons from three different points of view:

1. From market perspective, Tehran is the largest city in the Middle East; Tehran province contains 1/6th of Iran's whole population, around 14 million.
2. From garden point of view: The only rainy part of Iran is around Caspian Sea, north and north-west of Iran. Therefore, the variety of fruits and gardens in that region is more.
3. From the warehouse perspective not only it makes sense to locate the warehouse near to the markets and gardens, also the company of our case study is located near Tehran in a village called Kondor therefore they prefer to be settled near their own village to have more control on the warehouses, markets and gardens.

The aim of this paper is helping the company, Pahnesar, to find the warehouse between potential ones to store their products and dispatch them to the other cities.

In this case study we have a three-part model: The gardens as suppliers are the first part the second part is cold storage warehouses; in other word warehouses as distribution centers of the fruits. The markets are the third and last part. We want to reduce the total cost, which consists of variable costs, and fixed costs. Simply speaking, we want to find the best warehouse by considering the transportation costs from gardens to warehouse and from warehouse to markets, variable costs & at the same time considering the fixed costs of each warehouse.

PROBLEM ASSUMPTIONS

In general, the conditions and assumptions of this case study are:

- Each garden is assigned to one distribution center.
- Each market is assigned to one distribution center.
- Gardens or markets can be assigned to a warehouse just if that warehouse is opened.
- The capacity of each cold storage warehouse is limited.
- The supply amount of gardens and the demand of markets should be less than the warehouse capacity.
- Transportation cost will increase when the shipment size increases.
- The cost of renting a cold storage warehouse is fixed for the time of contract; by renting the warehouse for more than one year there can be a discount rate which is different warehouse to warehouse.
- The location of the gardens, markets and warehouses are fixed.
- All the demand of customers in the markets should be fulfilled.
- The input of the model is known in advance, so the model is definite.

4. LITERATURE REVIEW

As the case study consists of different scenarios, the literature review is classified based on coming up important subjects and scenarios. Most papers of facility location consider the factories as the facility but in our paper, we have gardens as plants and warehouses. In past studies, there is lack of research about gardens as plants but in reality, both natures are the same and act as plant and producer. In addition, as the studies about “cold storage warehouses” are so rare, we have used “warehouse” literatures.

4. 1. WAREHOUSE LOCATION PROBLEM

In regards to the warehouse location problem the first studies back to one century ago when for the first time Alfred Weber (1909) proposed the concept of choosing the warehouse location by locating a warehouse in that way that the total distance travelled between the warehouse and the clients was minimized. After that more different models related to WLP, Warehouse Location Problems, were proposed but the main models back to the 60's; when Valinsky (1955) published a paper about finding the best place for locating the fire trucks. After that in 1958 Mansfield's finding was about discovering the best location regards to railway network or locating the waste disposal site (Wersan et al., 1962); in the same year Rappy worked on how to locate switching centers in a telecommunication network (Rappy, 1962). Again in that year Burstall published his paper which was about finding the location of a factory. In 1963 the topic of SPLP, Simple Planet Location Problem, was proposed by Kuehn & Hamburger and followed by Balinski (1965).

Hakimi (1964) examined location problem theory more in detail, his paper was about problem of locating one or more facilities in a network in order to minimize the sum of distances or maximize the distance between facilities.

Efroymson and Ray (1966) claimed that linear programs can be solved analytically so that the bound at each node of the enumeration tree could be computed so fast with fixed time. Some scientists improved the Efroymson's and Ray's algorithm like Spielberg (1969), Khumawala (1977) and Hansen (1972). There are some constraints regarding the location problem like limited capacity of the warehouses and fulfilling all the demands of customers. Generally, problems with covering constraints were defined in the 70's. Church & ReVelle (1974) claimed that in a model where the number of facilities are fixed, satisfying all demands cannot be promised. Klincewicz (1985) worked on a multi-stage problem, different products were sent from vendors to DCs, then to the local distributions and at the end to the last stage where the products get dispatched to the customers. Tomas and Griffin (1996) claimed that, designing the best supply chain model has become more and more important because of the competitive situation of markets, globalization, and increasing the number of competitors. Beamon (1998) proposed different models and approaches for solving the supply chain problems.

Later, Erenguc (1999) worked on integration of production and designing distribution models for planning the supply chain network. The SSCFL problem, Single Source Capacitated Facility Location, is about capacitated facility location problem in which each client can be satisfied by only one facility (Tragantalerngsak, 2000). Jang (2002) developed a combined model for planning the distribution of products for a SCN. The objective in such cases are locating the facilities in that way that demand areas of customers are satisfied (Galvão, 2004). Galvão adds that a demand should be covered by a facility if it is within a critical, predefined distance from this facility.

Most studies deal with supply of a single commodity from a set of potential locations, where facilities could be located, to the customers of known places and known demands, with the minimum cost (Galvão, 2004). Also, Park (2005) suggested an integrated approach for production and distribution model in supply chain management. A model was suggested by Amiri for supply chain

problems to decide the best production's location plants and dispatch the products from the warehouses to the customers by considering minimizing the costs (Amiri, 2006). Sharma (2007) considered a problem as SSCWLP, single stage capacitated warehouse location problem, the problem was about choosing some points where the warehouse can be located in order to the total shipping costs and the warehouse location cost (fixed cost) are minimized.

Riccardo (2008) proposed an optimized model for a facility-location-allocation dynamic problem. Gebennini suggested a three level production distribution system in order to minimize the cost; the method was formulated as a dynamic location-allocation problem by controlling customer service level and optimizing the warehouse inventory (Gebennini et al., 2009).

Supply chain network offers an optimal solution for managing the supply chain system efficiently and in a well-organized supply chain network the goal is selecting the facilities, warehouses or plants, in a way to fulfill the market request by minimum cost and obtaining the maximum profit (Tiwari, 2012). Vidalakis (2013) in his paper worked on supply chain operations by paying attention to the logistics function of construction material suppliers. The assumptions of the CFLP is that demands are fix and known as well as the capacity of warehouses; also it is a variation of facility location problem, which includes capacities for the facilities. (Silva, 2014).

4. 2. ADD / DROP HEURISTIC

To solve the case study problem both heuristic and exact methods are used. As heuristic ones ADD/DROP and as exact one, mixed integer programming, CPLEX 12.0. Bilde and Krarup (1977) and later Erlenkotter (1978), used heuristic methods to reach a most feasible solution. Erlenkotter took one-step more by using the complementary slackness mode of LP, Linear programming, to

make the bound determination better. His procedure was successful as he tested 48 problems and 45 out of them optimality reached at the first node of the branch-and-bound algorithm.

The ADD method is known as greedy heuristic approach. The literature reviews related to ADD method back to 1963 when it was elaborated by Kuehn and Hamburger in their papers about plant location. Also Domschke and Drexl (1985) proposed priority rules for the ADD procedure to make its performance better for the cases that the facilities have different capacities or different fixed costs. For ADD method all facilities are closed and we open them one by one and combining them together to gain a better result in contrast for DROP method, all facilities are in the beginning opened and a facility becomes closed if by closing reduction in the total cost would be achieved. This step ends when closing a facility does not result in any further decrease in the total cost.

Also Whitaker (1985) used these two heuristic methods in his paper, Add-Drop and Drop-Add, in the first one, he started with none opened warehouse; in contrast, DROP heuristic method begins with all warehouses opened and reduces them set by a net loss of one plant on every iteration of the algorithm. In addition, a two-stage supply chain model with fixed costs and transportation costs, that did not have precise capacity and followed the maximum profit was presented by Pramanik to satisfy the retailers demand by selecting the best distribution center (Pramanik et al., 2015). Later, Mousavi proposed a model of supply chain network for sessional multiple products in a certain time horizon (Mousavi et al., 2016).

4. 3. MULTI-ECHELON & MULTI-COMMODITY

As one of the scenarios of this paper is related to multi-commodity and multi-echelon case, some literature about this problem has been investigated. In our case study on one hand we have several producing sites as gardens and based on the capacity of the cold storage warehouses the

markets can be satisfied by single cold storage warehouse or by multi of them. Based on mathematical models a multi-product problem is a complicated supply chain network because it has different types of practical applications (Vemuganti et al., 1989). Jayaraman (2001) developed a heuristic solution according to “Lagrangian Relaxation” for the single source, multi-commodity, multi-layer SCN, design problem. For a supply chain with discrete-period variable demand, Chiu et al. (2003) presented a mixed integer programming model to reduce the total cost of supply chain model including transportation cost and fixed cost over the periods. Also, a multi-commodity, multi-layer, and multi-period planning model which is related to a multi-echelon supply chain network with undetermined customer demands and product prices, is presented by Chen and Lee (2004).

Ahn and Seo (2005) proposed a multi-product model by solving the transportation constraint in the management’s inventory during the planning horizon. In the same year, Huang worked a single-warehouse multi-retailer system in which each retailer had a fixed and predefined demand in a planning horizon, after that he has formulated the transportation and inventory problem as a 0-1 integer linear programming. A memetic algorithm for the multi-level supply chain network problem was presented by Yeh (2006). One of the most important factors regarding the designing the network of distribution is the location of the warehouses or in the other word DCs, distribution centers; if we would have just one stage it would be better the warehouse be located near to the plant or in a two stage case near plant or near market. In a two-stage model, we have to make the decisions and consider other factors that the warehouse should be near to customers or close to the plant (Hindi et al, 2006).

Nystrom et al. (2006) proposed an approach for organizing the multi-stage processes with parallel units where the problem was separated into an MILP, mixed integer linear programming. Fandel and Stammen-Hegene (2006) suggested a big variety of scheduling problems for multi-

product multi-level lot sizing in order to decrease the total costs and to fulfill the needs of customers.

In 2007, Bose and Bhattacharya offered the solution for a three stage, three-commodity problem. Amaro and Barbosa-Povoa (2008) worked on a supply chain problem which was a mixed-integer linear programming; the model was based on using unit-specific event-based, for multi-period scheduling of a multi-stage multi product process from a bio-pharmaceutical industry. Liang (2008) wrote a paper about a fuzzy multi-objective linear programming with the goal of reducing the total fuzzy costs and delivery times in an integrated multi-commodity multi-period production-distribution planning decision problem. In the beginning, we consider the problem as a single one because based on the high and different fixed costs for the company it would be impossible to open more than one warehouse but furthermore we will go through some scenarios. For example, what if the company buys the warehouse and achieves a lower periodical fixed cost? In such scenarios, we will have multi-echelon and multi-commodity cases.

To review the literatures related to such scenarios we will go back to Azaron et al. (2008) worked on a paper about a supply chain network with three-echelon and a tri-objective stochastic programming approach. He wanted to minimize the total cost of current and future; in addition decreasing the variance of costs. Hongwei (2009) developed an optimization-simulation model for a stochastic multi-objective production–distribution.

On the other hand, in the same year Cardona-Valdés presented a two-echelon supply chain model for minimizing at the same time the total costs and the total service time (Cardona-Valdés et al., 2011). In the same year, Mirzapour developed a multi-objective model that the first goal was minimizing total costs and the second goal was minimizing the total maximum amount of shortages for middle clients; also 2 years later he and Bozorgi-Amiri considered cost and demand as uncertainty parameters by working on a three-echelon multi-product multi-period supply chain

problem (Bozorgi-Amiri et al., 2013). A model of single-product and four-echelon supply chain was proposed by Shankar; the goal of his paper was achieving two targets: 1. Reducing the transportation cost 2. Maximizing the customer needs (Shankar et al., 2013).

The main focus of practical case studies are more heterogeneous commodities, which are about location-allocation-problem. These kinds of problems are much more complicated (Ghiani et al., 2013). In single-product problems it can be presumed that a single homogeneous flow of commodities exists in the supply chain system, however in a multi-commodity problem there are different products and each product is related to a specific flow pattern (Ghiani et al., 2013). Junliang He proposed a multi-echelon container supply chain problem and modeled it as mixed integer linear programming to minimize the total supply chain cost (Junliang et al., 2014). In the same year, Kristianto published his paper which was related to minimizing the inventory allocation costs and also transportation routing costs (Kristianto et al., 2014). In contrast to single-echelon location problems, that just one warehouse or facility must be located or selected among potential ones; in multi-echelon problems, several kinds of facilities or warehouses have to be located or selected.

4. 4. UNCERTAINTY DEMAND

One of the first studies about uncertainty and specifically demand uncertainty was done by Davis (1993); he claimed three different main types of uncertainties in the field of supply chain are: demand; manufacturing process and supply uncertainty. Also, Lee (1977) worked on two main concepts of uncertainties, the product – supply and demand uncertainty. In addition, from his perspective the other uncertainty sources are derived from demand uncertainty, which was split into end-customer demand and demand amplification. Also Sanchez-Rodrigues (2008) in his paper of “establishing a transport operation focused uncertainty model for the supply chain”, defines the uncertainty as the situation that the decision makers cannot predict the result or probability of an

occurrence (Sanchez-Rodrigues Vasco et al., 2008). One year later, Pishvaei proposed a programming model under uncertainty; in fact, he developed a MILP, mixed integer linear programming and then he used this model in different stochastic approaches (Pishvaei, Jolai, and Razmi, 2009).

Two years later, Zamarripa suggested two different supply chain models, each of them included three levels for minimizing the system costs and accumulated delivery time from different production echelons to warehouses (Zamarripa et al., 2011). Georgiadis (2011) worked on a four-echelon supply chain model under uncertainties in time and demand; the paper is based on possibilities of different scenarios of life-time-network (Georgiadis et al., 2011). In the same year, Fildes, Kingsman and Taylor claimed that demand uncertainty is one of the most important factors affecting supply chain operations and cost efficiency (Fildes and Kingsman, 2011; Taylor, 2011).

In 2013, Bozorgi-Amiri, suggested a model for minimizing the total cost of a multi-objective demand uncertainty. Also, Pasandideh worked on uncertainty factors, which were involved in the distribution network of supply chain system. They defined a model to minimize the costs and on the other hand maximizing the demand of customers (Pasandideh et al., 2015).

