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An Integrated Location-Inventory Model for Supply Chain Network with Correlated Demand

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Abstract. Existence of uncertainties and some constraints such as capacity and correlation between demand causing complexity of the supply chain network design. This paper considers a three level location-inventory problem where demand across the retailers is assumed to be correlated. The purpose of the model is to minimize total inventory system and facility location cost simultaneously. Innovation of this study is considering existence of different vehicles, multi-product and different capacity of potential warehouses. To ensure the accuracy and validity of the model, a numerical example has been solved by GAMS and two Meta heuristic algorithm of GA and hybrid of GA and SA with local search. ANOVA test have showed sufficient efficiency of Meta heuristic algorithms. We did sensitivity analysis for some important parameters such as transportation cost, holding cost and demand of retailers. Sensitivity analysis showed total cost of inventory system and facility location have high sensitives too mode of transportation. While we increase transportation cost, the total cost will increase exponentially.

Keywords: Supply chain, Location-Inventory Problem, Demand Correlation, Meta-heuristic, ANOVA.

1 Introduction

Intensifying global competition in an environment that is constantly changing causes to double the necessity of the suitable reactions of the production industrial organizations and companies and make them to increase their flexibilities in the uncertain external environment. The nowadays organization need to gain the appropriate position in the national and international environments and to maintain it and manage the supply chain in order to achieve the competitive advantages and customer expectations. Today, in the competitive market, it is very crucial to meet the risky and uncertain functional environment to design the efficient and responsive supply chain network [1].

In the 60s and 70s, the enterprises tried to standardize and improve their domestic processes in order to increase their competitiveness and produce the products with better quality and low costs [2]. At that time, the prevailing thinking was that strong engineering and design as well as manufacturing operations coordinated prerequisite to achieve the demands of the market and thus gain more market share. For this reason, organizations have focused their efforts on increasing efficiency. In the 80s with increasing diversity in the patterns of customer expectations, organizations increasingly increased flexibility in production lines and developed new products to satisfy the needs of the clients. In the 90s, by improving the production processes and using the re-engineering patterns, the managers of many industries realized that it is not enough to improve the domestic processes and the flexibility in the company abilities in order to continue their presences in the market but the distributors of the materials and products, also, need to produce the material with better quality and low cost. Distributors of products also should have a close correlation with development policies and market producers [2,3].

A supply chain includes all facilities, tasks and activities that all suppliers and customers are involved in the production and delivery of the goods or services and planning and managing the supply and demand management, production and application, timing the products and services, warehousing, inventory control and distribution, delivery and customer service. All these activities are coordinated supply chain management so that customers can produce high quality and reliable service at the least cost. Supply chain management can provide a competitive advantage to turn for the company [4]. According to Harrison, a network design strategy potentially could reduce supply chain costs by 60%. The basic design of the system on issues has been related to its strategy that can be used to count the warehouse and factory space in the network with minimum cost without addressing the operational difficulties noted [5].

Daskin et al, Shen et al and Miranda &Garido were among first parsons delivered the mathematical model in order to establish the positions and problems of the inventory. Their model was included the specifications of the warehouse place and the assignment of etch customer to the warehouse in order to optimize the inventory decisions. They, also, considered the safety stock to deal with the demand uncertainty by assuming a constant lead time at the factory and the enterprise level [6,7,8].

Most researchers have focused on the demand correlation model in the supply chain management. Park et al investigated three levels of the inventory problem from the factory to the warehouse and then from the warehouse to the retailer where the cost of the safety stock for the factory depends on the lead time[9]. However, their model has not considered the impact of the demand correlation between the retailers [10,11].

In 2012, Kiskin and Oster have suggested a three-level production distribution system by considering the inventory, capacity constraints and retailers [12]. Frizz et al have studied the effects of competitive environment in the supply chain network [1]. Also, Chiadomrong et al. have investigated the design of the warehouse and distribution network for the export of the sugar. They developed a single-product, single-period model and considered the decision about the locations of the factories and distribution centers including warehouses and export ports, distribution centers and customer allocation assigned to the centers of factories [13].

