*J. Appl. Environ. Biol. Sci.*, 6(3S)286-296, 2016

ISSN: 2090-4274
Journal of Applied Environmental and Biological Sciences
*www.textroad.com*

# The Design of a Supply Chain with Efficient Manufacturers

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*Received: January2, 2016*
*Accepted: February 29, 2016*

## ABSTRACT

This paper presents a model for supply chain design, considering the efficiency of producers. The proposed model has several products and raw materials, and includes four layers of suppliers, manufacturers, distributors and customers. The objectives of the suggested model are increasing production efficiency and decreasing the total cost of the supply chain. The suggested model deals with allocation of producer and warehouses and plans the amount of purchases from each supplier. In this study, we used data envelop analysis (DEA) to calculate the efficiency of the manufacturers. The result of the numerical example, shows that adding the efficiency parameter to the supply chain model will improve it, also by considering a low coefficient for efficiency parameter the amount of costs are kept fixed and do not increase. Therefore, the design of an efficient supply chain is preferred to a simple supply chain.
**KEYWORDS**: Design of a supply chain, efficiency, DEA.

## 1. INTRODUCTION

The supply chain includes all the sections which are directly or indirectly in communication with each other for supplying the customers' needs. These sections can include producers, suppliers, transport suppliers, warehouses, retail shops and customers. These sections include activities such as new product development, marketing, executive operations, distribution, financial services, customer services, etc. [1]. Acting in a chain has improved the competitive advantages of the organizations in order to have a higher opportunity to survive and succeed in the markets.

In recent years, the supply chain management has been significantly paid attention to by the researchers and scholars. In [2]a perfect review of the articles related to locating problem in supply chain has been collected. Also in [3] an abstract of the modeling methods of the robust supply chain management has been collected. In this paper, the quantitative models for the forwarded supply chain have been investigated. The different researches done in regard of risk management of supply chain have been collected in [4].

A supply chain may include different layers. Some of them are as following: 1. the customers or the final consumers, 2. retailers or intermediates, 3. warehouse owners, distributers and wholesalers,4. manufacturers, 5. raw material suppliers. Researchers have supposed different layers for their supply chains. For example, the article of[5] has designed a multi-period, n layers and single product supply chain which plans the producing amounts and the raw material amounts of each factory in each stage of each period. Melo et al.,[6] have designed the multi-period and multi-products supply chain which includes 4 layers of supplier, manufacturer, distributer and customers. In this chain, the supplier, manufacturer and distributer are located. The same article [6] has also designed the multi-layers supply chain of the product's family. Another multi-period supply chain has been designed in [7] which include 3 layers of level 1 and 2 manufacturers and the customer which locates the level 1 and 2 manufacturers. Also their model has considered a warehouse for each manufacturer level for each product family which selects whether it locates in location *i* or not. This model includes several product families and several sub-products for each product family. A nonlinear integer programming model has been introduced in [8] to design the supply chain of (single product, single raw material, and single period) 4 layers of supplier, manufacturer, distributer and customer. They have located the producer and distributer considering the assumption of customer's satisfaction. In solving genetic algorithm, they have benefited from 3 target functions of minimizing the total cost of supply chain, maximizing the services for customers and balancing the utilization capacity which were introduced in design of their chain. They added the programming of buying amount from each supplier to their previous model following their studies in [9]. Paper [10] has promoted the supply chain presented by [9] so that they have supposed several products and several raw materials in this model. In addition, research [11] has been designed a comprehensive model of supply chain using the above models. In this study, we have used this model as the basic model. Continually, their model will be explained in details.

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Several studies have been done considering the assumption of the conditions of uncertainty for developing the supply chain design. In order to implement the uncertainty conditions, the researchers have used different methods. For example [12, 13]have benefited from the robust optimization method; the articles of [14, 15] have used the fuzzy approach.