5. METHODOLOGY

To solve the case study the first step is gathering the data. Data is provided by a family company, Pahnesar, which is located in Kondor where the main way of living is farming. The numbers in following tables are based on ton and costs are based on Rials, currency of Iran. 5 zeros are omitted from numbers for comfort. Table 1 indicates the gardens and amount of their fruit.

Fruit/Garden	Karaj	Shahryar	Nazarabad	Saveh	Qazvin	Shiraz	Chalus
Cherry	50						
Apricot		40					
Nectarine			35				
Apple				70			
Pear					100		
Pomegranate						70	
Kiwi							80

Table 1. Supply amount of each garden per ton

The data in table 2 indicates the transportation cost per one unit from garden to each of the potential warehouses and the last row shows the sum of supplied fruit in each of the gardens.

Warehouse/Garden	Karaj	Shahryar	Nazarabad	Saveh	Qazvin	Shiraz	Chalus
Tehran	15	14	19	23	24	71	34
Shahryar	13	11	16	21	22	70	25
Karaj	11	14	14	25	20	74	25
Qazvin	15	17	12	28	16	75	29
Zanjan	34	36	32	35	26	79	46
Tonekabon	29	30	32	40	35	82	16
Supply	50	40	35	70	100	70	80

Table 2. Transportation cost per ton

By multiplying the supply of each garden to the transportation cost per unit the third table which is final transportation cost from garden to the warehouse will be achieved.

Warehouse/Garden	Karaj	Shahryar	Nazarabad	Saveh	Qazvin	Shiraz	Chalus
Tehran	750	560	665	1610	2400	4970	2720
Shahryar	650	440	560	1470	2200	4900	2000
Karaj	550	560	490	1750	2000	5180	2000
Qazvin	750	680	420	1960	1600	5250	2320
Zanjan	1700	1440	1120	2450	2600	5530	3680
Tonekabon	1450	1200	1120	2800	3500	5740	1280

Table 3. Final transportation cost from garden to cold storage warehouse

There is the same process from warehouse to the markets. Table 4 indicates the needs of each market, table 5 transportation cost of transferring one ton from warehouse to the market. By multiplying table 4 and 5, table 6 will be gained which is total transportation cost from warehouse to the market.

Fruit/Market	Tehran	Shiraz	Mashhad	Hamedan	Sari	Rasht	Tabriz	Urmia
Cherry	20	15	15					
Apricot	25			15				
Nectarine					20	15		
Apple	70							
Pear	50		50					
Pomegranate	40						30	
Kiwi	50							30

Table 4. Demand of markets per ton

Warehouse/Market	Tehran	Shiraz	Mashhad	Hamedan	Sari	Rasht	Tabriz	Urmia
Tehran	12	72	70	37	34	37	56	63
Shahryar	14	70	71	44	36	36	55	62
Karaj	15	72	72	38	37	34	53	61
Qazvin	19	74	74	35	40	31	51	59
Zanjan	37	79	84	32	55	30	36	45
Tonekabon	31	81	73	47	30	23	55	62
Demand	225	15	65	15	20	15	30	30

Table 5. Transportation cost per ton

Warehouse/Market	Tehran	Shiraz	Mashhad	Hamedan	Sari	Rasht	Tabriz	Urmia	Fixed cost	Capacity
Tehran	2700	1080	4550	555	680	555	1680	1890	26700	4000
Shahryar	3150	1050	4615	660	720	540	1650	1860	24475	150000
Karaj	3375	1080	4680	570	740	510	1590	1830	24475	4000
Qazvin	4275	1110	4810	525	800	465	1530	1770	22250	25000
Zanjan	8325	1185	5460	480	1100	450	1080	1350	20025	20000
Tonekabon	6975	1215	4745	705	600	345	1650	1860	17800	5000

Table 6. Final transportation cost from warehouse to market

In table 6 the last two columns indicates fixed cost and the capacity of each warehouse. It is per ton and the capacity is for the whole warehouse and not just one salon.

5. 1. MATHEMATICAL MODEL

Indexes:

g index of garden, $g=1, 2, \dots, G$

j index of potential cold storage warehouse, $j=1, 2, \dots, J$

i index of market, $i=1, 2, \dots, I$

Parameters:

F_j fixed cost of cold storage warehouse j.

X_g quantity of produced fruit in garden g.

X'_i quantity of requested fruit by market i.

D_{gj} transportation cost of transferring fruit from garden g to cold storage warehouse j.

D'_{ji} transportation cost of transferring fruit from cold storage warehouse j to market i.

C_j capacity of cold storage warehouse j

Decision variable:

$Y_j \begin{cases} 1 & \text{if cold storage warehouse j is opened} \\ 0 & \text{otherwise} \end{cases}$

$Y'_{gj} \begin{cases} 1 & \text{if garden g is assigned to warehouse j} \\ 0 & \text{otherwise} \end{cases}$

$Y''_{ji} \begin{cases} 1 & \text{if market i is assigned to warehouse j} \\ 0 & \text{otherwise} \end{cases}$

Min Z=

$$\sum_{j=1}^J F_j * Y_j + \sum_{g=1}^G \sum_{j=1}^J D_{gj} * Y'_{gj} + \sum_{j=1}^J \sum_{i=1}^I D'_{ji} * Y''_{ji} \quad (1)$$

Subject to

$$\sum_{g=1}^G X_g \leq C_j Y_j \quad \forall j \quad (2)$$

$$\sum_{i=1}^I X'i \leq CjYj \quad \forall j \quad (3)$$

$$\sum_{j=1}^J Y''ji = 1 \quad \forall i, j \quad (4)$$

$$\sum_{i=1}^I Y''ji \leq Yj \quad \forall j \quad (5)$$

$$\sum_{j=1}^J Y'gj = 1, \quad \forall g, j \quad (6)$$

$$\sum_{j=1}^J Y'gj \leq Yj \quad \forall j \quad (7)$$

$$\sum_{g=1}^G Xg \leq \sum_{i=1}^I X'i \quad \forall g, i \quad (8)$$

$$Yj \in \{0, 1\}; \quad \forall j \quad (9)$$

$$Y'gj \in \{0, 1\}; \quad \forall g, j \quad (10)$$

$$Y''ij \in \{0, 1\}; \quad \forall i, j \quad (11)$$

$$Xg, X'i \geq 0; \quad \forall g, i \quad (12)$$

Explanation of constraints:

- (1) Minimizing the sum of the fixed costs and the variable costs
- (2) The tonnage of supplied fruits is less than the capacity of the cold storage warehouse j.
- (3) The demand of markets doesn't exceed the capacity of cold storage warehouse j.
- (4) The market is assigned to a warehouse.
- (5) The market can be assigned to the warehouse just if the warehouse is opened.
- (6) The garden is assigned to a cold storage warehouse.
- (7) The garden can be assigned to the warehouse just if the warehouse is opened.

- (8) The demand of the market will be satisfied; the amount of supplied fruit is more than market's demand.
- (9) The binary variable that the cold storage warehouse is opened or not.
- (10) The binary variable if the garden g is allocated to cold storage warehouse j or not.
- (11) The binary variable if the market i is allocated to cold storage warehouse j or not.
- (12) The quantity of produced fruit in gardens and dispatched from cold storage warehouses should be positive.

5. 2. HEURISTIC METHODS

In this paper, we use two heuristic methods and we compare the achieved results with the exact method, mixed integer programming by using CPLEX.

The first method is ADD heuristic method, then DROP heuristic method. For solving the ADD/DROP heuristic method the course note of Prof. Dr. Hartl is used, which is based on Hilier (1986) and Kasana (2004) findings.

5. 2. 1. ADD HEURISTIC

In ADD heuristic, the first step is finding the best single solution. This optimal solution is the lowest total cost, which is the sum of transportation costs and fixed costs. In the next step, this optimal warehouse will be combined with other warehouses to find a better solution, lower total cost, will be achieved or not. After combining two warehouses if a better result is obtained we go one step further to combine three warehouses together. The maximum combination is related to number of facilities in this paper we have 6 facilities therefore we could have 63 different combinations:

Combination: $2^m - 1 = 2^6 - 1 = 64 - 1 = 63$

Combination					
1	Tehran	22	Tehran-Shahryar-Karaj	43	Tehran-Shahryar-Karaj-Zanjan
2	Shahryar	23	Tehran-Shahryar-Qazvin	44	Tehran-Shahryar-Karaj-Tonekabon
3	Karaj	24	Tehran-Shahryar-Zanjan	45	Tehran-Shahryar-Qazvin-Zanjan
4	Qazvin	25	Tehran-Shahryar-Tonekabon	46	Tehran-Shahryar-Qazvin-Tonekabon
5	Zanjan	26	Tehran-Karaj-Qazvin	47	Tehran-Shahryar-Zanjan-Tonekabon
6	Tonekabon	27	Tehran-Karaj-Zanjan	48	Tehran-Karaj-Qazvin-Zanjan
7	Tehran-Shahryar	28	Tehran-Karaj-Tonekabon	49	Tehran-Karaj-Qazvin-Tonekabon
8	Tehran-Karaj	29	Tehran-Qazvin-Zanjan	50	Tehran-Karaj-Zanjan-Tonekabon
9	Tehran-Qazvin	30	Tehran-Qazvin-Tonekabon	51	Tehran-Qazvin-Zanjan-Tonekabon
10	Tehran-Zanjan	31	Tehran-Zanjan-Tonekabon	52	Shahryar-Karaj-Qazvin-Zanjan
11	Tehran-Tonekabon	32	Shahryar-Karaj-Qazvin	53	Shahryar-Karaj-Qazvin-Tonekabon
12	Shahryar-Karaj	33	Shahryar-Karaj-Zanjan	54	Shahryar-Karaj-Zanjan-Tonekabon
13	Shahryar-Qazvin	34	Shahryar-Karaj-Tonekabon	55	Shahryar-Qazvin-Zanjan-Tonekabon
14	Shahryar-Zanjan	35	Shahryar-Qazvin-Zanjan	56	Karaj-Qazvin-Zanjan-Tonekabon
15	Shahryar-Tonekabon	36	Shahryar-Qazvin-Tonekabon	57	Tehran-Shahryar-Karaj-Qazvin-Zanjan
16	Karaj-Qazvin	37	Shahryar-Zanjan-Tonekabon	58	Tehran-Shahryar-Karaj-Qazvin-Tonekabon
17	Karaj-Zanjan	38	Karaj-Qazvin-Zanjan	59	Tehran-Shahryar-Karaj-Zanjan-Tonekabon
18	Karaj-Tonekabon	39	Karaj-Qazvin-Tonekabon	60	Tehran-Shahryar-Qazvin-Zanjan-Tonekabon
19	Qazvin-Zanjan	40	Karaj-Zanjan-Tonekabon	61	Tehran-Karaj-Qazvin-Zanjan-Tonekabon
20	Qazvin-Tonekabon	41	Qazvin-Zanjan-Tonekabon	62	Shahryar-Karaj-Qazvin-Zanjan-Tonekabon
21	Zanjan-Tonekabon	42	Tehran-Shahryar-Karaj-Qazvin	63	Tehran-Shahryar-Karaj-Qazvin-Zanjan-Tonekabon

Table 7. Possible warehouse combinations

ADD heuristic procedure:

Notation

- $J = \{1, \dots, m\}$ set of all potential warehouse locations.
- J_0 set of definitely forbidden locations.
- J_0^{Pot} set of potentially forbidden locations.

- J_1 set of definitely realized locations.
- ω_j savings in transportation costs if location p is realized in addition to the already selected.
- Z total costs (objective value).

Initialization

- decide which warehouse should be opened: for each warehouse location j calculate $c_j = \sum_{i=1}^I c_{ij}$ select location k with the smallest cost value $c_k + f_k$
- set $J_1 = \{k\}$, $J_0^{\text{Pot}} = J \setminus \{k\}$ and $Z = c_k + f_k$
- calculate the savings in transportation costs
 $\omega_{ji} = \max\{c_{ki} - c_{ji}, 0\}$ for each j in J_0^{Pot} and all customers i , and the row sum $\omega_j = \sum_{i=1}^I \omega_{ji}$

Iteration step

- in each iteration exactly one potential warehouse $k \in J_0^{\text{Pot}}$ becomes part of the set J_1 ; it is the one with the largest value for $\omega_k - f_k$
- set $J_1 = J_1 \cup \{k\}$, $J_0^{\text{Pot}} = J_0^{\text{Pot}} \setminus \{k\}$ and $Z = Z - \omega_k + f_k$
- all locations j with a negative value for $\omega_j - f_j$ (fixed costs are greater than the savings in transportation costs) can be definitely forbidden:
for all $j \in J_0^{\text{Pot}}$ with $\omega_j \leq f_j \rightarrow J_0 = J_0 \cup \{j\}$ and $J_0^{\text{Pot}} = J_0 \setminus \{j\}$
- for each $j \in J_0^{\text{Pot}}$ compute $\omega_{ji} = \max\{\omega_{ji} - \omega_{ki}, 0\}$

Termination criterion

The procedure ends as soon as $J_0^{\text{Pot}} = \{\}$.

Result Build a warehouse at all locations $\in J_1$ and assign each garden to warehouse j and each customer i to the warehouse $h \in J_1$ for which $j = \arg \min_{j \in J_1} \{c_{gj}, c_{ji}\}$

Based on ADD method in the beginning we find the best option which has the lowest total cost then we combine it with other ones to have two combinations and so on.