Javaher & Balachi delivered, in their model, a model for the distribution issue in two-level supply chain and suggested a solution due to GA (genetic algorithm). The results showed that this model is able to deliver better answers than the approximation method or equal/ close answers to the lower limit [14]. Mello et al introduced the facility location model that are applicable in the supply chain and followed the correlations between the facility location model and the strategic programming of the supply chain [15]. Shahabi and et al have delivered, in their study, a three- level supply chain network from the suppliers to the warehouse by considering the lead time and demand correlation between the retailers with one product. The purpose of the study is to minimize the inventory and location costs of the factory and the warehouse [16].

This study presents a three level supply chain model just like Shahabi et al. [16] survey. In addition of considering a multi-product system, the main innovation of this paper is selecting mode of transportation among different type of vehicles and having different level of warehouses which approaching the model to reality. According to complexity of the model, two meta heuristic algorithm is used to solve the NP-hard model. It is known that meta heuristic algorithm results needs to verify. So an ANOVA test is applied to examine reliability of the results. Finally, a sensitivity analysis is done to show impact of changing some parameter on total objective function cost.

2 Notations

All material on each page should fit within the A4 paper size of 21 × 29.7 cm (8.27 × 11.69 in), centered on the page, beginning margin 3 cm (1.18 in) from the top of the page and ending with 3 cm (1.18 in) from the bottom. The right and left margins should be 3 cm (1.18 in) as well.
Typescripts must be typed with single spacing on one column, preferably using a word-processor with a high quality printer. Use of the "Times New Roman" typeface, size 10, is preferred; do not indent when starting a new paragraph.

2.1 Typeset Text

Index, parameters and variables of the issue are as following notations:

Indices:
I & L Index set of retailer(s) zone(s).
J Index set of potential warehouse sites.

K Index set of potential companies sites.
N Index set of vehicles.
P Index set of products.
H Index set of capacity levels available to the potential warehouses.

Parameters;

A_{jp} ordering cost of product p from warehouse on site j to the factory.
c_{ijp} unit cost of supplying product p to customer zone i from warehouse on site j.
cap_{jh} capacity of warehouse on site j with capacity level h.
f_{jk}^{h} fixed cost per unit of time for opening and operating warehouse assigned to factory k with capacity level h on site j.
g_{kp} fixed cost per unit of time for opening and operating factory k to produce product p
H_{jp} holding cost per time unit of product p in warehouse on site j.
L_{JKpn} Lead-time for delivered product p to warehouse zone j from factory k with vehicle n.
r_{jp} Optimal reorder point for warehouse j and product p
t_{jkpn} unit cost of supplying product p to warehouse on site j from the factory k by vehicle n.
β Number of working days per year
σ_i, σ_l Variance of daily demand at retailer i and j
μ_{ip} Mean daily demand at retailer i for product j
ρ Correlation coefficient between daily demands at retailer i and at retailer l
z_α a-percentile of the standard normal distribution

Decisions variables;

D_{jhp} Mean daily demand of product p at warehouse j with capacity level h
U_{jhp} Variance of daily demand at warehouse j
Q_{jhp} Optimal order quantity of product p at warehouse j with capacity level h
SS_{jhp} Safety stock level of product p at warehouse j with capacity level h
TC_{jhp} Optimal inventory cost of product p at warehouse j with capacity level h
L_{jhp} Order lead time of product p at warehouse j with capacity level h (day)

3 Model description

In this section, there has been delivered mathematical formula for three-level inventory location with regard to the demand correlation among the retailers.

Decision variables include:

1. Numbers and locations of factories and warehouses
2. Allocation of retailers to the warehouse and then the warehouse to the factory
3. Decisions of inventory control in each warehouse

The aim of this study is to minimize the inventory and location costs of the factories with different products and the warehouses with different capacities by considering the transportation of the products with different vehicles, the demand correlation between retailers and multi-product factories.