Cardoso et al[16] have designed a 4 layer supply chain including manufacturer, wholesaler, retailer, and stores with the return relationships in which the customers can directly return the product to the producer, wholesaler and retailer. In mentioned study, it has been supposed that the forwarded relationships are in the way that the manufacturer, wholesaler and retailer can directly sell products to the customer. The target function of this article is maximization of the current pure value. Also it deals with the programming of size and locating the manufacturer, wholesaler and retailer. This model is multi-courses and the uncertainty of demands has been implemented on it based on the scripting.

A 3 layer supply chain has been designed in paper [12], including several suppliers, several manufacturers and customers. This chain has assumptions such as leveling of employees, hiring and dismissal of staff in each period, multiple raw materials, labor productivity, sub-contracts, overtime, storage capacity, and minimum time of delivering products the above model has been formulated in multi-period and multi-products form with the uncertain demands and the supplier sale price; and the stable optimization has been used in order to implement the uncertainty. This model has two target functions, the first one is minimizing the total costs (costs of producing, hiring, dismissing and training, and also costs of raw material and the final product and keeping the inventory, transportation and shortages) and the second one is considering the customer's satisfaction through minimizing the maximum shortage among the customers' areas in all periods. The multi-target function model has been solved through LP metric method.

The article of [17] has designed the supply chain in uncertainty conditions through robust optimization. In this chain, demands, resources, transports, shortages and the costs of development of the assumption capacity of the suppliers and development of the unreliable capacity have been introduces as the uncertain parameters. This model have several target functions, minimum of the total current and future costs of process investment, transportation, shortage and the capacity of development costs, minimum variance of the total costs and minimum financial risk and budget shortage and it has been solved through the method of achieving the goals.

In the article of [18], a two layer supply chain and the stores has been designed which has the assumption of product return and facilities for reconstruction. In this single period and single product model, the manufacturer and the facilities are located and the uncertain conditions of demands and the return amount are solved and implemented through robust optimization.

Researches like the articles of [19, 20, 21] have focused on the integration of supply chain and efficiency, but in all of these articles, the efficiency has been used in order to evaluate the supply chain. But, no significant research has been done in the field of designing an efficient supply chain. There have been done many studies such as [22, 23] in regard of locating facilities with the assumption of maximizing their efficiency and this indicates the necessity of considering the facilities' efficiency and its influence on the process of solving and the results of these issues.

The first model for efficiency has been suggested by Farrell[24]. He described the approach of equivalent cover for measuring the efficiency of agriculture productivity in the United States. Charnes et al.[25]formulated the approach of [24] and expanded the relationship to several outputs and inputs. He also provided a method in order to find the cover using the fractional linear program. After that, he turned the fractional program into the linear program and then the approach of data envelopment analysis was suggested for the first time. In this model, the efficiency amount of each unit has been expressed from dividing the sum of weighted outputs of unit into the sum of the same unit's inputs and this value must be lesser than one for all of units. Paper [22] has used the multiple input-based CCR model in the article of [25]and has introduced the two models of MDEA and SDEA. In the above article, the suggested models have been integrated with the allocation locating issue model.

In this research, the design model of the supply chain network and the data envelopment analysis model are integrated with each other in order to design a supply chain with efficient manufacturers. This supply chain tries to select the most appropriate location for manufacturers, distributers and in this way reduce the total costs of the supply chain and increase the manufacturers' efficiency.

## 2. MATERIALS AND METHODS

The methodology has been given in the second part or the text which includes introducing the basic model of supply chain, a summary of the efficiency concept and DEA and ultimately the suggested supply chain model. The numeric example and the result have been given in the third and fourth part and also the fifth part has been allocated to the discussion and conclusion.

### 2.1. Supply Chain Design

One of the most important strategic decisions made in the same basic steps of forming the chain is to design the supply chain network which determines that how the organizations to be integrated with each other in a network frame. The supply chain design determines that this structure have a significant influence on the efficiency, flexibility, costs and the competitiveness of the company [26].