Warehouse/ Garden and Market	Garden							Market								Fixed cost	f+c
	Karaj	Shahryar	Nazarabad	Saveh	Qazvin	Shiraz	Chalus	Tehran	Shiraz	Mashhad	Hamedan	Sari	Rasht	Tabriz	Urmia		
Tehran	750	560	665	1610	2400	4970	2720	2700	1080	4550	555	680	555	1680	1890	26700	54065
Shahryar	650	440	560	1470	2200	4900	2000	3150	1050	4615	660	720	540	1650	1860	24475	50940
Karaj	550	560	490	1750	2000	5180	2000	3375	1080	4680	570	740	510	1590	1830	24475	51380
Qazvin	750	680	420	1960	1600	5250	2320	4275	1110	4810	525	800	465	1530	1770	22250	50515
Zanjan	1700	1440	1120	2450	2600	5530	3680	8325	1185	5460	480	1100	450	1080	1350	20025	57975
Tonekabon	1450	1200	1120	2800	3500	5740	1280	6975	1215	4745	705	600	345	1650	1860	17800	52985

Table 8. ADD method first step under standard situation¹

Build $k = 4$ with $Z_4 = c_4 + f_4 = 50515$, $J_1 = \{4\}$, $J_0^{\text{Pot}} = \{1, 2, 3, 5, 6\}$

The second step for combine two warehouses is as below:

Warehouse/ Garden and Market	Garden							Market								Fixed cost	ω_i	Diff.
	Karaj	Shahryar	Nazarabad	Saveh	Qazvin	Shiraz	Chalus	Tehran	Shiraz	Mashhad	Hamedan	Sari	Rasht	Tabriz	Urmia			
Tehran		120		350		280		1575	30	260		120				26700	2735	-23965
Shahryar	100	240		490		350	320	1125	60	195		80				24475	2960	-21515
Karaj	200	120		210		70	320	900	30	130		60				24475	2040	-22435
Zanjan											45		15	450	420	20025	930	-19095
Tonekabon							1040			65		200	431			17800	1736	-16064

Table 9. ADD method second step under standard situation

Build $k=1$, $Z_{14}=50515-2735+26700= 74480$ Build $k=2$ $Z_{24}=50515-2960+24475= 72030$

$Z_{34}=72950$ $Z_{54}=69610$ $Z_{64}=66890$ $J_0^{\text{Pot}} = \{\}$ $J_0 = \{1,2,3,5,6\}$ forbidden as $\omega_i < f_j$ (Fixed cost)

In the other word, the table is like below:

Warehouses based on their numbers	Combination	Variable cost 1	Variable cost 2	Fixed cost	Total cost
4-1	Qazvin-Tehran	12230	13300	48950	74480
4-2	Qazvin-Shahrya	11480	13825	46725	72030
4-3	Qazvin-Karaj	12060	14165	46725	72950
4-5	Qazvin-Zanjan	12980	14355	42275	69610
4-6	Qazvin-Tonekabon	11940	14900	40050	66890

Table 10. ADD method second step, simple form of table 9

Table 10 is a simple form of table 9. Variable 1 is summing up transportation costs from garden to warehouse and variable 2 is summing up transportation costs from warehouse to market. As it is shown, there are five possibilities of combining two warehouses and between them combining

¹ Standard situation is the solution based on given data without changing any parameters. In section 6 we will change the parameters to figure out different outcomes under different scenarios and conditions.

warehouse 4 and 6 has the lowest cost. However, the total cost is 66890, which is more than 50515, by opening warehouse 4. Therefore, we don't combine them so we don't go any further to combine more than two warehouses and now we solve the case through DROP method to compare the results.

5. 2. 2. DROP HEURISTIC

Notation

- $J = \{1, \dots, m\}$ set of all potential warehouse locations.
- J_0 set of definitely forbidden locations.
- J_0^{Pot} set of potentially possible locations.
- J_1 set of definitely realized locations.
- Z total costs (objective value).

Initialization

- The DROP heuristic is the opposite approach to the ADD method: we start from a solution where all locations are opened.
- In the beginning all the warehouses are opened.
- Set $J_1^{\text{Pot}} = J$, $J_0 = J_1 = \{\}$, $Z = \sum_{j=1}^m f_j + \sum_{j=1}^m \min_{j \in J_1^{\text{Pot}}} c_{ij}$

Iteration step

- Close and drop exactly one potential location from the set J_1^{Pot} (based on total costs - select the location that causes the largest decrease in the total costs)
- Move all locations, cause a cost increase if forbidden, take from the set J_1^{Pot} to the set J_1 .

Warehouse/ Garden and Market	Gardens							Markets								Fixed cost	δ_j	decrease
	Karaj	Shahryar	Nazarabad	Saveh	Qazvin	Shiraz	Chalus	Tehran	Shiraz	Mashhad	Hamedan	Sari	Rasht	Tabriz	Urmia			
1 Tehran	750	560	665	1610	2400	4970	2720	2700	1080	4550	555	680	555	1680	1890	26700	515	26185
2 Shahryar	650	440	560	1470	2200	4900	2000	3150	1050	4615	660	720	540	1650	1860	24475	360	24115
3 Karaj	550	560	490	1750	2000	5180	2000	3375	1080	4680	570	740	510	1590	1830	24475	100	24375
4 Qazvin	750	680	420	1960	1600	5250	2320	4275	1110	4810	525	800	465	1530	1770	22250	470	21780
5 Zanzan	1700	1440	1120	2450	2600	5530	3680	8325	1185	5460	480	1100	450	1080	1350	20025	915	19110
6 Tonekabon	1450	1200	1120	2800	3500	5740	1280	6975	1215	4745	705	600	345	1650	1860	17800	905	16895

Ch1j	550	440	420	1470	1600	4900	1280	2700	1050	4550	480	600	345	1080	1350
Ch2j	650	560	490	1610	2000	4970	2000	3150	1080	4615	525	680	450	1530	1770
h1	3	2	4	2	4	2	6	1	2	1	5	6	6	5	5
h2	2	1	3	1	3	1	2	2	3	2	4	1	5	4	4

Table 11. DROP method first step under standard situation

Warehouse/ Garden and Market	Gardens							Markets								Fixed cost	δ_j	decrease
	Karaj	Shahryar	Nazarabad	Saveh	Qazvin	Shiraz	Chalus	Tehran	Shiraz	Mashhad	Hamedan	Sari	Rasht	Tabriz	Urmia			
2 Shahryar	650	440	560	1470	2200	4900	2000	3150	1050	4615	660	720	540	1650	1860	24475	1000	23475
3 Karaj	550	560	490	1750	2000	5180	2000	3375	1080	4680	570	740	510	1590	1830	24475	100	24375
4 Qazvin	750	680	420	1960	1600	5250	2320	4275	1110	4810	525	800	465	1530	1770	22250	470	21780
5 Zanzan	1700	1440	1120	2450	2600	5530	3680	8325	1185	5460	480	1100	450	1080	1350	20025	915	19110
6 Tonekabon	1450	1200	1120	2800	3500	5740	1280	6975	1215	4745	705	600	345	1650	1860	17800	945	16855

Ch1j	550	440	420	1470	1600	4900	1280	3150	1050	4615	480	600	345	1080	1350
Ch2j	650	560	490	1750	2000	5180	2000	3375	1080	4680	525	720	450	1530	1770
h1	3	2	4	2	4	2	6	2	2	2	5	6	6	5	5
h2	2	3	3	3	3	3	2	3	3	3	4	2	5	4	4

Table 12. DROP method second step under standard situation

Warehouse/ Garden and warehouse	Gardens							Markets								Fixed cost	δ_j	decrease
	Karaj	Shahryar	Nazarabad	Saveh	Qazvin	Shiraz	Chalus	Tehran	Shiraz	Mashhad	Hamedan	Sari	Rasht	Tabriz	Urmia			
2 Shahryar	650	440	560	1470	2200	4900	2000	3150	1050	4615	660	720	540	1650	1860	24475	2495	21980
4 Qazvin	750	680	420	1960	1600	5250	2320	4275	1110	4810	525	800	465	1530	1770	22250	740	21510
5 Zanzan	1700	1440	1120	2450	2600	5530	3680	8325	1185	5460	480	1100	450	1080	1350	20025	915	19110
6 Tonekabon	1450	1200	1120	2800	3500	5740	1280	6975	1215	4745	705	600	345	1650	1860	17800	945	16855

Ch1j	650	440	420	1470	1600	4900	1280	3150	1050	4615	480	600	345	1080	1350
Ch2j	750	680	560	1960	2200	5250	2000	4275	1110	4745	525	720	450	1530	1770
h1	2	2	4	2	4	2	6	2	2	2	5	6	6	5	5
h2	4	4	2	4	2	4	2	4	4	6	4	2	5	4	4

Table 13. DROP method third step under standard situation

	Warehouse/ Garden and warehouse	Gardens							Markets							Fixed cost	δ_j	decrease	Cost of single warehouse	Cost of Opening all
		Karaj	Shahryar	Nazarabad	Saveh	Qazvin	Shiraz	Chalus	Tehran	Shiraz	Mashhad	Hamedan	Sari	Rasht	Tabriz	Urmia				
4	Qazvin	750	680	420	1960	1600	5250	2320	4275	1110	4810	525	800	465	1530	1770	22250	8345	13905	50515
6	Tonekabon	1450	1200	1120	2800	3500	5740	1280	6975	1215	4745	705	600	345	1650	1860	17800	1425	16375	52985
																				66890

Ch1j	750	680	420	1960	1600	5250	1280	4275	1110	4745	525	600	345	1080	1770
Ch2j	1450	1200	1120	2800	3500	5740	1280	6975	1215	4810	705	800	465	1650	1860
h1	4	4	4	4	4	4	6	4	4	6	4	6	6	4	4
h2	6	6	6	6	6	6	4	6	6	4	6	4	4	6	6

Table 14. DROP method fourth step under standard situation

	Warehouse/ Garden and warehouse	Gardens							Markets							Fixed cost	δ_j	de- crease	Cost of single ware- house	Cost of opening all
		Karaj	Shahryar	Nazarabad	Saveh	Qazvin	Shiraz	Chalus	Tehran	Shiraz	Mashhad	Hamedan	Sari	Rasht	Tabriz	Urmia				
4	Qazvin	750	680	420	1960	1600	5250	2320	4275	1110	4810	525	800	465	1530	1770	22250	5185	17065	50515
5	Zanjan	1700	1440	1120	2450	2600	5530	3680	8325	1185	5460	480	1100	450	1080	1350	20025	915	19110	57975
6	Tonekabon	1450	1200	1120	2800	3500	5740	1280	6975	1215	4745	705	600	345	1650	1860	17800	1410	16390	52985
																				86000

Ch1j	750	680	420	1960	1600	5250	1280	4275	1110	4745	480	600	345	1080	1350
Ch2j	1450	1200	1120	2450	2600	5530	2320	6975	1185	4810	525	800	450	1530	1770
h1	4	4	4	4	4	4	6	4	4	6	5	6	6	5	5
h2	6	6	6	5	5	5	4	6	5	4	4	4	5	4	4

Table 15. DROP method last step under standard situation

As it is depicted based on DROP method we achieve the same result of ADD method, opening warehouse 4 with total cost of 5015. Also like ADD method the 2 best warehouses to combine them are warehouse 4 and warehouse 6 but the total cost of opening both of them is more than just opening warehouse 4.

5. 3. EXACT METHOD

The whole mixed-integer program (MIP) is about capacitated multi-level lot-sizing problems that can hardly be solved exactly within a reasonable time, if real-world problem sizes are considered and big, solving that will be more difficult (Rapeepan Pitakaso et al., 2006). Therefore, in this

paper CPLEX is used to solve the problem to compare the result of heuristic methods with exact method. The version of CPLEX is IBM ILOG CPLEX 12.0.

CPLEX optimizer is a platform in logistics fields; it provides an environment with optimization programming language (OPL). It is flexible for strategic planning and operational modules can be implemented separately; also, the MILP models can be generated and solved by the IBM ILOG CPLEX Optimizer as linear solver (Biswas, 2016).

5. 3. 1. CPLEX

CPLX consists of two parts, “.data” environment and “.mode” environment. Data part includes received data from the company and in “.mode” part based on the mathematical model, we define indexes, decision variables, objective function and constraint. The CPLEX solution under standard situation (without changing any parameters) is as below:

.dat Part:

```
stores = 8;           //Markets
gardens = 7;
warehouses = 6;
Fix = [26700, 24475, 24475, 22250, 20025, 17800]; //Fixed costs

// Transportation cost based on tonnage/kilometer from gardens to warehouses
Supplycost = [[750, 650, 550, 750, 1700, 1450],
[560, 440, 560, 680, 1440, 1200],
[665, 560, 490, 420, 1440, 1440],
[1610, 1470, 1750, 1960, 2450, 2800],
[2400, 2200, 2000, 1600, 2600, 3500],
[4970, 4900, 5180, 5250, 5530, 5740],
[2720, 2000, 2000, 2320, 3680, 1280]];

// Transportation cost based on tonnage/kilometer from warehouses to markets
Demandcost = [[2700, 1080, 4550, 555, 680, 555, 1680, 1890],
[3150, 1050, 4615, 660, 720, 540, 1650, 1860],
[3375, 1080, 4680, 570, 740, 510, 1590, 1830],
[4275, 1110, 4810, 525, 800, 465, 1530, 1770],
[8325, 1185, 5460, 480, 1100, 450, 1080, 1350],
[6975, 1215, 4745, 705, 600, 345, 1650, 1860]];

Capacity = [4000, 150000, 4000, 25000, 20000, 5000]; //Capacity of warehouses
ProducedFruit = [50, 40, 35, 70, 100, 70, 80]; // Supplied fruits in gardens
NeedsOfMarket = [255, 15, 65, 15, 20, 15, 30, 30]; // Demand of Markets
```

.mod Part

```
//Indexes
int stores= ...; range S=1..stores;
int gardens= ...; range G=1..gardens;
int warehouses= ...; range W=1..warehouses;
int Fix[W]= ...;
int Supplycost[G][W]=...;
int Demandcost[W][S]=...;
int Capacity[W]=...;
int ProducedFruit[G]=...;
int NeedsOfMarket[S]=...;

//Decisions variables
dvar boolean Open[W];           //1 if warehouse is opened, otherwise 0
dvar boolean Supply[G][W];      // 1 if garden is assigned to warehouse otherwise 0
dvar boolean Demand[S][W];      // 1 if store is assigned to warehouse otherwise 0

//Objective function
minimize sum(w in W) Open[w] * Fix[w] + sum(g in G, w in W) Supplycost[g][w] *
Supply[g][w] + sum(w in W, s in S) Demandcost[w][s] * Demand[s][w];

//Constraints
subject to {

// Capacity should be more than supply
forall(w in W, g in G)
    sum (g in G) ProducedFruit[g] * Supply[g][w] <= Capacity[w] * Open[w];

// Capacity should be more than supply
forall(w in W, s in S)
    sum (s in S) NeedsOfMarket [s] * Demand[s][w] <= Capacity[w] * Open[w];

//Each market is connected to one Warehouse:
forall (s in S)
    sum (w in W) Demand[s][w] == 1;

//We can assign a market to a warehouse only if it is opened
forall (w in W, s in S, g in G)
    Demand[s][w] <= Open[w];

// Each garden is connected to one Warehouse
forall(g in G)
    sum (w in W) Supply[g][w] == 1;

//We can assign a garden to a warehouse only if it is opened
forall (w in W, s in S, g in G)
    Supply[g][w] <= Open[w];

//Supply should be more than demand
forall (s in S, g in G)
    sum (s in S) NeedsOfMarket [s] <= sum (g in G) ProducedFruit[g];
}
```

After configuration in CPLEX the result would be as below:

```
// solution (optimal) with objective 50515
Open = [0 0 0 1 0 0];
Supply = [
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]];
Demand = [
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]];
Solving CPU Elapsed Time in (Second):3.25
```

“Open” index indicates that warehouse 4 should be opened.