Model assumptions are as follows:

1. Cost of the factory and warehouse is fixed
2. Costs of transport between factories to warehouses and warehouses to retailers follow a Euclidean distance.
3. Every warehouse is supplied by a factory and every retailer is supplied by a warehouse.
4. There has been considered an inventory control system only for the warehouses by using of the continuous assessment of the reorder point and the economic order.
5. Due to the demand diversity of the retailers, the safety stock has been considered for the warehouses.
6. Demand of the retailers follows a normal distribution.

7. Lead time between the factories to the warehouse depends on the distance between the factories to the warehouse.
8. There has not been considered the shortage cost.
9. The factories produce different products.
10. The limited capacity is different for the warehouses and there has not been considered the limited capacity for the factories.
11. There has been diversity in the type of transportation from the factory to the warehouse and from the warehouse to the retailers.

The demand of the retailer i and the retailer I are related to each other by the correlation coefficient Pil. The daily demand of each warehouse j is followed by the capacity level h for the product p from the normal distribution with the mean:

$D_{jhp} = \sum_i \mu_{ip} x_{ij}$

And the variation:

$$U_{jhp} = \sum_i \sum_l \rho_{il}\sigma_i\sigma_l x_{ij} x_{lj}$$

and the delivery time of the order:

$$L_{jhp} = \sum_k l_{jkpn} y_{jkp}^{hn}$$

In this article, according to EOQ model, the quantity of economic order (Q_{jhp}), reorder point (r_{jp}), safety stock (SS_{jhp}) and the total costs of inventory system (TC_{jhp}) are as follows:

$$Q_{jhp} = \sqrt{2A_{jp}\beta^{D_{jhp}}/H_{jp}} = \sqrt{2A_{jp}\beta \sum_i \mu_{ip} x_{ij}/H_{jp}} \quad \textbf{(1)}$$

$$r_{jp} = D_{jhp}L_{jhp} + z_\alpha\sqrt{U_{jhp}}L_{jhp} \quad \textbf{(2)}$$

$$SS_{jhp} = z_\alpha \sqrt{U_{jhp}L_{jhp}} \quad \textbf{(3)}$$

$$= z_\alpha \sqrt{\sum_i \sum_l \rho_{il}\sigma_i\sigma_l x_{ij}x_{lj} \sum_k l_{jkpn} y_{jkp}^{hn}} = z_\alpha \sqrt{\sum_i \sum_l \sum_k \rho_{il}\sigma_i\sigma_l x_{ij}x_{lj} l_{jkpn} y_{jkp}^{hn}} \quad \textbf{(4)}$$

$$TC_{jhp} = \sqrt{2A_{jp}\beta H_{jp} D_{jhp}} + z_\alpha H_{jp}\sqrt{U_{jhp}L_{jhp}} = \sqrt{2A_{jp}\beta H_{jp} \sum_i \mu_{ip} x_{ij}}$$

$$+ z_\alpha H_{jp} \sqrt{\sum_i \sum_l \sum_k \rho_{il}\sigma_i\sigma_l x_{ij}x_{lj} l_{jkpn} y_{jkp}^{hn}}$$

3.1. The Objective Function to Location and Inventory Control

The aim of this study is to minimize the inventory and location costs of the factories with different products and the warehouses with different capacities by considering the transportation of the products with different vehicles, the demand correlation between retailers and multi-product factories.