**Model's parameters**

| | |
|---|---|
| I | Set of customers |
| J | Set of distribution centers (warehouses) |
| K | Set of plants |
| L | Set of products |
| R | Set of Raw materials |
| V | Set of suppliers |
| N | set of output indexes |
| H | set of input indexes |
| $c_j^{'}$ | The annual fixed cost for establishing warehouse j |
| $c_k^{''}$ | The annual fixed cost for establishing plant k |
| $v_{jl}^{'}$ | The cost of maintenance of the unit of product l in warehouse |
| $v_{lk}$ | The cost of manufacturing of the per unit of product l in plant k |
| $t_{vkr}$ | The cost of purchasing and transportation of the per unit of the raw material r from supplier v to plant k |
| $t_{ijkl}^{'}$ | The cost of transporting per unit of product l from plant k to warehouse j and from warehouse j to the customer i |
| $a_{il}$ | Demands for product l at customer i |
| $w_j$ | Distributor (warehouse) j throughout (for ins. Capacity of storing space, ...) |
| $D_k$ | Production capacity of plant k (for ins. Budget, equipment, human resource, …) |
| $S_{vr}$ | Capacity of supplier v for raw material r |
| $u_{rl}^{'}$ | Use rate of the raw material r in per unit of product l |
| $u_l$ | Use rate of per unit of product l at production capacity of the plant |
| $u_l^{''}$ | Use rate of per unit of product l at distributors throughput |
| W | The maximum number allowed for the establishment of warehouses |
| P | The maximum number allowed for the establishment of plants |
| $O_{kn}$ | amount of n'th output of plant k |
| $I_{kh}$ | amount of h'th input of plant k |

**Decision variables:**

| | |
|---|---|
| $z_j$ | **1**; if the warehouse establishes in **j**, otherwise; **0** |
| $p_k$ | **1**; if the plant establishes in **k**, otherwise; **0** |
| $y_{ij}$ | **1**; if warehouse **j** responds the demands of customer **i**, otherwise; **0** |
| $q_{vkr}$ | The amount of raw material **r** transported from supplier **v** to plant **k** |
| $q_{ijkl}^{'}$ | The amount of product **l** sent from plant **k** by warehouse **j** to customer **i** |
| $1 - d_k$ | Numerator of efficiency fraction, in other words the weighted sum of outputs of plant k |
| $f_{kh}$ | Coefficient of input h at plant k |
| $g_{kn}$ | Coefficient of output n at plant k |

### 2.2. The Basic Model of Supply Chain

In this article we have used the suggested model of [11] as the basic model of design. In the model, it has been supposed that the supply chain includes 4 layers of supplier, manufacturer, warehouse (distributer or wholesaler) and customer. The aim of this chain is to locate the manufacturers and distributers. Also this chain determines the sale amount from each supplier. This supply chain is single-period and plans the producing and sale cycle of several products and the amount of raw material needed for each product to be manufactured. The chain is forwarding and there is no return, reconstruction or waste possibility of the products. The parameters of the issue exist and the model has been designed for certain conditions and perfect trust. The facilities are limited and have determined maximum value. Each of the facilities has a fixed annual cost and a variable cost of the product unit.

$$\min z = \sum_j c_j^{'} z_j + \sum_i \sum_j \sum_l v_{jl}^{'} a_{il} y_{ij} + \sum_k c_k^{''} p_k + \sum_i \sum_j \sum_l \sum_k v_{lk}\, q_{ijkl}^{'} + \sum_v \sum_k \sum_r t_{vkr} q_{vkr} + \sum_i \sum_l \sum_k \sum_j t_{ijkl}^{'} q_{ijkl}^{'} \qquad (1)$$