“Supply” index indicates that all gardens should be assigned to warehouse 4.

“Demand” index shows that all markets should be assigned to warehouse 4 and consequently all the gardens. The result of assigning the gardens, warehouse and markets on map will be as below:

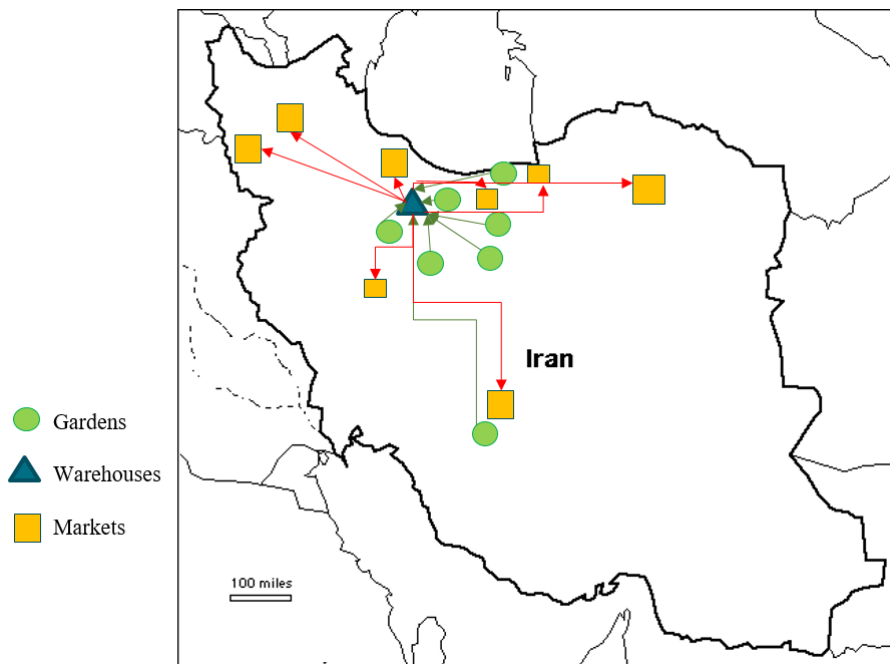


Figure 4. Assignments on map of Iran under standard situation

6. SCENARIOS

Under standard situation warehouse 4 is selected with total cost of 50515, and the result of ADD/DROP and CPLEX were the same. Now we want to change the parameters and have different situations as decreasing the capacity of warehouses, decreasing the fixed costs, taking into account uncertainties and using random demand instead of determined demand.

6.1. CHANGING THE CAPACITIES

The first scenario is about changing the capacity of the currently selected warehouse. The company rents the warehouse for just a short period of time, eight months. What if for the coming year the selected warehouse, warehouse 4, not be available or taken?

Below we can see the current capacities:

Capacity = [4000, 150000, 4000, **25000**, 20000, 5000];

Based on these capacities choosing the warehouse 4 with total cost 50515 was the optimal solution.

What if that capacity of the selected warehouse gets reduced to 250?

Capacity = [4000, 150000, 4000, **250**, 20000, 5000];

Then based on the CPLEX the second optimal solution would be warehouse 2 by total cost of 50940.

The other possibility of this scenario is playing with the capacity of our optimal solutions one by one. It means reducing the capacity of selected warehouses to see what will be the next optimal

warehouse. In other words, what if for the coming years the capacities one by one are cut down?

What would be the order of selecting the warehouses by considering the perspective of total cost?

Capacity = [4000, 150000, 4000, **25000**, 20000, 5000]; Total cost: 50515

Capacity = [4000, **150000**, 4000, **0**, 20000, 5000]; Total cost: 50940

Capacity = [4000, **0**, **4000**, **0**, 20000, 5000]; Total cost: 51380

Capacity = [4000, **0**, **0**, **0**, 20000, **5000**]; Total cost: 53305

Capacity = [**4000**, **0**, **0**, **0**, 20000, **0**]; Total cost: 54065

Capacity = [**0**, **0**, **0**, **0**, **20000**, **0**]; Total cost: 58295

As it is indicated, the best option is warehouse 4 with total cost of 50515 and the worst one is warehouse 5 with total cost of 58295.

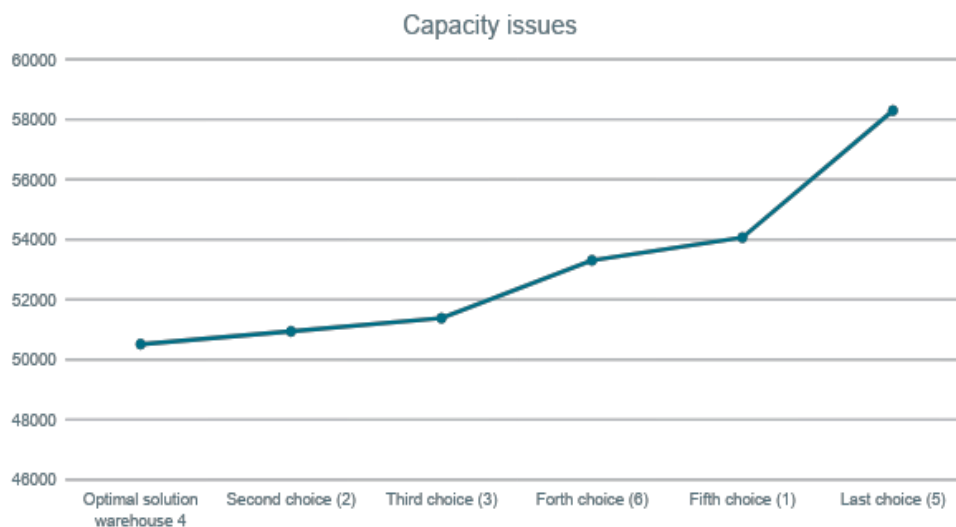


Figure 5. Increase of total costs by getting far away from optimal solution

A sub-scenario, which is related to the capacity issue, is increase in supply. “Supply increase” is like the “capacity reduction” scenario with a big difference by increasing supply amount there

will be a positive effect on transportation cost. If supply increases, transportation cost will increase and consequently the total cost grows up.

In this scenario there is this possibility that for next year one of the gardens will produce more fruits or get expanded more and the company decides to buy more gardens in that city which produce the same product.

Supply of gardens = [50, 40, 35, 70, ~~100~~ 100000, 70, 80];

Capacity = [4000, 150000, 4000, 25000, 20000, 5000];

If the supply 100 times goes up the selected warehouse will be like scenario 2, warehouse 2. The only difference is that “Supply increase” has a direct effect on transportation cost and transportation cost has influence on total cost therefore in that case the total cost will be 2115690 which is way more than the case of “Capacity reduction” of warehouses.

6. 2. FIXED COST REDUCTION

The second scenario is buying the warehouse instead of renting it. The company requested this scenario, they want to know if they invest more in the beginning and pay less periodical fixed costs, how much the total cost will decrease and which warehouse or warehouses would be selected? Is it the same warehouse which is chosen under standard condition? Or not.

Under this condition, the case will change to a multi-commodity and multi-echelon case. Because up to now, just one warehouse could be opened, as the fixed costs were so high therefore the case study was a single product and all the products used to come to a warehouse and then get dispatched from there.

But, in this situation, the fixed costs are less and it makes sense to assign the markets and gardens to the warehouse, which is close to them. To make it more clear based on figure 6, if a garden provides the needs of two markets, would it be better just to open warehouse 1 which is close to

market 1 and pay more transportation cost for shipping the fruit from warehouse 1 to market 2? Or open additionally warehouse 2 which is close to market 2 and pay less transportations. If the second warehouse gets opened, the fixed cost of warehouse 2 would compensate the transportation cost of longer path for transferring fruits from warehouse 1 to market 2? Or the fixed cost of opening a second warehouse is more than the transportation cost of a longer path.

On the other hand, if a market requests fruits from two different gardens would it be better to open two warehouses near each of them and pay less transportation cost of transferring fruit from gardens to the warehouses and more fixed cost? Or the fixed cost of opening the second warehouse will be more than the cost that we save by choosing the shorter path? The figure is as below:



Figure 6. Two possibilities of multi-echelon case

As it is shown in table 14, up to now we had 8 markets but by specifying the needs of markets we will have 14 markets because the case is switched to multi-commodity; we categorize each market based on its needs. To make it more clear, Tehran is a market with total demand of 255. Tehran requests six different fruits; therefore, instead of considering Tehran as a single market we consider it as 6 markets.

Market	Total need
Tehran	255
Shiraz	15
Mashhad	65
Hamedan	15
Sari	20
Rasht	15
Tabriz	30
Urmia	30

Table 16. Market demand under single-commodity, single-echelon condition

Market	Specific need	Total need
Tehran-Cherry	20	255
Tehran-Apricot	25	
Tehran-Apple	70	
Tehran-Pear	50	
Tehran-Pomegranate	40	
Tehran-Kiwi	50	
Shiraz-Cherry	15	15
Mashhad-Cherry	15	65
Mashhad-Pear	50	
Hamedan-Apricot	15	15
Sari-Nectarine	20	20
Rasht-Nectarine	15	15
Tabriz-Pomegranate	30	30
Urmia-Kiwi	30	30

Table 17. Market demand under multi-commodity, multi-echelon condition

Below on figures 7 and 8 we have different supply chain models and mathematical models of single warehouse vs. multi warehouse under condition of opening just one warehouse or multi warehouses

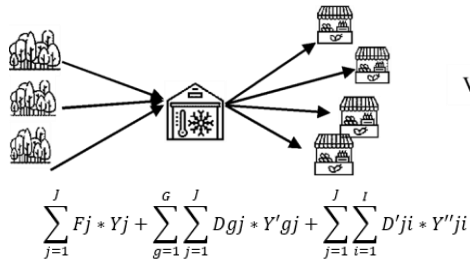


Figure 7. Single warehouse condition

vs.

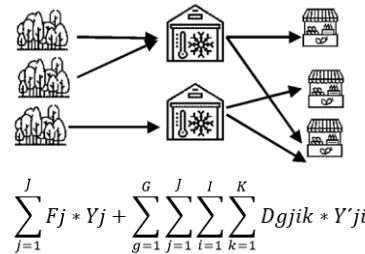


Figure 8. Multi-warehouses condition

For this multi-echelon, multi-commodity scenario, the mathematical has two changes:

$$\sum_{j=1}^J F_j * Y_j + \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K D_{gjik} * Y'_{ji}$$

1. New index “K” which indicates type of fruit
2. New index “Dgjik” which is the cost of sending product k from garden g to market i through warehouse j. It means if market 1 needs product k from garden 1 what would be transportation cost if it receives the fruits through 6 different potential warehouses.

To figure out that in case of buying the warehouse, the same warehouse will be selected or not? How much the total cost will be decreased and opening just one warehouse will be enough or more than that? We solve the problem at first with heuristic methods ADD and DROP and then compare the results with each other and then with result of CPLEX.

ADD Method:

	Warehouse/ Market	Cherry			Apricot		Nectarine		Apple	Pear		Pomegranate		Kiwi		Fixed cost	Total cost
		Tehran	Shiraz	Mashhad	Tehran	Hamedan	Sari	Rasht	Tehran	Tehran	Mashhad	Tehran	Tabriz	Tehran	Urmia		
1	Tehran	540	1305	1275	650	765	1060	840	2450	1800	4700	3320	3810	2300	2910	768	28493
2	Shahryar	540	1245	1260	625	825	1040	780	2450	1800	4650	3360	3750	1950	2610	545	27430
3	Karaj	520	1245	1245	725	780	1020	720	2800	1750	4600	3560	3810	2000	2580	545	27900
4	Qazvin	680	1335	1335	900	780	1040	645	3290	1750	4500	3760	3780	2400	2640	375	29210
5	Zanjan	1420	1695	1770	1825	1020	1740	930	5040	3150	5500	4640	3450	4150	2730	375	39435
6	Tonekabon	1200	1650	1530	1525	1155	1240	825	4970	3300	5400	4520	4110	2350	2340	343	36458

Table 18. ADD method first step under second scenario condition

Build k = 2 with $Z_2 = c_2 + f_2 = 27430$, $J_1 = \{2\}$, $J_0^{\text{Pot}} = \{1, 3, 4, 5, 6\}$

	Warehouse/ Market	Cherry			Apricot		Nectarine		Apple	Pear		Pomegranate		Kiwi		Fixed cost	ω_i	Different
		Tehran	Shiraz	Mashhad	Tehran	Hamedan	Sari	Rasht	Tehran	Tehran	Mashhad	Tehran	Tabriz	Tehran	Urmia			
1	Tehran	0	0	0	0	60	0	0	0	0	0	40	0	0	0	768	100	-668
3	Karaj	20	0	15	0	45	20	60	0	50	50	0	0	0	30	545	290	-255
4	Qazvin	0	0	0	0	45	0	135	0	50	150	0	0	0	0	375	380	5
5	Zanjan	0	0	0	0	0	0	0	0	0	0	0	300	0	0	375	300	-75
6	Tonekabon	0	0	0	0	0	0	0	0	0	0	0	0	0	270	343	270	-73

Table 19. ADD method second step under second scenario condition

Build k=4, $Z_{24}=27430-380+375= 27425$ $J_1 = \{4\}$, $J_0^{\text{Pot}} = \{1, 3, 5, 6\}$
 $J_0=\{1,3,5,6\}$ forbidden as $\omega_j < \text{Fixed cost}$

So the result is opening warehouse 2 and 4 with total cost of 27425 which is less than situation of “renting the warehouse” under standard situation the warehouse which was 50515. Now we go through DROP method.