P_1 :

(5)

$$\text{Min} \sum_k \sum_p g_{kp}\, v_{kp} + \sum_j \sum_k \sum_p \sum_h \sum_n f_{jkp}^{hn}\, y_{jkp}^{hn}$$

$$+ \sum_i \sum_j \sum_p \sum_k \sum_h \sum_n \beta \mu_{ip}\, t_{jkpn}\, x_{ijp}\, y_{jkp}^{hn} + \sum_i \sum_j \sum_p \beta\, \mu_{ip}\, c_{ijp}\, x_{ijp} +$$

$$\sum_j \sum_p \sqrt{2A_{jp} H_{jp}\, \beta \sum_i \mu_{ip} x_{ijp}} +$$

$$\sum_j \sum_p z_\alpha\, H_{jp} \sqrt{\sum_i \sum_l \sum_k \sum_h \sum_n \rho_{il}\, \sigma_i \sigma_l\, l_{jkphn} x_{ijp} x_{ljp} y_{jkp}^{hn}}$$

Subject to;

$$\sum_j x_{ijp} = 1 \quad \forall\, i, p \tag{6}$$

$$X_{ijp} \leq \sum_k \sum_n y_{jkpn} \quad \forall\, i, j, h, p \tag{7}$$

$$\sum_i \sum_p \mu_{ip} . S_p . x_{ijp} \leq cap_{jh} \quad \forall j, h \tag{8}$$

$$\sum_k \sum_p \sum_h \sum_n y_{jkp}^{hn} \leq 1 \quad \forall j \tag{9}$$

$$\sum_h \sum_n y_{jkp}^{hn} \leq v_{kp} \quad \forall\, j, k, p \tag{10}$$

$$x_{ijp}, y_{jkp}^{hn}, v_{kp} \in \{0,1\}, \forall i, j, p, h, n, k \tag{11}$$

The equations (7) and (10) show that every retailer is assigned to every established warehouse and every warehouse is assigned to every established factory. The equation (6) and (9) show that every warehouse receives every product from only one factory by only one vehicle. The constraint (8) shows the capacity limitation for every warehouse.

3.2. Linearization of Objective Function

Because of non-linear equation for the solution, we face some problems to solve it that it can be converted to the linear equation by replacing M_{ijp}^{khn} instead of $x_{ijp} . y_{jkp}^{hn}$.

$$M_{ijp}^{khn} \leq x_{ijp} \quad \forall\, i, j, p, k, h, n \tag{12}$$

$$M_{ijp}^{khn} \leq y_{jkp}^{hn} \quad \forall\, i, j, p, k, h, n \tag{13}$$

$$M_{ijp}^{khn} \geq x_{ijp} + y_{jkp}^{hn} - 1 \quad \forall\, i,j,p,k,h,n \tag{14}$$

$$M_{ijp}^{khn} \geq 0 \quad \forall\, i,j,p,k,h,n \tag{15}$$

The above equations show that when M_{ijp}^{khn} is 1 that $x_{ijp} = 1$ otherwise it is zero. The above limits can be reduced as follows in order to decrease the size of problem. According to the study of Mehrdad Shahabi et al. for each possible answer, the equation can be written as follows:

$$\sum_{n}\sum_{h}\sum_{k} M_{ijp}^{khn} = x_{ijp} \quad \forall\, i,j,p \tag{16}$$

$$M_{ijp}^{khn} \leq y_{jkp}^{hn} \quad \forall\, i,j,p,k,h,n \tag{17}$$

$$M_{ijp}^{khn} \geq 0 \quad \forall\, i,j,p,k,h,n \tag{18}$$

The final model of the problem will be delivered as follows:

P2:

$$\text{Min} \sum_{k}\sum_{p} g_{kp}\, v_{kp} + \sum_{j}\sum_{k}\sum_{p}\sum_{h}\sum_{n} f_{jkp}^{hn}\, y_{jkp}^{hn} + \sum_{i}\sum_{j}\sum_{p}\sum_{k}\sum_{h}\sum_{n} \beta\mu_{ip}\, t_{jkpn}\, M_{ijp}^{khn} + \sum_{i}\sum_{j}\sum_{p} \beta\, \mu_{ip}\, c_{ijp}\, x_{ijp} + \sum_{j} t_{1j} + \sum_{j}\sum_{p} z_{\alpha}\, H_{jp} t_{2j} \tag{19}$$

s.t;