St:

$$\sum_j y_{ij} = 1 \qquad \forall i \qquad (2)$$

$$\sum_i \sum_l u_l^{''} a_{il} y_{ij} \le w_j z_j \qquad \forall j \qquad (3)$$

$$\sum_j z_j \le W \qquad (4)$$

$$\sum_k q_{vkr} \le S_{vr} \qquad \forall v, r \qquad (5)$$

$$\sum_i \sum_j \sum_l u_{rl}^{'} q_{ijkl}^{'} \le \sum_v q_{vkr} \qquad \forall k, r \qquad (6)$$

$$\sum_i \sum_j \sum_l u_l^{''} q_{ijkl}^{'} \le D_k p_k \qquad \forall k \qquad (7)$$

$$\sum_k q_{ijkl}^{'} = a_{il} y_{ij} \qquad \forall i, j, l \qquad (8)$$

$$\sum_k p_k \le P \qquad (9)$$

$$z_j = \{0,1\} \qquad \forall j \qquad (10)$$

$$p_k = \{0,1\} \qquad \forall k \qquad (11)$$

$$y_{ij} = \{0,1\} \qquad \forall i, j \qquad (12)$$

$$q_{vkr} \ge 0 \qquad \forall v, k, r \qquad (13)$$

$$q_{ijkl}^{'} \ge 0 \qquad \forall i, j, k, l \qquad (14)$$

The equation (1) indicates the target function of minimizing the total costs of the supply chain. The equation (2) indicates limitation of allocation of a distributer to a customer. The equation (3) indicates limitation of the distributer's capacity. The equation (4) indicates maximum number of the established distributers. The equation (5) indicates the limitation of producing capacity of the raw material supplier. The equation (6) indicates the fact that the raw material sent by the supplier to each factory must be more than the manufacturer's need; and the manufacturer's need for each raw material equals to the amount of the produced product in that factory in the consuming rate of the raw material in each product. The equation (7) indicates the capacity of each producer. The equation (8) indicates each product's amount which is sent from all the factories to the distributer and then to the customer must be tailored to the customer's demand and his need must be met by the same distributer. The equation (9) indicates the limitation of the maximum number of the established manufacturers. The equations (10) to (12) indicate whether the decision making variables are zero or one. Also the equations (13) and (14) indicate the non-negativity of $q_{vkr}$ and $q'_{ijkl}$ decision making variables.

**2.3 Efficiency**

Efficiency indicates how an organization uses the best performance at some point of time [27]. Data Envelopment analysis (DEA) is a nonparametric approach to measure the relative efficiency which provides a general criterion among the comparable units. That is a function of inputs and outputs of decision making units. One of the advantages of DEA is that these inputs and outputs remain in their physical units without reducing them or changing them to another scale [22].

The SDEA model is the integrated simultaneous model of DEA. Article [22] has integrated this model with the model of allocation locating issue. Also in this study we use SDEA model in order to calculate the efficiency. SDEA model is as following:

$$\max z = \sum_{r}(1-d_r) \tag{15}$$

$$\sum_{i=1}^{I} v_{ri} I_{ir} = 1 \qquad \forall r \tag{16}$$

$$\sum_{j=1}^{J} u_{rj} O_{jr} + d_r = 1 \qquad \forall r \tag{17}$$

$$\sum_{j=1}^{J} u_{rj} O_{jk} - \sum_{i=1}^{I} v_{ri} I_{ik} \leq 0 \qquad \forall r, \forall k, k \neq r \tag{18}$$

$$u_{rj}, v_{ri} \geq \varepsilon \qquad \forall i, j, r \tag{19}$$

$$d_r \geq 0 \qquad \forall r \tag{20}$$

Which parameters and variables are:

| | |
|---|---|
| $O_{jr}$ | amount of the output j per unit of r |
| $I_{ir}$ | amount of the input i per unit of r |
| $v_{ri}$ | weight coefficient of input i per unit of r |
| $u_{rj}$ | weight coefficient of output j per unit of r |

The equation (15) indicates the total efficiency of the units which we want to maximize it. The equation (16) indicates the limitation of balanced total of inputs of each unit which is equal to one. The equation (17) indicates that $1-d_r$ is the same balances total of outputs of each unit. The equation (18) expresses that each unit must have the minimum value of each input and output.