Drop Method:

	Warehouse /Market	Cherry			Apricot		Nectarine		Apple	Pear		Pomegranate		Kiwi		Fixed cost	δ_j	decrease
		Tehran	Shiraz	Mashhad	Tehran	Hamedan	Sari	Rasht	Tehran	Tehran	Mashhad	Tehran	Tabriz	Tehran	Urmia			
1	Tehran	540	1305	1275	650	765	1060	840	2450	1800	4700	3320	3810	2300	2910	768	55	713
2	Shahryar	540	1245	1260	625	825	1040	780	2450	1800	4650	3360	3750	1950	2610	545	75	470
3	Karaj	520	1245	1245	725	780	1020	720	2800	1750	4600	3560	3810	2000	2580	545	55	490
4	Qazvin	680	1335	1335	900	780	1040	645	3290	1750	4500	3760	3780	2400	2640	375	175	200
5	Zanjan	1420	1695	1770	1825	1020	1740	930	5040	3150	5500	4640	3450	4150	2730	375	300	75
6	Tonekabon	1200	1650	1530	1525	1155	1240	825	4970	3300	5400	4520	4110	2350	2340	343	240	103

Table 20. DROP method first step under second scenario condition

	Warehouse /Market	Cherry			Apricot		Nectarine		Apple	Pear		Pomegranate		Kiwi		Fixed cost	δ_j	decrease
		Tehran	Shiraz	Mashhad	Tehran	Hamedan	Sari	Rasht	Tehran	Tehran	Mashhad	Tehran	Tabriz	Tehran	Urmia			
2	Shahryar	540	1245	1260	625	825	1040	780	2450	1800	4650	3360	3750	1950	2610	545	730	-185
3	Karaj	520	1245	1245	725	780	1020	720	2800	1750	4600	3560	3810	2000	2580	545	55	490
4	Qazvin	680	1335	1335	900	780	1040	645	3290	1750	4500	3760	3780	2400	2640	375	175	200
5	Zanjan	1420	1695	1770	1825	1020	1740	930	5040	3150	5500	4640	3450	4150	2730	375	0	375
6	Tonekabon	1200	1650	1530	1525	1155	1240	825	4970	3300	5400	4520	4110	2350	2340	343	***	***

Table 21. DROP method second step under second scenario condition

	Warehouse /Market	Cherry			Apricot		Nectarine		Apple	Pear		Pomegranate		Kiwi		Fixed cost	δ_j	decrease
		Tehran	Shiraz	Mashhad	Tehran	Hamedan	Sari	Rasht	Tehran	Tehran	Mashhad	Tehran	Tabriz	Tehran	Urmia			
2	Shahryar	540	1245	1260	625	825	1040	780	2450	1800	4650	3360	3750	1950	2610	545	***	***
4	Qazvin	680	1335	1335	900	780	1040	645	3290	1750	4500	3760	3780	2400	2640	375	380	-5
5	Zanjan	1420	1695	1770	1825	1020	1740	930	5040	3150	5500	4640	3450	4150	2730	375	300	75
6	Tonekabon	1200	1650	1530	1525	1155	1240	825	4970	3300	5400	4520	4110	2350	2340	343	***	***

Table 22. DROP method third step under second scenario condition

	Warehouse /Market	Cherry			Apricot		Nectarine		Apple	Pear		Pomegranate		Kiwi		Fixed cost	δ_j	decrease	Open just one	Open all
		Tehran	Shiraz	Mashhad	Tehran	Hamedan	Sari	Rasht	Tehran	Tehran	Mashhad	Tehran	Tabriz	Tehran	Urmia					
2	Shahryar	540	1245	1260	625	825	1040	780	2450	1800	4650	3360	3750	1950	2610	545	***	***	27430	27498
4	Qazvin	680	1335	1335	900	780	1040	645	3290	1750	4500	3760	3780	2400	2640	375	***	***	29210	
6	Tonekabon	1200	1650	1530	1525	1155	1240	825	4970	3300	5400	4520	4110	2350	2340	343	***	***	36458	

Table 23. DROP method fourth step under second scenario condition

In this stage, three warehouses are left opened. We take a look at the total cost we build just one of them or three of them? By building all three we do not achieve the best result therefore, we go one step further, because 27448 is more than 27430.

	Warehouse/ Market	Cherry			Apricot		Nectarine		Apple	Pear		Pomegranate		Kiwi		Fixed cost	δ_j	decrease
		Tehran	Shiraz	Mashhad	Tehran	Hamedan	Sari	Rasht	Tehran	Tehran	Mashhad	Tehran	Tabriz	Tehran	Urmia			
2	Shahryar	540	1245	1260	625	825	1040	780	2450	1800	4650	3360	3750	1950	2610	545	2250	-1705
4	Qazvin	680	1335	1335	900	780	1040	645	3290	1750	4500	3760	3780	2400	2640	375	380	-5
6	Tonekabon	1200	1650	1530	1525	1155	1240	825	4970	3300	5400	4520	4110	2350	2340	343	270	73

Table 24. DROP method fifth step under second scenario condition

Based on table 22 we close warehouse number six.

	Warehouse/ Market	Cherry			Apricot		Nectarine		Apple	Pear		Pomegranate		Kiwi		Fixed cost	δ_j	decrease	Open single	Open both
		Tehran	Shiraz	Mashhad	Tehran	Hamedan	Sari	Rasht	Tehran	Tehran	Mashhad	Tehran	Tabriz	Tehran	Urmia					
2	Shahryar	540	1245	1260	625	825	1040	780	2450	1800	4650	3360	3750	1950	2610	545	***	***	27430	27425
4	Qazvin	680	1335	1335	900	780	1040	645	3290	1750	4500	3760	3780	2400	2640	375	380	-5	29210	

Table 25. DROP method last step under second scenario condition

As it is indicated by opening both warehouses, 2 and 4, the lowest total cost will be achieved.

The result is exactly like ADD method, 27425. Now we go through CPLEX solution:

.dat Part:

```
stores = 14;      //Markets
warehouses = 6;
Fix = [768, 545, 545, 375, 375, 343];
// Transportation cost based on ton/kilometer from gardens to fourteen markets through
6 different warehouses
Supplycost = [
[540, 540, 520, 680, 1420, 1200],
[1305, 1245, 1245, 1335, 1695, 1650],
[1275, 1260, 1245, 1335, 1770, 1530],
[650, 625, 725, 900, 1825, 1525],
[765, 825, 780, 780, 1020, 1155],
[1060, 1040, 1020, 1040, 1740, 1240],
[840, 780, 720, 645, 930, 825],
[2450, 2450, 2800, 3290, 5040, 4970],
[1800, 1800, 1750, 1750, 3150, 3300],
[4700, 4650, 4600, 4500, 5500, 5400],
[3320, 3360, 3560, 3760, 4640, 4520],
[3810, 3750, 3810, 3780, 3450, 4110],
[2300, 1950, 2000, 2400, 4150, 2350],
[2910, 2610, 2580, 2640, 2730, 2340]];
```

.mod Part:

```
//Indexes
int stores = ...; range S = 1..stores;
int warehouses = ...; range W = 1..warehouses;
int Fix[W] = ...;
int Supplycost[S][W] = ...;
dvar boolean Open[W]; //1 if warehouse is opened, otherwise 0
dvar boolean MarketsDemand[S][W]; // 1 if store is assigned to warehouse otherwise 0

//Objective function
minimize sum(w in W) Open[w] * Fix[w] + sum(w in W, s in S) Supplycost[s][w] *
MarketsDemand[s][w];

subject to {
forall (s in S)
    sum(w in W) MarketsDemand[s][w] == 1; //Each market is connected to one Warehouse:

forall (w in W, s in S)
    MarketsDemand[s][w] <= Open[w]; //We can assign a market to a warehouse only if
it is opened
}
```

Result of CPLEX:

```
// solution (optimal) with objective 27425
Open = [0 1 0 1 0 0];
MarketsDemand = [
    [0 1 0 0 0 0]
    [0 1 0 0 0 0]
    [0 1 0 0 0 0]
    [0 1 0 0 0 0]
    [0 0 0 1 0 0]
    [0 1 0 0 0 0]
    [0 0 0 1 0 0]
    [0 1 0 0 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 1 0 0 0 0]
    [0 1 0 0 0 0]
    [0 1 0 0 0 0]
    [0 1 0 0 0 0]
];
Solving CPU Elapsed Time in (Second):3.296875
```

“Open” index indicates that warehouses 2 and 4 should be opened.

“Demand” index shows that markets 5, 7, 9 and 10 should be assigned to warehouse 2 and the rest markets should be connected and get their demands to warehouse 4.

The results of ADD/ DROP and CPLEX method are the same by opening warehouse 2 and 4 with total cost of 27425. Based on table 24 we can see the needs of each market should get fulfilled through which warehouse:

		Market/Warehouse	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Cherry	1	Tehran	540	540	520	680	1420	1200
	2	Karaj	1305	1245	1245	1335	1695	1650
	3	Karaj	1275	1260	1245	1335	1770	1530
Apricot	4	Tehran	650	625	725	900	1825	1525
	5	Hamedan	765	825	780	780	1020	1155
Nectarine	6	Sari	1060	1040	1020	1040	1740	1240
	7	Rasht	840	780	720	645	930	825
Apple	8	Tehran	2450	2450	2800	3290	5040	4970
Pear	9	Tehran	1800	1800	1750	1750	3150	3300
	10	Mashhad	4700	4650	4600	4500	5500	5400
Pomegranate	11	Tehran	3320	3360	3560	3760	4640	4520
	12	Tabriz	3810	3750	3810	3780	3450	4110
Kiwi	13	Tehran	2300	1950	2000	2400	4150	2350
	14	Urmia	2910	2610	2580	2640	2730	2340
Fixed cost			768	545	545	375	375	343
Total cost			27425					

Table 26. Assignment of the gardens and the markets to the warehouses

According to table 4, we know the demand of each market for each product. Based on table 24 the cherry garden should be assigned to the second warehouse and the needs of market 1, 2, 3 should be fulfilled through warehouse 2. For Apricot, we should ship 25 tons to warehouse 2, to cover demand of market 4 and 15 tons should be shipped to warehouse 4 to cover the need of market 5. 20 tons of Nectarine should be sent to warehouse 2 to fulfill the request of market 6 and 15 tons to warehouse 4 to cover the request of market 7. Apple garden should be assigned to warehouse 2 to cover the needs of Tehran, market 8.

Market 9 and 10 request for pear, both markets and pear garden should be connected to warehouse 4. Market 11 and 12 request pomegranate; pomegranate garden produces 70 tons of pomegranate. It should be assigned to warehouse 2 to cover the need of market 11, 40 tons, and to cover

market 12, 30 tons. There are two markets for kiwi, the need of market 13 is 50 tons of kiwi and market 14, 30 tons kiwi both of them and the garden of kiwi should be connected to warehouse 2. On the map of Iran the network of supply chain through the second scenario, buying the warehouse instead of renting it will be as in figure 9.

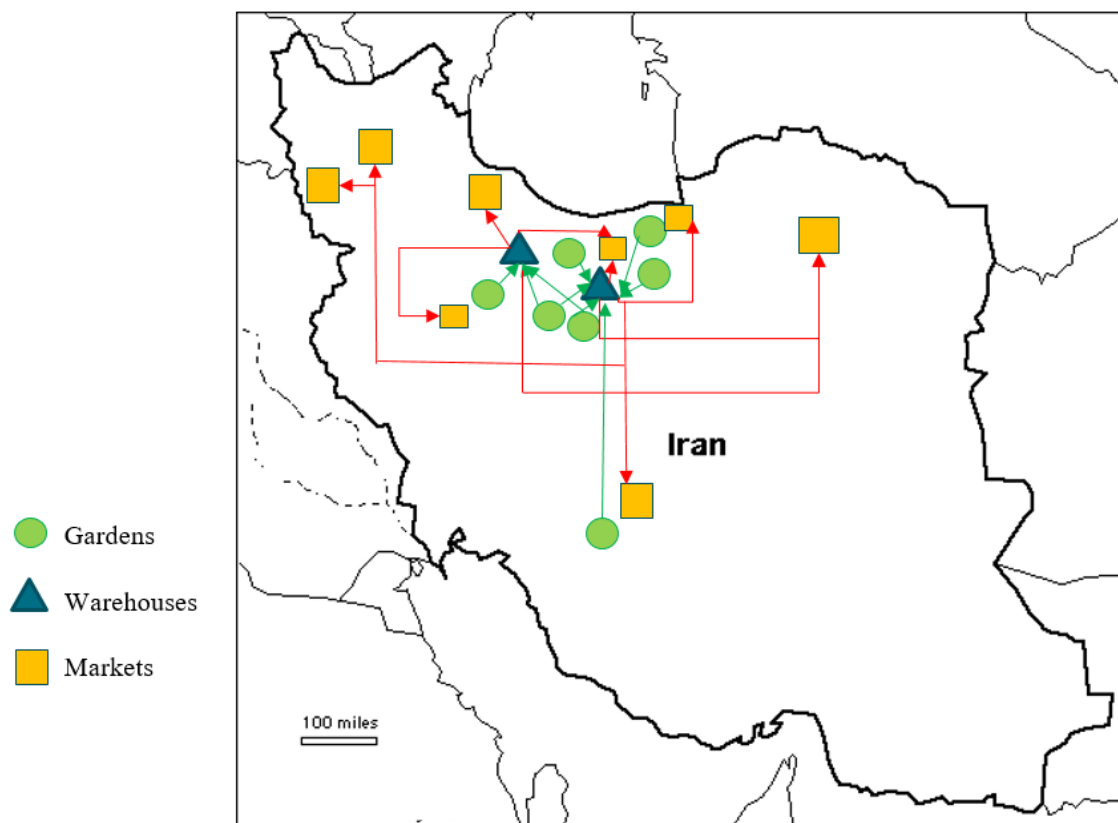


Figure 9. The result of second scenario on the map of Iran

6. 3. DEMAND UNCERTAINTY

This scenario is inspired by the book of “Introduction to Logistics Systems Management” by Ghiani, which is published in 2013. Till now we have had determined demand but if the company wants to rent the warehouse for the coming ten years there will be some doubts about amount of market demands. Therefore, the company provided the probabilities table for each market over ten years and beside of that discount rate on warehouses which is different warehouse to warehouse

due to renting a warehouse for a long term. This scenario considers a long time horizon for renting a warehouse. Before going through the demand probabilities table, on figure 10 we have some factors, which cause demand uncertainty and the mathematical model.