$$\sqrt{2A_{jp}H_{jp}\,\beta \sum_{i} \mu_{ip}x_{ijp}} \leq t_{1j} \quad \forall j,p \tag{20}$$

$$\sqrt{\sum_{i}\sum_{l}\sum_{k}\sum_{h}\sum_{n} \rho_{il}\, \sigma_i\sigma_l\, l_{jkphn} x_{ijp} x_{ljp} y_{jkp}^{hn}} \leq t_{2j} \quad \forall j \tag{21}$$

$$M_{ijp}^{khn} = x_{ijp} \quad \forall\, i,j \tag{22}$$

$$M_{ijp}^{khn} \leq y_{jkp}^{hn} \quad \forall\; i,j,k \tag{23}$$

$$t_{1j}.t_{2j} \geq 0 \quad \forall\, j \tag{24}$$

$$M_{ijp}^{khn} \geq 0 \quad \forall\, i,j,k \tag{25}$$

4 Computational Results

In this section, in order to validate and verify the integrity of the model, the problem has been solved by data of used previous studies with Barons solver of GAMS Software, versions 24.1.2 and classic GA and a hybrid of GA-SA for small-size problems and the meta heuristics for large-size problems.
Percentage relative error (PRE) is used to measure performance of small-size instances and relative percentage deviation (RPD) is used to measure performance of large-size instances, since this category the optimum solution could be found as mentioned in [17]:

$$PRE=\frac{Alg_{sol}-O}{O} \quad (26) \qquad RPD=\frac{Alg_{sol}-Min_{sol}}{Min_{sol}} \quad (27)$$

Where O is the optimum cost obtained by GAMS, Alg_{sol} is the objective cost which obtained by selected heuristic method and Min_{sol} is the best solution which obtained for each instance. In this occasion, lower value of PRE and PRD are preferable. Table 1 and 3 show the computational results for small and large size problems.

Table 1: Computational results for small-size problems

Problem (i#j#k#p#h#n)	GAMS MCPU Time	GA		Hybrid GA-SA	
		MCPU Time	PRE_{avg}	MCPU Time	PRE_{avg}
1) 4#3#2#2#2#2	856.70	9.80	0.014	19.11	0.078
2) 4#3#2#2#3#2	968.09	13.21	0.083	17.79	0.009
3) 4#3#2#3#2#2	839.20	12.20	0.095	12.89	0.01
4) 4#3#2#3#3#3	1274.51	15.82	0.127	13.22	0.012
5) 4#3#3#2#2#3	1054.35	12.52	0.149	14.95	0.048
6) 5#3#3#3#3#3	1423.29	8.60	0.076	18.88	0.012
7) 6#4#3#3#3#3	1383.82	16.43	0.056	19.76	0.09
8) 6#4#4#3#3#3	1670.20	18.24	0.06	14.72	0.011
9) 6#4#4#4#4#3	1485.42	16.47	0.034	18.47	0.0003
10) 6#4#4#4#4#4	1559.59	23.89	0.041	13.35	0.0005

Now, analysis of variance (ANOVA) is performed to check whether the differences observed in Table 2 are statistically significant or not. Table 3 is the ANOVA output for obtained PRE of both algorithms. According to Table 2, since the p-value is approximately 0.1, the differences among both algorithms are not significant.

Table 2: ANOVA results for small size instances

	ANOVA of PRE			
	Sum of squares	df	Mean square	F
Between groups	0.005	1	0.005	3.69
Within groups	0.026	18	0.00142	
Total	0.031	19		

In large-size instances, as it can be seen from RPD's value, hybrid algorithm outperforms classic GA. By increasing the problem size, GA performed better due to extra stage in hybrid algorithm for local search via SA which caused better performance than SA in value of objective function.