**2.4. The Suggested Model**

Some relationships and attachments must be created between the supply chain design model and the DEA integration model in the way that the variables of DEA integration model are attached to variables of established distributer and manufacturer. This attachment is based on the fact that a facilitator can be effective if it has input and output and the input and output indices of a facilitator can have value when it is active, that is to say that it has been established.

The equations (21) to (23) indicate the target functions. The relations of the first and second target functions represent the sum of the numerator of efficiency fraction of all units, that is to say that the sum of weighted outputs and due to the fact that the sum of weighted inputs in the limitations equals to one, the numerator of efficiency fraction indicates the same efficiency value and maximizing this value maximizes the efficiency. The first target function tries to maximize the manufacturers' efficiency. The second target function tries to minimize the total costs. In this model $f_{kh}$and $g_{kn}$indicate that how much of each input and output of each manufacturer is used in this programing. The equations (2) to (14) are also repeated in this model identically.

$$\max z_1 = \sum_{k=1}^{K}(1-d_k) \tag{21}$$

$$\min z_2 = \sum_j c'_j z_j + \sum_i\sum_j\sum_l v'_{jl}a_{il}y_{ij} + \sum_k c''_k p_k + \sum_i\sum_j\sum_l\sum_k v_{lk}\, q'_{ijkl} + \sum_v\sum_k\sum_r t_{vkr}q_{vkr} + \sum_i\sum_l\sum_k\sum_j t'_{ijkl}q'_{ijkl} \tag{22}$$

St:

$$\sum_h f_{kh}I_{kh} = p_k \qquad \forall k \tag{23}$$

$$\sum_n g_{kn}O_{kn} + d_k = p_k \qquad \forall k \tag{24}$$

$$\sum_n g_{kn}O_{tn} - \sum_h f_{kh}I_{th} \le 0 \qquad \forall k{:}\ \forall t{:}\ (k \ne t) \tag{25}$$

$$g_{kn} \ge \varepsilon p_k \qquad \forall k,n \tag{26}$$

$$f_{kh} \ge \varepsilon p_k \qquad \forall k,h \tag{27}$$

$$g_{kn} \ge 0 \qquad \forall k,n \tag{28}$$

$$f_{kh} \ge 0 \qquad \forall k,h \tag{29}$$

$$d_k \ge 0 \qquad \forall k \tag{30}$$

And Equations (1) to (14) repeated in this model to.

The equation (23) expresses that in the case of establishing a manufacturer, the sum of weighted inputs of that equals to one, otherwise it equals to zero. The equation (24) expresses that in case of establishment of the k'th manufacturer, $1-d_k$ equals to the sum of weighted output of the k'th manufacturer. The equations (25) and (30) indicate the limitation that the efficiency value of each unit must be lesser than one. The equations (26) and (27) indicate the fact that in case of the establishment of each producer, it will have a little input and output. Of course, regarded to these equations and also the equation (11) there is no need of the two limitations of (28) and (29) and they can be eliminated.

## 3. Numerical Example

It is assumed that the supply chain has the following known parameters (table 1):

**Table 1: parameters of numerical example**

| I | 10 |
|---|---|
| J | 10 |
| K | 10 |
| L | 2 |
| R | 2 |
| V | 5 |
| n | 3 |
| h | 4 |
| $c'_j$ | U[10000,30000] |
| $c''_k$ | U[10000,30000] |
| $v'_{jl}$ | U[1,10] |
| $v_{lk}$ | U[1,10] |
| $t_{vkr}$ | 1* Euclidean distance |

| | |
|---|---|
| $t'_{ijkl}$ | 1* Euclidean distance |
| $a_{il}$ | U[10,100] |
| $w_j$ | $U[0.17\sum_i\sum_l u''_l a_{il}, 0.5\sum_i\sum_l u''_l a_{il}]$ |
| $D_k$ | $U[0.17\sum_i\sum_l u_l a_{il}, 0.5\sum_i\sum_l u_l a_{il}]$ |
| $S_{vr}$ | $u[0.17\sum_i\sum_l u'_{rl} a_{il}, 0.5\sum_i\sum_l u'_{rl} a_{il}]$ |
| $u'_{rl}$ | U[2,5] |
| $u_l$ | U[2,5] |
| $u''_l$ | U[2,5] |
| **W** | 5 |
| **P** | 5 |
| $O_{kn}$ | U[40,100] |
| $I_{kh}$ | U[10,100] |