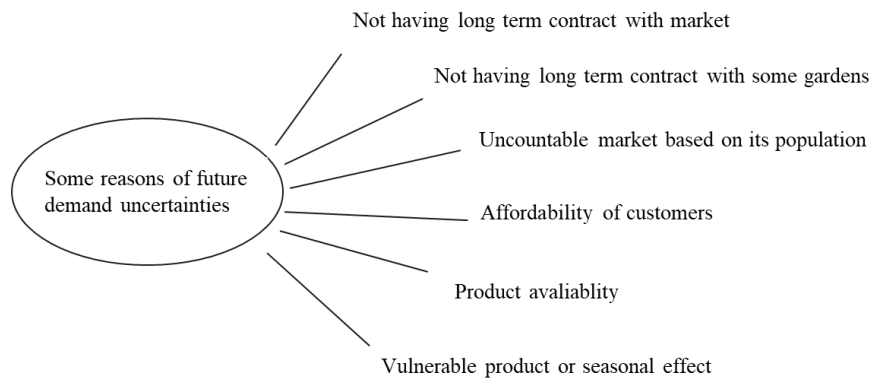


Figure 10. Factors that cause demand uncertainty

Two first factors are related to long-term contracts with markets or gardens. Sometimes the company has a long-term contract with a market therefore, they can be sure about counting on this market. Alternatively, some gardens are rented without having a long-term contract and the company cannot be sure about the supply amount; therefore, if there be no supply thus they will lose the market for that specific fruit. To explain the third factor; some markets like Tehran province which has one sixth of the population of Iran (14 million) the demand is always one hundred percent, the company considers such markets an ocean that even if they lose their current business partner they can find another dealer. Fourth factor is affordability of customers; it means how much is the shopping power of people in different cities, markets; and how much people can pay for fruits that are more expensive. Fifth factor is product availability; some fruits in Iran are getting produced in limited regions like kiwi in north of Iran. Therefore, if a company owns or rents the gardens of kiwi in that region there will not be so many competitors. About last factor, some fruits like pomegranate have so many known pests and if they infected they can transfer the insects and

pests to the other fruits quickly; or as another example cherry is one of those type of fruits that get spoiled easily therefore for long distance markets, it will be risky and expensive for insuring the fruit. Currently the company sends cherry to far away cities from garden of cherry to Mashhad and Shiraz, maybe in long term view the markets don't want to extend the contract as they receive fruit not in a high quality condition. On the other hand, the company will not like to take that risk to continue shipping cherry to those cities.

As we have different offers for each warehouse over ten years and also different probability for each market over ten years, which means 140 possibilities for markets, thus the mathematical model is more complicated than previous ones, also if we solve the case manually it will be so time-consuming we use CPLEX for the last two scenarios.

The mathematical model of this scenario will be as below:

Min Z=

$$\begin{aligned} & \sum_{j=1}^J \sum_{s=1}^S F_s * F_j * Y_j + \sum_{s=1}^S \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K P_{s1} * D_{gjik} * Y'_{ji} + \sum_{j=1}^J \sum_{s=1}^S F_s * F_j * Y_j + \sum_{s=1}^S \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K P_{s2} * D_{gjik} * Y'_{ji} + \\ & \sum_{j=1}^J \sum_{s=1}^S F_s * F_j * Y_j + \sum_{s=1}^S \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K P_{s3} * D_{gjik} * Y'_{ji} + \sum_{j=1}^J \sum_{s=1}^S F_s * F_j * Y_j + \sum_{s=1}^S \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K P_{s4} * D_{gjik} * Y'_{ji} + \\ & \sum_{j=1}^J \sum_{s=1}^S F_s * F_j * Y_j + \sum_{s=1}^S \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K P_{s5} * D_{gjik} * Y'_{ji} + \sum_{j=1}^J \sum_{s=1}^S F_s * F_j * Y_j + \sum_{s=1}^S \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K P_{s6} * D_{gjik} * Y'_{ji} + \\ & \sum_{j=1}^J \sum_{s=1}^S F_s * F_j * Y_j + \sum_{s=1}^S \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K P_{s7} * D_{gjik} * Y'_{ji} + \sum_{j=1}^J \sum_{s=1}^S F_s * F_j * Y_j + \sum_{s=1}^S \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K P_{s8} * D_{gjik} * Y'_{ji} + \\ & \sum_{j=1}^J \sum_{s=1}^S F_s * F_j * Y_j + \sum_{s=1}^S \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K P_{s9} * D_{gjik} * Y'_{ji} + \sum_{j=1}^J \sum_{s=1}^S F_s * F_j * Y_j + \sum_{s=1}^S \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K P_{s10} * D_{gjik} * Y'_{ji} \end{aligned}$$

F_s Discount of renting the warehouse for 10 years

F_j Fixed cost of cold storage warehouse j.

$Y_j \begin{cases} 1 & \text{if warehouse j is opened} \\ 0 & \text{otherwise} \end{cases}$

D_{gjik} The cost of transferring product k from garden g to market i from warehouse j.

P_{si} Demand probability of market i

$Y'_{ij} \begin{cases} 1 & \text{if market i is assigned to warehouse j} \\ 0 & \text{otherwise} \end{cases}$

In the new mathematical model there are two new indexes F_s , which is discount rate of renting a warehouse for a long term, 10 years. “ P_{si} ” which is the probability of the demands of market i.

Psi is different year to year and for unstable markets, it gets reduced over ten years. Below there is the given table of demand probabilities over ten years.

	Market/ Warehouse	1	2	3	4	5	6	7	8	9	10
Cherry	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Shiraz	100%	100%	100%	100%	100%	50%	50%	50%	50%	50%
	Mashhad	100%	100%	100%	70%	70%	60%	60%	60%	50%	50%
Apricot	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Hamedan	100%	100%	100%	100%	100%	100%	70%	70%	70%	70%
Nectarine	Sari	100%	100%	80%	80%	70%	70%	60%	60%	50%	50%
	Rasht	100%	100%	80%	80%	70%	70%	60%	60%	50%	50%
Apple	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Pear	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Mashhad	100%	100%	80%	80%	70%	60%	60%	50%	50%	40%
Pomegranate	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Tabriz	100%	100%	100%	100%	100%	90%	90%	90%	90%	80%
Kiwi	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Urmia	100%	100%	100%	100%	80%	80%	80%	70%	70%	70%

Table 27. Demand probabilities of 14 markets during 10 years

Table 25 should be multiple to the table 16, transportation costs of transferring the needs of market through 6 different warehouses, the result will be table 26 as below:

	Market/ Warehouse	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon	1	2	3	4	5	6	7	8	9	10
Cherry	Tehran	540	540	520	680	1420	1200	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Shiraz	1305	1245	1245	1335	1695	1650	100%	100%	100%	100%	100%	50%	50%	50%	50%	50%
	Mashhad	1275	1260	1245	1335	1770	1530	100%	100%	100%	70%	70%	60%	60%	60%	50%	50%
Apricot	Tehran	650	625	725	900	1825	1525	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Hamedan	765	825	780	780	1020	1155	100%	100%	100%	100%	100%	100%	70%	70%	70%	70%
Nectarine	Sari	1060	1040	1020	1040	1740	1240	100%	100%	80%	80%	70%	70%	60%	60%	50%	50%
	Rasht	840	780	720	645	930	825	100%	100%	80%	80%	70%	70%	60%	60%	50%	50%
Apple	Tehran	2450	2450	2800	3290	5040	4970	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Pear	Tehran	1800	1800	1750	1750	3150	3300	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Mashhad	4700	4650	4600	4500	5500	5400	100%	100%	80%	80%	70%	60%	60%	50%	50%	40%
Pomegranate	Tehran	3320	3360	3560	3760	4640	4520	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Tabriz	3810	3750	3810	3780	3450	4110	100%	100%	100%	100%	100%	90%	90%	90%	90%	80%
Kiwi	Tehran	2300	1950	2000	2400	4150	2350	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Urmia	2910	2610	2580	2640	2730	2340	100%	100%	100%	100%	80%	80%	80%	70%	70%	70%
Fixed cost		26700	24475	24475	22250	20025	17800										
Discount on fixed costs		--	5%	5%	10%	10%	10%										
Fixed cost		26700	23251,25	23251,3	20025	18022,5	16020										

Table 28. Transportation cost, demand probabilities and rate of discount of warehouses

As it is indicated in table 26, by multiplying the discount of renting a warehouse to its current fixed cost we will have the fixed cost of warehouse over ten years. When a warehouse is rented for ten years the owner offer a better deal but for a big city like Tehran the company doesn't get any better offers because the competition to rent a warehouse in Tehran is so high, companies are interested to rent a warehouse in Tehran to be near to the market of Tehran, biggest market of Iran.

We multiply these two tables, demand probabilities of each market to the transportation cost of the market. As it is shown in table 27, warehouse 4 will be selected with total cost of 455692 over ten years that means the average total cost would be 45569, in below table there is summary of selecting the warehouse over ten years:

	1					
	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Variable cost	27725	26885	27355	28835	39060	36115
Fixed cost	26700	23251,25	23251,3	20025	18022,5	16020
Total cost	54425	50136,25	50606,25	48860	57082,5	52135

	6					
	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Variable cost	23150	22456	22976	24422	33613	31020
Fixed cost	26700	23251,25	23251,25	20025	18022,5	16020
Total cost	49849,5	45706,75	46226,75	44447	51635	47039,5

	2					
	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Variable cost	27725	26885	27355	28835	39060	36115
Fixed cost	26700	23251	23251	20025	18023	16020
Total cost	54425	50136,25	50606,25	48860	57082,5	52135

	7					
	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Variable cost	22730	22026	22568	24020	33040	30467
Fixed cost	26700	23251,25	23251,25	20025	18022,5	16020
Total cost	49430	45277,25	45818,75	44044,5	51062	46486,5

	3					
	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Variable cost	26405	26885	26087	27598	37426	34622
Fixed cost	26700	23251,25	23251,25	20025	18022,5	16020
Total cost	53105	50136,25	49338,25	47623	55448,5	50642

	8					
	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Variable cost	21969	21300	21850	23306	32217	29693
Fixed cost	26700	23251,25	23251,25	20025	18022,5	16020
Total cost	48669	44551,25	45100,75	43330,5	50239	45712,5

	4					
	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Variable cost	26023	25213	25714	27198	36895	34163
Fixed cost	26700	23251,25	23251,25	20025	18022,5	16020
Total cost	52722,5	48464,25	48964,75	47222,5	54917,5	50183

	9					
	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Variable cost	21652	20992	21551	23004	31773	29333
Fixed cost	26700	23251,25	23251,25	20025	18022,5	16020
Total cost	48351,5	44243,25	44802,25	43028,5	49795	45353

	5					
	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Variable cost	24781	24044	24564	26051	35532	32949
Fixed cost	26700	23251,25	23251,25	20025	18022,5	16020
Total cost	51480,5	47295,25	47814,75	46076	53554,5	48968,5

	10					
	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Variable cost	20801	20152	20710	22176	30878	28382
Fixed cost	26700	23251,25	23251,25	20025	18022,5	16020
Total cost	47500,5	43403,25	43961,25	42200,5	48900	44402

Table 29. Selected warehouse over ten years

Now we go through CPLEX solution:

.dat Part:

```
stores = 14;      //Markets for different fruits
warehouses = 6;
Fix = [26700, 24475, 24475, 22250, 20025, 17800];
```

```

X = [1, 0.95, 0.95, 0.9, 0.9, 0.9]; // Discount of renting each warehouse for ten
years
// Demand probability during 10 years for each market
P1 = [1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1];
P2 = [1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1, 1];
P3 = [1, 1, 1, 1, 1, 0.8, 0.8, 1, 1, 0.8, 1, 1, 1, 1];
P4 = [1, 1, 0.7, 1, 1, 0.8, 0.8, 1, 1, 0.8, 1, 1, 1, 1];
P5 = [1, 1, 0.7, 1, 1, 0.7, 0.7, 1, 1, 0.7, 1, 1, 1, 0.7];
P6 = [1, 0.5, 0.6, 1, 1, 0.7, 0.7, 1, 1, 0.6, 1, 0.9, 1, 0.7];
P7 = [1, 0.5, 0.6, 1, 0.7, 0.6, 0.6, 1, 1, 0.6, 1, 0.9, 1, 0.6];
P8 = [1, 0.5, 0.6, 1, 0.7, 0.6, 0.6, 1, 1, 0.5, 1, 0.9, 1, 0.6];
P9 = [1, 0.5, 0.5, 1, 0.7, 0.5, 0.5, 1, 1, 0.5, 1, 0.9, 1, 0.5];
P10= [1, 0.5, 0.5, 1, 0.7, 0.5, 0.5, 1, 1, 0.4, 1, 0.8, 1, 0.5];

Supplycost = [
[540, 540, 520, 680, 1420, 1200],
[1305, 1245, 1245, 1335, 1695, 1650],
[1275, 1260, 1245, 1335, 1770, 1530],
[650, 625, 725, 900, 1825, 1525],
[765, 825, 780, 780, 1020, 1155],
[1060, 1040, 1020, 1040, 1740, 1240],
[840, 780, 720, 645, 930, 825],
[2450, 2450, 2800, 3290, 5040, 4970],
[1800, 1800, 1750, 1750, 3150, 3300],
[4700, 4650, 4600, 4500, 5500, 5400],
[3320, 3360, 3560, 3760, 4640, 4520],
[3810, 3750, 3810, 3780, 3450, 4110],
[2300, 1950, 2000, 2400, 4150, 2350],
[2910, 2610, 2580, 2640, 2730, 2340],
];