Table 3: Computational results for large-size problems

Problem (i#j#k#p#h#n)	GA		Hybrid Algorithm	
	MCPU Time	RPD_{avg}	MCPU Time	RPD_{avg}
1) 40#10#2#3#3#2	82.293561	0.021	86.17	0.045
2) 40#10#2#2#2#2	87.856741	0.065	101.31	0.011
3) 40#10#2#3#2#2	92.34468	0.065	96.65	0.013
4) 40#10#2#4#3#3	98.617482	0.057	107.15	0.026
5) 40#10#2#4#2#3	110.52648	0.098	112.56	0.02
6) 40#15#3#3#3#3	123.03656	0.034	117.31	0.042
7) 40#15#3#4#2#3	124.25911	0.014	121.38	0.004
8) 40#15#3#4#3#3	142.55357	0.019	133.25	0.01

9) 50#10#2#3#3#4	158.48567	0.012	140.05	0.009
10) 50#15#2#3#3#4	171.20783	0.002	147.76	0.036
11) 50#20#2#2#2#4	189.62507	0.056	169.72	0.001
12) 50#20#2#2#3#4	199.31454	0.032	165.97	0.012
13) 50#20#2#3#2#4	209.56131	0.03	179.11	0.018
14) 50#20#2#3#3#4	231.97114	0.001	192.67	0.037
15) 50#20#2#4#2#4	240.31231	0.014	197.51	0.01
16) 50#20#2#4#3#4	261.0917	0.037	215.85	0.012
17) 50#20#3#3#2#4	278.48065	0.015	233.23	0.038
18) 50#20#3#3#3#5	295.20722	0	245.40	0.046
19) 50#20#3#4#2#5	297.2008	0.008	245.68	0.017
20) 50#20#3#4#3#5	319.6967	0.027	270.50	0.009
21) 75#20#2#2#2#5	339.84129	0.002	283.96	0.034
22) 75#20#2#3#2#5	366.31069	0.009	314.61	0.043
23) 75#20#2#3#3#5	371.15939	0.011	321.94	0.013
24) 75#20#2#4#2#5	393.56368	0.032	349.49	0.003

As mentioned, it is necessary to check whether the differences observed in table 4 are statistically important or not. In same way as we did for small size instances, ANOVA is applied over the results. Table 4 demonstrates the ANOVA output for the obtained RPD in average. As it can be seen again, no significant differences is not observed (p-value≈0.025 ≥ α=0.05) among the RPD's result in Table 4.

Table 4: ANOVA results for large-size instances

	ANOVA of RPD			
	Sum of squares	df	Mean square	F
Between groups	0.0005	1	0.000481	5.8267
Within groups	0.0038	46	0.000083	
Total	0.0043	47		

5 Sensitivity analysis

It should be noted that in order to analyze the sensitivity for a parameter, by assuming other parameters, that parameter was multiplied in coefficients and the results were investigated. The horizontal axis in the below axis shows the parameter and the vertical axis represents the objective function level due to the changes of the parameter.

5.1. Changing in Holding Cost

Table 5: Changing in the holding cost

Holding cost factor	0.05	0.1	1	10	20
Objective function value)*10^8(	2/52	2/52	2/52	2/52	2/52

As mentioned in figure 1, the sensitivity of the model is high toward the increase of the holding cost but by decreasing the holding cost, there have not been formed high changes in the total cost.