## 4. RESULTS

MATLAB software has been used to produce the above parameters and it has been assumed that these parameters are uniformly distributed in order to facilitate the producing process. Also the location of each of the facilities has been selected randomly and with the uniform distribution between [0, 1000]. The parametric method has been used in order to solve this model. The target functions values have been given in table 2 through different coefficients.

The table 2 indicates the three mutations in the target function value of costs during the changes of efficiency target function; also the small number of mutations may be due to discreteness and smallness of the problem. However the target function value of costs is a constant value between the efficiency target function between 0.1 to 0.675, but all of the variables of the issue are not similar in this period; in other words, in this period, the product *l* amount which is produced in factory *k* and is sent to the customer *i* by the warehouse *j* changes in the way that the amount of product *l* which is produced in factory *k* be constant. Also these changes have been repeated in the other periods which have similar target function.

**Table 2: results of calculation objective functions by applying various weights**

| Efficiency Coefficient | Costs Coefficient | manufacturer efficiency | total costs |
|---|---|---|---|
| 0 | 1 | 6.083 | 2721617 |
| 0.1 | 0.9 | 9.725 | 2721617 |
| 0.2 | 0.8 | 9.725 | 2721617 |
| 0.3 | 0.7 | 9.725 | 2721617 |
| 0.4 | 0.6 | 9.725 | 2721617 |
| 0.5 | 0.5 | 9.725 | 2721617 |
| 0.6 | 0.4 | 9.725 | 2721617 |
| 0.7 | 0.3 | 9.936 | 3159592 |
| 0.8 | 0.2 | 9.936 | 3159592 |
| 0.9 | 0.1 | 10 | 3569178 |
| 1 | 0 | 10 | 10756839 |