```

CPLEX.mod

```

//Indexes
int stores = ...; range S = 1..stores;
int warehouses = ...; range W = 1..warehouses;
int Fix[W] = ...;
int Supplycost[S][W] =...;
float P1[S] =...;
float P2[S] =...;
float P3[S] =...;
float P4[S] =...;
float P5[S] =...;
float P6[S] =...;
float P7[S] =...;
float P8[S] =...;
float P9[S] =...;
float P10[S]=...;
float X[W] = ...;

//Decisions variables
dvar boolean Open[W]; //1 if warehouse is opened, otherwise 0
dvar boolean Demand[S][W]; // 1 if market is assigned to warehouse otherwise 0

//Objective function

```

```

minimize
sum(w in W)Open[w] * Fix[w] * X[w] + sum(w in W, s in S)Supplycost[s][w] * De-
mand[s][w] * P1[s]+
sum(w in W)Open[w] * Fix[w] * X[w] + sum(w in W, s in S)Supplycost[s][w] * De-
mand[s][w] * P2[s]+
sum(w in W)Open[w] * Fix[w] * X[w] + sum(w in W, s in S)Supplycost[s][w] * De-
mand[s][w] * P3[s]+
sum(w in W)Open[w] * Fix[w] * X[w] + sum(w in W, s in S)Supplycost[s][w] * De-
mand[s][w] * P4[s]+
sum(w in W)Open[w] * Fix[w] * X[w] + sum(w in W, s in S)Supplycost[s][w] * De-
mand[s][w] * P5[s]+
sum(w in W)Open[w] * Fix[w] * X[w] + sum(w in W, s in S)Supplycost[s][w] * De-
mand[s][w] * P6[s]+
sum(w in W)Open[w] * Fix[w] * X[w] + sum(w in W, s in S)Supplycost[s][w] * De-
mand[s][w] * P7[s]+
sum(w in W)Open[w] * Fix[w] * X[w] + sum(w in W, s in S)Supplycost[s][w] * De-
mand[s][w] * P8[s]+
sum(w in W)Open[w] * Fix[w] * X[w] + sum(w in W, s in S)Supplycost[s][w] * De-
mand[s][w] * P9[s]+
sum(w in W)Open[w] * Fix[w] * X[w] + sum(w in W, s in S)Supplycost[s][w] * De-
mand[s][w] * P10[s] ;
subject to {
forall (s in S)
    sum (w in W) Demand[s][w] == 1; //Each market is connected to one Warehouse:

forall (w in W, s in S)
    Demand[s][w] <= Open[w];
//We can assign a market to a warehouse only if it is opened
}

```

CPLEX RESULT:

```

// solution (optimal) with objective 455692.5
Open = [0 0 0 1 0 0];
Demand = [
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]
    [0 0 0 1 0 0]];

```

Solving CPU Elapsed Time in (Second):3.21875

“Open” index indicates that warehouse 4 should be opened.

“Demand” index shows that all markets should be assigned to warehouse 4.

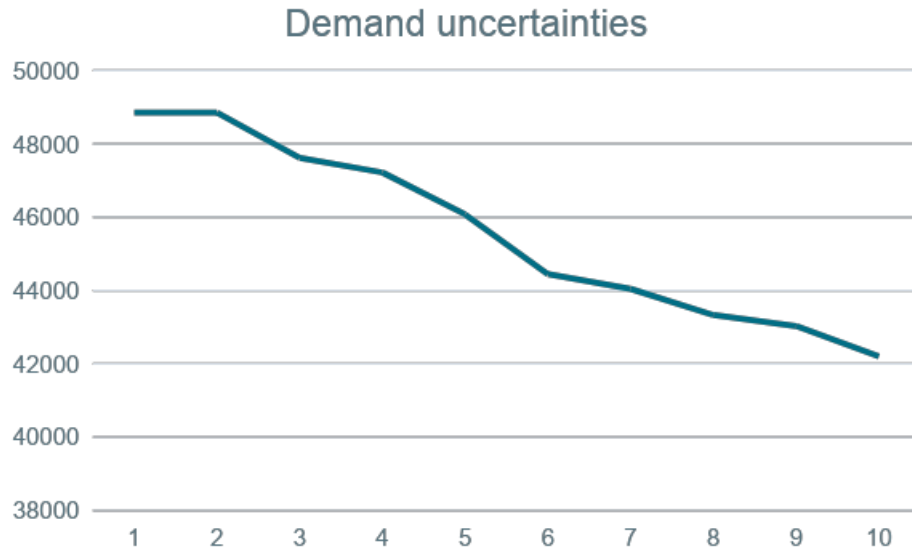


Figure 11. Total cost over ten years under demand uncertainty condition

As it is depicted in figure 11, as the probability cuts down the total cost gets lower as well. Based on CPLEX optimizer, the result is 455692 for ten years, which is an average cost of 45692 per year.

6. 4. STOCHASTIC DEMAND

Now we solve the case based on random numbers with fixed probability rate of 0.2: The mathematical model will be as below:

Min Z=

$$\sum_{j=1}^J F_j * Y_j + \sum_{r=1}^R \sum_{g=1}^G \sum_{j=1}^J \sum_{i=1}^I \sum_{k=1}^K D_{gjikr} * Y'_{ji} * P/10$$

F_j Fixed cost of cold storage warehouse j.

Y_j Binary variable if the warehouse is open 1 otherwise 0.

D_{gjikr} The cost of transferring product k from garden g to market i from warehouse j in 10 different scenarios.

P Probability of the demand here equals to 0.2.

R 10 times different random demand tables.

Y_{ij} Binary variable if market i is assigned to warehouse j.

For solving these case 10 different tables are generated through website of random.org² and imported them to the CPLEX environment.

CPLEX.dat

```
stores = 140;        //Markets for different fruits
warehouses = 6;
Fix= [26700, 24475, 24475, 22250, 20025, 17800];
P = 0.2;
Supplycost = [        //Ten times different random demand

//1                    //3                    //5                    //7                    //9
[4339 4871 1872 2073 724 3436], [2189 2095 2164 1254 2063 4460], [3498 3526 1605 2948 4360 1742], [4530 4246 4130 802 2064 3040], [4870 3538 2101 3499 4542 3756],
[563 4303 4210 2268 4503 4090], [1220 799 2532 4051 2996 1232], [2840 4588 1096 1547 2086 654], [974 3588 5036 1012 4175 2490], [4697 3774 2151 1736 1471 4580],
[1405 2198 3120 2543 546 4322], [4520 4491 1806 3385 4441 3215], [2256 2737 2941 879 536 2245], [4606 1190 2577 2651 3768 1079], [3014 4707 3618 2604 1507 1521],
[2323 3256 3884 3479 5009 2924], [810 939 2785 4421 3396 3834], [3939 4625 3539 3524 2160 601], [3146 2473 2222 574 1420 3285], [704 690 4459 1249 2934 795],
[3361 2120 4690 2807 1779 3110], [1262 1680 1013 2525 4691 3003], [1875 2510 3686 2769 3915 3018], [713 3128 3407 865 641 2785], [4887 1502 4773 1174 955 4594],
[3535 3549 2158 3639 1720 1751], [2431 2634 2552 2200 578 2154], [2057 1987 2691 817 875 1837], [5038 1091 2688 1632 1247 779], [2183 2274 3419 1282 2064 2747],
[3981 4735 3854 1200 621 1093], [4604 669 3699 4893 1104 957], [4406 5033 4581 1308 2013 3242], [4576 578 3972 2959 815 945], [2782 4132 4729 4429 1677 4320],
[672 2947 2918 2853 4507 3697], [3685 1030 4082 4461 4684 3982], [4406 5033 4581 1308 2013 3242], [2825 4252 586 1021 1934 2206], [2101 840 3379 2998 1034 1176],
[1400 3225 1156 2303 1696 3830], [2676 1568 1528 3622 4533 4076], [4141 1525 4948 1784 640 3529], [3776 2607 1863 4834 3609 1368], [2257 3293 4026 3843 3750 1885],
[3219 1331 1930 2427 1462 2591], [4473 983 4975 3005 3542 1768], [3930 636 3080 1790 1534 1790], [4574 2763 3656 2495 3652 3519], [4339 979 4832 3762 4299 2825],
[1972 2614 1859 3141 4640 3014], [725 3074 4514 2069 2037 2345], [809 537 3509 2866 4687 3263], [2957 670 2510 2430 2548 4752], [4278 3007 2622 1599 4648 2754],
[3559 3656 2030 2181 3450 4337], [2844 2450 3959 3718 3955 669], [2395 3871 4777 1938 4559 4867], [3070 1029 2521 3233 4247 2563], [983 4681 2431 4916 3398 1189],
[3233 3759 2478 3692 4150 1956], [1438 679 1795 2251 2629 2185], [3471 2667 3786 1383 1951 5009], [801 1049 3458 4729 4059 2811], [1293 2825 2356 2619 3040 2353],
[1526 3197 1686 4844 2730 4885], [3560 580 3808 1225 3930 4591], [2833 3546 1228 1932 1801 4184], [3259 931 2754 1274 2923 3536], [4071 3146 4637 4656 1573 2060],

//2                    //4                    //6                    //8                    //10
[814 1810 3736 769 2519 2448], [3031 2093 665 4509 4635 4915], [716 4915 2155 3251 4088 3190], [1896 4824 1448 3176 4848 3516], [2732 1605 4928 1622 2737 3613],
[701 2431 2185 2873 2705 2913], [4452 668 1925 2337 840 4350], [1961 2272 3328 1788 5002 586], [699 3019 4450 3569 1648 1047], [2484 3382 1948 4187 2247 3787],
[4316 912 1523 998 2549 4130], [1335 1227 4041 2511 4145 2199], [4976 618 688 3585 4866 2436], [1036 2380 4035 3815 1382 1364], [3514 3573 600 4288 1035 3314],
[554 1018 718 2473 1191 1546], [808 3314 1581 1910 1268 4795], [2764 2437 3380 3987 4495 5010], [812 2026 1003 4461 3247 2376], [2065 777 2176 2352 4048 4796],
[3611 2120 4690 2807 1779 3110], [2050 2173 3773 4632 3020 688], [1866 3332 609 2137 3505 4928], [3610 4074 1859 3743 1691 2996], [4432 1459 3618 4454 3859 2987],
[1038 2725 4425 2418 2245 2871], [2676 1274 1145 1269 4381 1446], [4957 3701 3026 2449 2380 4220], [4924 3018 2969 3407 884 1648], [2017 1157 1020 2856 563 2869],
[1191 3584 4415 762 1108 2295], [4910 1982 2490 4695 1254 3911], [690 4292 3858 1249 3995 4837], [2652 3112 2460 4195 1851 4358], [5023 3017 1751 4782 4273 4697],
[4428 2125 4665 1579 3090 2625], [1853 2923 4419 740 5034 3243], [3245 1201 4962 4013 4888 2323], [2449 1560 2897 1910 1224 1462], [3716 574 3989 3139 4280 1447],
[4336 3462 2354 2443 4507 4157], [2781 2874 1838 573 1290 2764], [2613 3206 1226 4254 3988 1999], [1613 1397 1370 3095 2932 3029], [3892 4757 4443 2450 1544 2933],
[3340 2485 4752 2409 4361 3625], [2087 1319 3009 3528 3195 3584], [4716 3604 1585 3445 2420 836], [4399 2804 1428 2399 2872 2200], [2767 927 4485 2599 3895 1152],
[629 4030 4653 4000 765 1279], [522 3538 930 1368 2062 4392], [1950 4121 2216 1323 3109 748], [2118 4882 3402 1316 4704 1001], [1733 2791 3259 3098 4882 1322],
[3852 4794 1684 3566 2853 4748], [4606 4494 1291 980 4173 2580], [1169 1387 2809 4853 3700 4766], [2976 759 4505 1893 708 4381], [3646 3607 1864 4866 2228 2199],
[1204 4425 4709 1651 3453 1041], [3672 3761 5013 3780 2872 4707], [4395 1876 4796 2277 1846 1345], [3742 3150 4181 1683 3000 3318], [861 2500 1892 2697 4133 4934],
[575 2558 685 3444 754 3501],
```

CPLEX.mod

```
//Indexes
int stores= ...; range S=1..stores;
int warehouses= ...; range W=1..warehouses;
int Fix[W]= ...;
int Supplycost[S][W]=...;
float P=...;
//Decisions variables
dvar boolean Open[W];        //1 if warehouse is opened, otherwise 0
dvar boolean Demand[S][W]; // 1 if store is assigned to warehouse otherwise 0

//Objective function
minimize
sum(w in W)Open[w] * Fix[w] + sum(w in W, s in S)Supplycost[s][w] * Demand[s][w] * P
/ 10 ;
```

² <https://www.random.org/integers/?num=84&min=520&max=5040&col=6&base=10&format=html&rnd=new>

```
subject to {
forall (s in S)
    sum(w in W) Demand[s][w] == 1; //Each market is connected to one Warehouse:

forall (w in W, s in S)
    Demand[s][w] <= Open[w]; //We can assign a market to a warehouse only if it is
opened
}
```

CPLEX RESULT:

```
// solution (optimal) with objective 25920.26
```

```
Open = [0 0 0 0 0 1];
```

Demand = [

[illegible]

Solving CPU Elapsed Time in (Second):3.4375

“Open” index indicates that warehouse 6 should be opened.