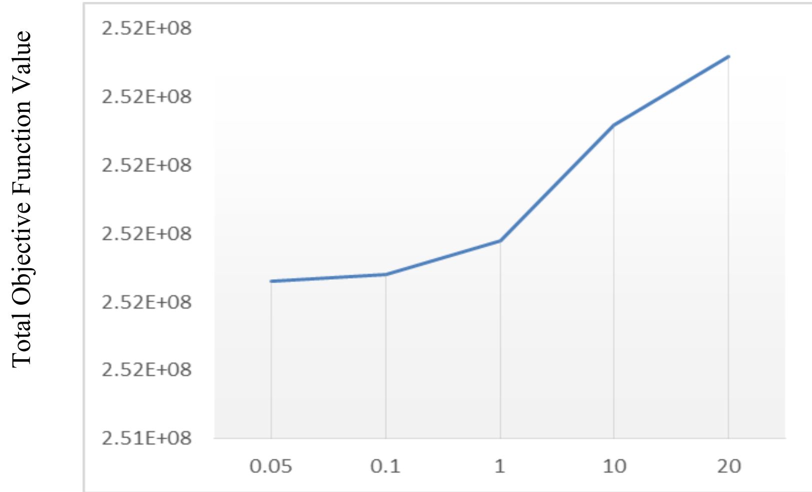

Figure 1: Sensitivity to changes in the holding costs

5.2. Changing in Demand Level of the Retailers

Table 6: Changing in demand level of the retailers

demand level factor	0.05	0.1	1	10	20
Objective function value)*10^8(	2/43	2/43	2/52	3/35	4/39

Figure 2, same as figure 1, represents the high changes in the total costs toward the increase of the demand retailers. This represents the importance of the correct estimation of the demand retailers because the estimation below the real demand level (due to unauthorized deficiency) will be included the heavy expenditures for the total inventory system.

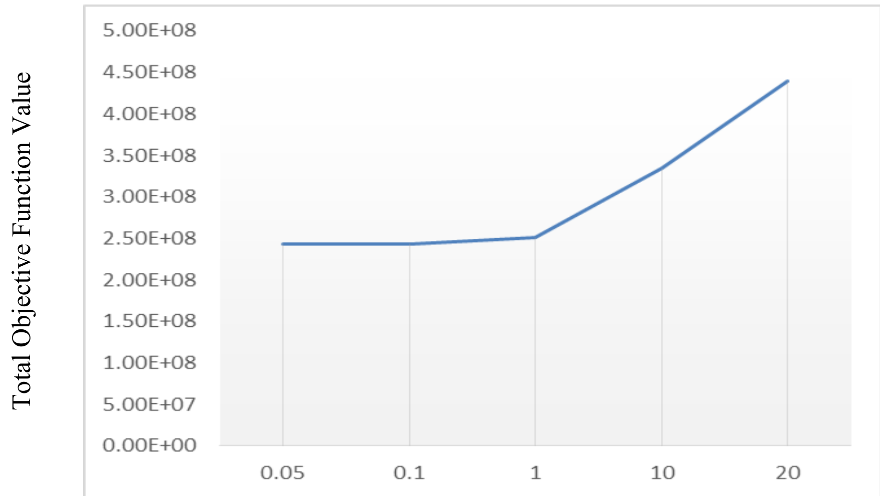

Figure 2: Sensitivity to changes in demand level of the retailers

5.3. Changing in Transportation Cost from the Warehouse to Retailers

Table 7: Changing in the transportation cost from the warehouse to retailers

Transportation Cost factor from the Warehouse to Retailers	0.05	0.1	1	10	20
Objective function value)*10^8(	2/50	2/50	2/52	2/68	2/85

The changes in the cost of transportation from the warehouse to retailers as well as rise due to the sharp increase in the total cost make to increase the total costs. But cutting costs will not let almost any impact on total cost of system.