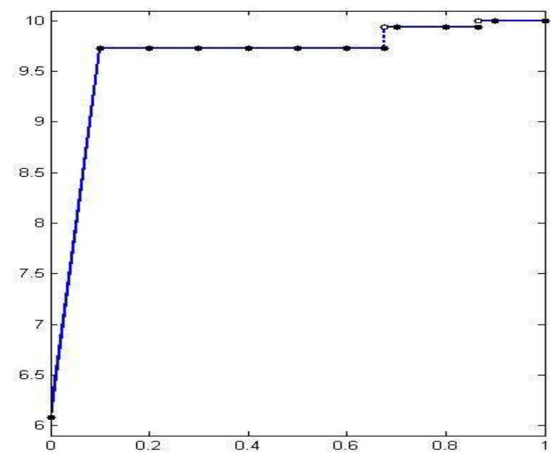


Figure 2: the changes on efficiency function by changing efficiency coefficient

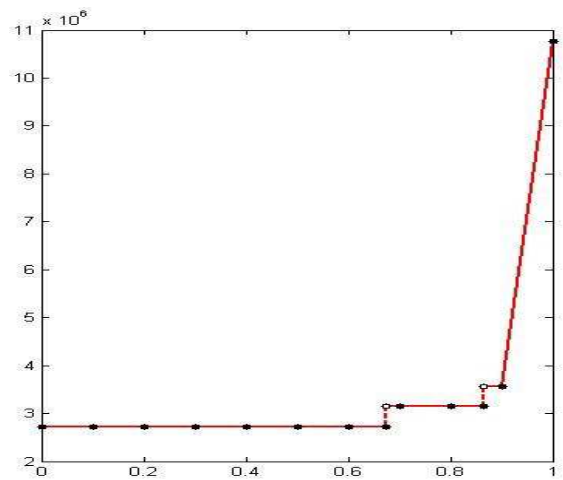


Figure 1: the changes on cost function by changing efficiency coefficient

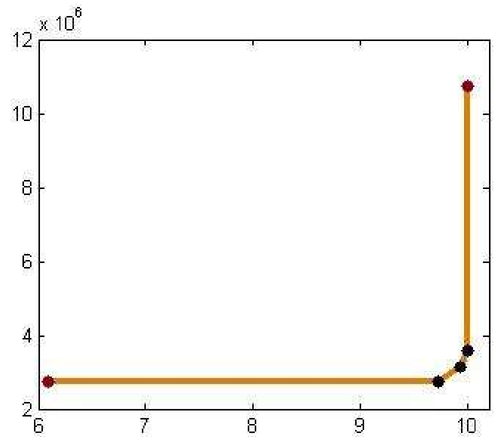


**Figure 3: the changes on pare to solutions by changing efficiency coefficient**

The efficiency in proportion to the target function coefficient indicates the efficiency. Also the graph 2 has indicated the changes of target function of costs compared to the efficiency target function coefficient. The graph 3 indicates the Pareto and non-Pareto points. The obtained solutions from the assumption of the two coefficients 0 and 1 are not Pareto because the other solutions are fluent to them.

In this numerical example, no change occurs in the total cost by entering the producers' efficiency with the lesser efficiency target function coefficient. With considering the coefficient 1 for the costs target function, the model only deals with solving the problem of supply chain through minimizing the costs. Thus, the efficiency reduces in this mode; but with entering the efficiency target function with the least possible coefficient the efficiency increases, while the value of costs' target function does not get worse and it remains constant. Also, in the last stages of the efficiency target function increase that the efficiency has the least possible value, and with changing the efficiency target function coefficient from 0.9 to 1 the efficiency does not change; and the other issues will not attempt for reducing the costs. Hence, the costs increase.