“Demand” index shows that all markets under all the possibilities and random tables should be assigned to warehouse 6 and consequently all the gardens.

As we have 14 markets and we considered 10 different scenarios for them therefore the result has 140 possibilities and in all of them warehouse 6 is selected with total cost of 25920 and all the markets should be assigned to warehouse 6 over all 10 different scenarios.

Up to now we have seen: 1. The result of determined data, 2. Determined data by considering the probability of markets demands over ten years, 3. Result based on random number.

Now in order to compare the determined data with the stochastic one we calculated the average of probability of markets demands over ten years and multiplying that to “determine” table and “random” table.

	Market/ Warehouse	1	2	3	4	5	6	7	8	9	10	Average
Cherry	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Shiraz	100%	100%	100%	100%	100%	50%	50%	50%	50%	50%	75%
	Mashhad	100%	100%	100%	70%	70%	60%	60%	60%	50%	50%	72%
Apricot	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Hamedan	100%	100%	100%	100%	100%	100%	70%	70%	70%	70%	88%
Nectarine	Sari	100%	100%	80%	80%	70%	70%	60%	60%	50%	50%	72%
	Rasht	100%	100%	80%	80%	70%	70%	60%	60%	50%	50%	72%
Apple	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
Pear	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Mashhad	100%	100%	80%	80%	70%	60%	60%	50%	50%	40%	69%
Pomegranate	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Tabriz	100%	100%	100%	100%	100%	90%	90%	90%	90%	80%	94%
Kiwi	Tehran	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%
	Urmia	100%	100%	100%	100%	80%	80%	80%	70%	70%	70%	85%

Table 30. Average of demand probabilities over ten years

	Market/ Warehouse	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Cherry	Tehran	540	540	520	680	1420	1200
	Shiraz	1305	1245	1245	1335	1695	1650
	Mashhad	1275	1260	1245	1335	1770	1530
Apricot	Tehran	650	625	725	900	1825	1525
	Hamedan	765	825	780	780	1020	1155
Nectarine	Sari	1060	1040	1020	1040	1740	1240
	Rasht	840	780	720	645	930	825
Apple	Tehran	2450	2450	2800	3290	5040	4970
Pear	Tehran	1800	1800	1750	1750	3150	3300
	Mashhad	4700	4650	4600	4500	5500	5400
Pomegranate	Tehran	3320	3360	3560	3760	4640	4520
	Tabriz	3810	3750	3810	3780	3450	4110
Kiwi	Tehran	2300	1950	2000	2400	4150	2350
	Urmia	2910	2610	2580	2640	2730	2340

Table 31. Determined demand before applying average probability rate

	Market/ Warehouse	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Cherry	Tehran	4339	4871	1872	2073	724	3436
	Shiraz	563	4303	4210	2268	4503	4090
	Mashhad	1405	2198	3120	2543	546	4322
Apricot	Tehran	2323	3256	3884	3479	5009	2924
	Hamedan	3361	2120	4690	2807	1779	3110
Nectarine	Sari	3535	3549	2158	3639	1720	1751
	Rasht	3981	4735	3854	1200	621	1093
Apple	Tehran	672	2947	2918	2853	4597	3697
Pear	Tehran	1480	3225	1156	2303	1696	3830
	Mashhad	3219	1331	1930	2427	1462	2591
Pomegranate	Tehran	1972	2614	1859	3141	4640	3014
	Tabriz	3559	3656	2030	2101	3450	4337
Kiwi	Tehran	3233	3759	2478	3692	4150	1956
	Urmia	1526	3197	1686	4844	2730	4885

Table 32. Stochastic demand before applying average probability rate

After multiplying the average demand probabilities over ten years (table 28) to “determine demand” (table 29) we gain table 31. Table 32 is the result of multiplying the average demand probabilities over ten years (table 29) to “random demand” (table 30).

	Market/ Warehouse	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Cherry	Tehran	540	540	520	680	1420	1200
	Shiraz	979	934	934	1001	1271	1238
	Mashhad	918	907	896	961	1274	1102
Apricot	Tehran	650	625	725	900	1825	1525
	Hamedan	673	726	686	686	898	1016
Nectarine	Sari	763	749	734	749	1253	893
	Rasht	605	562	518	464	670	594
Apple	Tehran	2450	2450	2800	3290	5040	4970
Pear	Tehran	1800	1800	1750	1750	3150	3300
	Mashhad	3243	3209	3174	3105	3795	3726
Pomegranate	Tehran	3320	3360	3560	3760	4640	4520
	Tabriz	3581	3525	3581	3553	3243	3863
Kiwi	Tehran	2300	1950	2000	2400	4150	2350
	Urmia	2474	2219	2193	2244	2321	1989

Table 33. Determined demand after applying average probability rate

	Market/ Warehouse	Tehran	Shahryar	Karaj	Qazvin	Zanjan	Tonekabon
Cherry	Tehran	4339	4871	1872	2073	724	3436
	Shiraz	422	3227	3158	1701	3377	3068
	Mashhad	1012	1583	2246	1831	393	3112
Apricot	Tehran	2323	3256	3884	3479	5009	2924
	Hamedan	2958	1866	4127	2470	1566	2737
Nectarine	Sari	2545	2555	1554	2620	1238	1261
	Rasht	2866	3409	2775	864	447	787
Apple	Tehran	672	2947	2918	2853	4597	3697
Pear	Tehran	1480	3225	1156	2303	1696	3830
	Mashhad	2221	918	1332	1675	1009	1788
Pomegranate	Tehran	1972	2614	1859	3141	4640	3014
	Tabriz	3345	3437	1908	1975	3243	4077
Kiwi	Tehran	3233	3759	2478	3692	4150	1956
	Urmia	1297	2717	1433	4117	2321	4152

Table 34. Random demand after applying average probability rate

We use CPLEX to solve these two conditions, determined data and random data to compare their outcomes.

Under determine situation CPLEX solution is as below:

.dat Part

```

stores = 14;      //Markets for different fruits
warehouses = 6;
Fix= [26700, 24475, 24475, 22250, 20025, 17800];
P= [1, .75, .72, 1, .88, .72, .72, 1, 1, .69, 1, .94, 1, .85];
SupplycostDetemined = [
[540, 540, 520, 680, 1420, 1200],
[1305, 1245, 1245, 1335, 1695, 1650],
[1275, 1260, 1245, 1335, 1770, 1530],
[650, 625, 725, 900, 1825, 1525],
[765, 825, 780, 780, 1020, 1155],
[1060, 1040, 1020, 1040, 1740, 1240],
[840, 780, 720, 645, 930, 825],
[2450, 2450, 2800, 3290, 5040, 4970],
[1800, 1800, 1750, 1750, 3150, 3300],
[4700, 4650, 4600, 4500, 5500, 5400],
[3320, 3360, 3560, 3760, 4640, 4520],
[3810, 3750, 3810, 3780, 3450, 4110],
[2300, 1950, 2000, 2400, 4150, 2350],
[2910, 2610, 2580, 2640, 2730, 2340],
];

```

.mode Part

```

//Indexes
int stores= ...; range S=1..stores;
int warehouses= ...; range W=1..warehouses;
int Fix[W]= ...;
int SupplycostDetemined[S][W]=...;

```

```
float P[S]=...;

//Decisions variables

dvar boolean Open[W];           //1 if warehouse is opened, otherwise 0

dvar boolean Demand[S][W]; // 1 if store is assigned to warehouse otherwise 0

//Objective function
minimize
    sum(w in W)Open[w]*Fix[w] + sum(w in W, s in S)SupplycostDetemined[s][w]* De-
mand[s][w]*P[s];

//constraints
subject to {
    forall (s in S)
        sum(w in W) Demand[s][w]==1; //Each market is connected to one Warehouse:

        forall (w in W, s in S)
            Demand[s][w]<=Open[w]; //We can assign a market to a warehouse only if it is
opened
}
```

CPLEX RESULT:

[illegible]

Solving CPU Elapsed Time in (Second):3.453125

“Open” index indicates that warehouse 4 should be opened.

“Demand” index shows that all markets under all the possibilities and random tables should be assigned to warehouse 4 and consequently all the gardens.

Based on CPLEX the result of determined data after applying the average probability is 47794 and warehouse 4 is the optimal warehouse to open. Now we go through random number that has the same probability.

Under random situation CPLEX solution is as below:

.dat Part

```
stores = 14;      //Markets for different fruits
warehouses = 6;
Fix= [26700, 24475, 24475, 22250, 20025, 17800];
P=    [1, .75, .72, 1, .88, .72, .72, 1, 1, .69, 1, .94, 1, .85];
```

```
SupplycostRandom = [
[4339 4871 1872 2073 724 3436],
[563 4303 4210 2268 4503 4090],
[1405 2198 3120 2543 546 4322],
[2323 3256 3884 3479 5009 2924],
[3361 2120 4690 2807 1779 3110],
[3535 3549 2158 3639 1720 1751],
[3981 4735 3854 1200 621 1093],
[672 2947 2918 2853 4597 3697],
[1480 3225 1156 2303 1696 3830],
[3219 1331 1930 2427 1462 2591],
[1972 2614 1859 3141 4640 3014],
[3559 3656 2030 2101 3450 4337],
[3233 3759 2478 3692 4150 1956],
[1526 3197 1686 4844 2730 4885],
];
```

.mod Part

```
//Indexes
int stores= ...; range S=1..stores;
int warehouses= ...; range W=1..warehouses;
int Fix[W]= ...;
int SupplycostRandom[S][W]=...;

float P[S]=...;

//Decisions variables

dvar boolean Open[W];      //1 if warehouse is opened, otherwise 0

dvar boolean Demand[S][W]; // 1 if store is assigned to warehouse otherwise 0

//Objective function
minimize
    sum(w in W)Open[w]*Fix[w] + sum(w in W, s in S)SupplycostRandom[s][w]* De-
mand[s][w]*P[s];
```

```

//constraints
subject to {
forall (s in S)
    sum(w in W) Demand[s][w]==1; //Each market is connected to one Warehouse:

    forall (w in W, s in S)
        Demand[s][w]<=Open[w]; //We can assign a market to a warehouse only if it is
opened
}

```

CPLEX RESULT:

Answer

Total cost:54434.69

Open = [0 0 0 0 1 0];

Demand = [

[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]
[0 0 0 0 1 0]

];

Solving CPU Elapsed Time in (Second):3.21875

“Open” index indicates that warehouse 5 should be opened.

“Demand” index shows that all markets under all the possibilities and random tables should be assigned to warehouse 5 and consequently all the gardens.

Based on random number the selected warehouse is warehouse 5 with total cost of 54435.

7. CONCLUSION

To sum it up, the goal of this thesis was helping Pahnesar Company to choose an optimal warehouse with the possible lowest total cost. We have seen that under standard situation, based on initial given data, warehouse 4 was selected with total cost of 50515, the results of ADD/DROP and CPLEX were the same. Then we went through different scenarios by changing the parameters:

The first scenario was changing the capacity; if for next year the selected warehouse been taken and not available the second option is warehouse 2 with total cost of 50940. In addition, if warehouse 2 not be available the third optimal warehouse would be warehouse 3 with total cost of 51380 and so on. Below there is table of priority of selecting the warehouses.

Warehouse	4	2	3	6	1	5
Total Cost	50515	50940	51380	53305	54065	58295

Table 35. Priority of selecting the warehouses

As it is shown in table 33, by getting far away from our first option, warehouse 4, total costs are growing up. Other scenario, which is related to the capacity issue, happens when the supply amount increases. In that case the order of selecting a warehouse is the same as table 33. The only difference is that by increasing the supply amount the transportation cost will go up. For example, if by having 100 times more supplied fruit the selected warehouse will be warehouse 2 but instead of 50940 the total cost will be 2115690.

Second scenario was reducing the fixed cost. In this scenario the company buys the warehouse or warehouses instead of renting them for longer period of time, therefore the periodical fixed cost would be less. Under this condition it makes sense to open more than one warehouse. Therefore we changed the case to a multi-echelon and as we have multi warehouses we have assigned markets to the gardens which are close to them thus the case is a multi-echelon, multi-commodity case.

The results of ADD/DROP and CPLEX were the same to open warehouse 2 and 4 together with total cost of 27425; which is almost half of the total cost under standard situation (50515).

Third scenario was about demand probability. In this scenario the company wanted to know if they rent a warehouse for a long time horizon how much the total cost decreases. The owner of warehouses offered a better deal for renting a warehouse for ten years but on the other hand demand of the coming ten years could not be as clear as today, therefore the company provided the table of probability over ten years for 14 markets. By solving the problem through CPLEX the result was again opening warehouse 4 with total cost of 45569.

Last scenario is about random demand. In this scenario, we used complete random number with fixed probability rate of 0.2 and we have seen that selected warehouse was warehouse 6; with total cost of 25920 but this result could be meaningful if it be comparable to the determined demand. Therefore, we took average probability of ten years demand, table 28, and use that for both determined demand and random demand and the result through CPLEX for determined demand was opening warehouse 4 with total cost 47794 and for random numbers, opening warehouse 5 with total cost of 54434. In table 34 there is a summary of all scenarios:

Scenario	Standard	Capacity issue	Fixed cost reduction	Demand uncertainty	Avg. probability on determined demand	Avg. probability on random demand
Warehouse	4	2	2 and 4	4	4	5
Total cost	50515	50940	27425	45569	47794	54435

Table 36. Summary of different scenarios

The result was interesting for company, because for so many years they have rented warehouse 1; but as we have seen in none of the scenarios warehouse 1 was selected. Based on the outcomes, they considered warehouse 4 as the optimal warehouse.

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