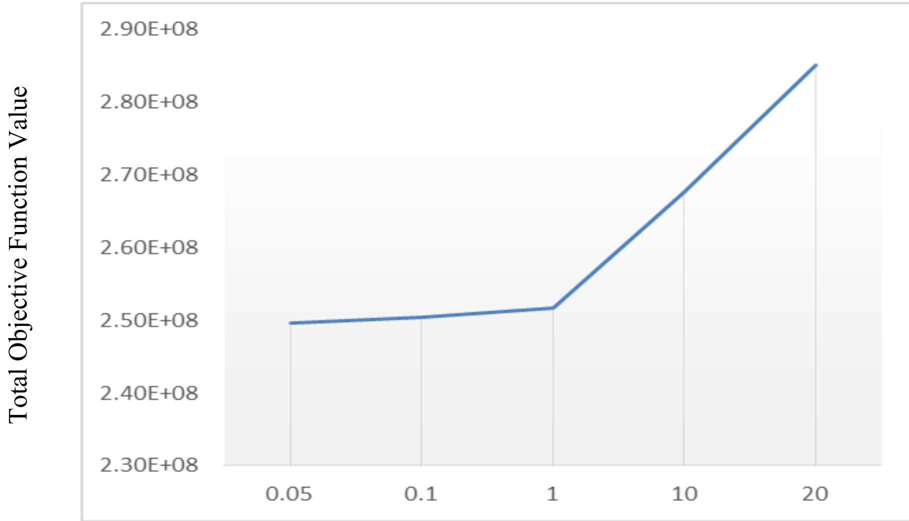

Figure 3: Sensitivity to changes in the transportation cost from the warehouse to retailers

5.4. Changing in Transportation Costs from Factory to Warehouse due to Different Vehicles

Table 8: Changing in the transportation costs from the factory to the warehouse

Transportation Cost factor from Factory to Warehouse	0.05	0.1	1	10	20
Objective function value)*10^8(	2/45	2/45	2/52	2/82	3/86

The most important part of the sensitivity analysis, in this article, is related to changes in the transportation costs from the factory to the warehouse. As shown in figure 4, with an increase in cost, the total cost of the system will increase exponentially. It will show the importance of choosing the right vehicle, because the wrong decision to choose the means of transportation causes to increase the transportation cost from the factory to the warehouse and also the inventory system costs exponentially.

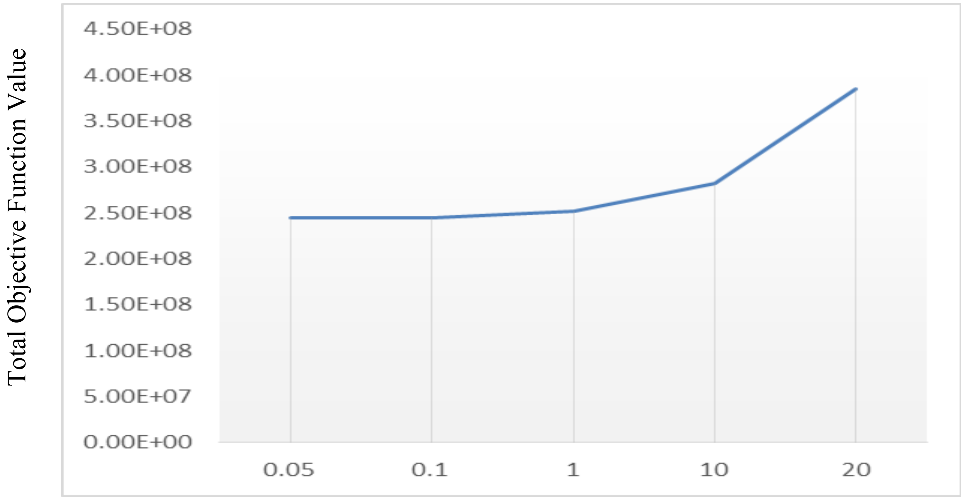

Figure 4: Sensitivity to the changes in the transportation cost from the factory to the warehouse

6 Conclusion

In this article, there has been delivered the mathematical model to locate the inventory of three-level supply chain. The aim of this model study is to minimize the inventory and location costs of the factories with different products and the warehouses with different capacities by considering the transportation of the products with different vehicles, the demand correlation between retailers and multi-product factories. The model is solved by exact method with GAMS for small-size instances and then two Meta heuristic algorithm is used for large-size ones. ANOVA test have showed that meta-heuristic algorithm provides efficient solution. The sensitivity analysis of the parameters of the transportation and holding costs and the final results and their charts were drawn that are the more significant. The sensitivity analysis toward the transportation cost parameter from the factory to the warehouse showed that by increasing the transportation cost, the total cost will be increased exponentially. This issue reflects the importance of choosing the right vehicle. Also, for the future studies, it is recommended that the shortage costs take into account.

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