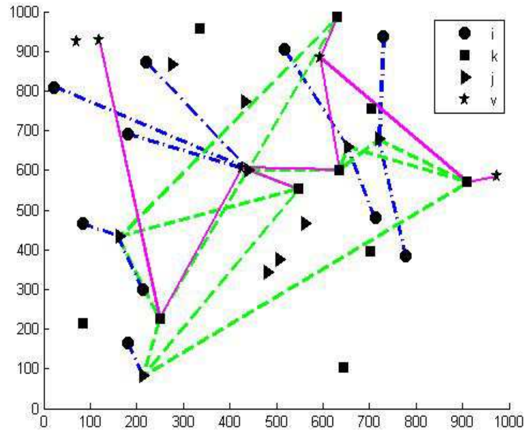


**Figure 5: Locations of suppliers when the efficiency is set to 0.7& 0.8**

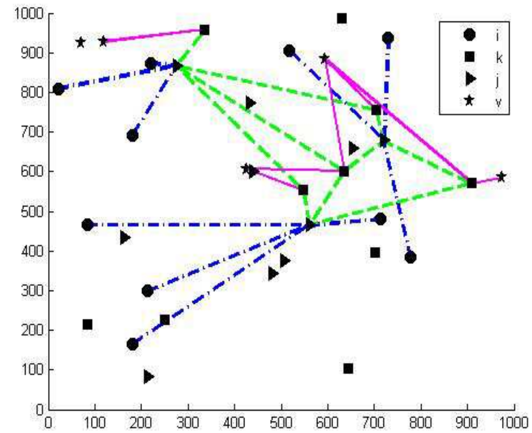


**Figure 4: Locations of suppliers when the efficiency is set to 0 - 0.6**

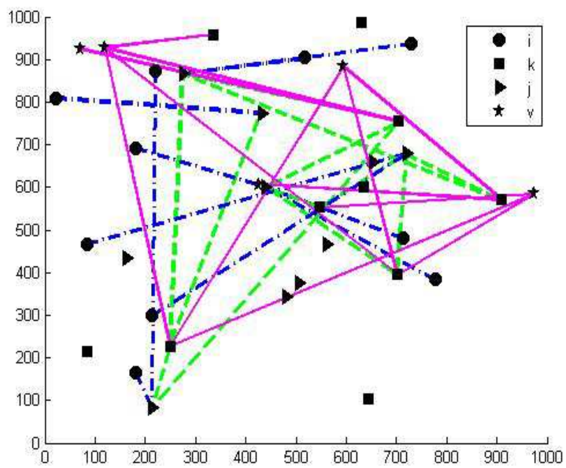


**Figure 7: Locations of suppliers when the efficiency is set to1**

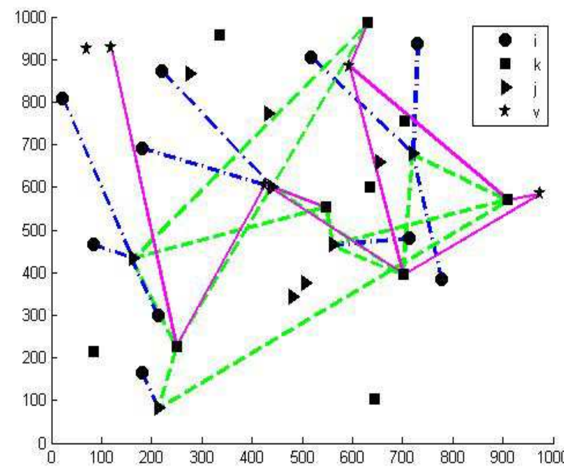


**Figure 6: Locations of suppliers when the efficiency is set to0.9**

The figures 4 to 7 indicate the location of supply chain in each solution obtained from solving the model with different coefficients for the efficiency target function. We can compare the Pareto solutions with each other through these figures. In these figures, the stars indicate the basic suppliers' location, squares indicate the manufacturers' location, triangles indicate the warehouses' (distributers') location, and the circles indicate the customers' location. The product's path from the supplier to the manufacturer has been indicated by a pink direct line, from the manufacturer to the distributer has been indicated by a green dotted line and from distributer to the customers has been indicated by a blue dot-line. The figures 4 to 6 express that in each solution, at least the establishment status of one manufacturer changes compared to the other solution and according to this change, sometimes the establishment status of warehouses and the product's path to the customer change. Due to considering the 0 coefficient for the costs target function, there are different paths in the figure 7 and regarded to the same fact, the model does not try to reduce the number of product's paths. It must be noted that this solution is not a Pareto solution.

## 5. DISCUSSION AND CONCLUSION

The globalization of markets and the numerous choices for the customers have led to the formation of supply chains. Acting in a chain has improved the competitive advantages of the organizations in order for them to have a higher opportunity to survive and succeed in the markets. Considering the efficiency increase target function causes the chain gives a more appropriate solution to the numerous choices. In this paper we presented a model for designing a multi-products supply chain with several raw materials. This chain includes 4 layers of supplier, manufacturer, warehouse (retailer) and the customer. Increase in efficiency of the manufacturer and decrease in the total costs are the target functions of this chain. The aim of the introduced model is locating the manufacturer and warehouse and also planning the purchase amount from each supplier. In this paper, the numerical example has been designed and solved and the results showed that adding efficiency to the supply chain model leads to its elevation. Also, considering each target function in itself, cause significant reduction in quality of the chain. Hence, efficient chain design is preferred to the simple chain design and a supply chain needs the efficient design in order to survive in the competitive markets.

Suggestions for future studies are as following:

- Designing supply chain with efficient facilities in uncertain conditions.
- Considering the assumption of maximizing the efficiency of the chain in pricing game of two chains and investigating the role of efficiency in the games' theory.
- Analyzing the sensitivity and investigating the impact of individual parameters of the chain in the obtained results.

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