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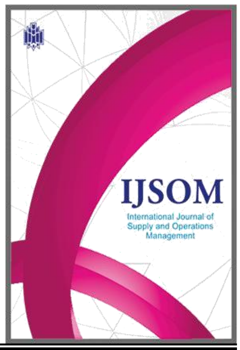

Multi-objective Optimization of Location and Distribution in a Closed-loop Supply Chain by Considering Market Share in Competitive Conditions

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Abstract

Development of supply chains is one of the practical concepts in the field of production and sales in competitive conditions. Accordingly, it is necessary to properly study the competitive conditions in which supply chain networks can be designed. In this regard, the present research contributes to the field by incorporating the market share and customer satisfaction to the competitive conditions of supply chains. For this purpose, a nonlinear mathematical model is presented in order to find locations and perform distributions in a closed-loop supply chain under competitive conditions. This model has two objectives including profit maximization and market share maximization. To solve the model, LP-metric and goal programming are implemented, and then the results of these two methods are discussed. Comparisons are also made in terms of the value of the objective functions as well as the solution time. Finally, the simple weighted sum method is used to select the superior method. The results show that the LP-metric method is worth performing to solve the mathematical model of the research.

Keywords: Location and distribution; Market share; Closed-loop supply chain; LP-metric; Goal programming.

1. Introduction

In recent years, supply chain management has attracted the attention of many academic researchers as well as production and sales managers. Increasing competitiveness and efforts for the survival of organizations have led to an approach of communication and advances in information technology. To meet customer needs and interests, efforts should be directed toward price reduction, timely shipping, good quality and environmental requirements. The proper management of a supply chain can satisfy these needs not only for customers, as the last link of the chain, but also for the upstream suppliers.

Since supply chains are formed for better sales in a competitive environment, it is necessary to consider the assumptions of competitive business in supply chain management. One of the major assumptions is customer satisfaction. Supply chains must regulate both the quality and the price of their products in such a way that economic benefits are provided to all the chain members and customer satisfaction is maximized.

In addition, reverse logistics has received a lot of attention due to e-commerce requirements and environmental laws. In the past, reverse logistics was considered as an activity for after-sales service departments, where customers returned defective or warranty products to suppliers. Reverse logistics is currently considered as a competitive area. It has received more attention not only for both environmental and economic issues but also as a viable manner in business.

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It is to be noted that various factors such as reverse logistics, customer satisfaction, and competitive conditions makes it difficult to find a proper solution for supply chain management. Therefore, optimized mathematical models with multiple objectives can be efficient tools for finding the best solutions for closed-loop supply chains in competitive conditions.

Considering the role of reverse logistics and the significance of customer satisfaction, this study aims at the optimization of a closed-loop supply chain in competitive conditions. For this purpose, a bi-objective mathematical model is developed and then optimized with LP-metric and goal programming methods.

The rest of the paper is organized as follows. In Section 2, the research background is presented. Section 3 introduces the proposed mathematical model and the solution methods. In Section 4, the numerical results obtained from solving the mathematical model are discussed. Finally, the research conclusion closes up the paper in Section 5.

2. Literature review

Designing supply chain networks, especially for location and distribution, is one of the best-known topics in the field of optimization. In this regard, concepts such as green supply chain, sustainable supply chain and competitive supply chain are the most popular research topics. In the following, some of the most important studies in the field are reviewed.

Kannan et al. (2010) examined battery recycling in the form of a closed-loop green supply chain. They aimed to design a multi-level chain and make decisions about how to produce and distribute, taking into account environmental conditions. This problem was solved by a genetic algorithm, and the results were analyzed. Amin and Zhang (2013) proposed a multi-objective mathematical model to design a closed-loop green supply chain. The structure of the chain under study included manufacturing plants, assembly centers, collection centers and recycling centers. The objectives were to reduce costs and the damage to the supply chain. The researchers analyzed the proposed problem with various numerical examples and results.

Govindan et al. (2015) reviewed closed-loop supply chain network design problems. The review covered the research from 2007 to 2013 regarding the themes and methodology. This article discussed the combination of green supply chains with closed-loop supply chains and the use of quantitative methods to design chains.

Talaei et al. (2016) designed a multi-echelon supply chain in the electronics industry as a green closed-loop one. They aimed to provide a chain with the lowest amount of carbon production and the lowest cost. In order to design the supply chain, locations were determined for production, storage and recycling centers. This problem was implemented in the conditions of fuzzy uncertainty. Kaya and Urek (2016) presented a nonlinear integer programming model for locating, inventory, and selling price optimization in a closed-loop supply chain. In this research, the amount of demand was presented as the exponential relationship of the selling price. In order to solve the model, an innovative method was designed and implemented based on the inventory ordering system as well as the ordering period. Zahl and Soleimani (2016) combined direct and reverse logistics to design a closed-loop supply chain. For this purpose, in addition to minimizing the costs of the whole chain, reducing CO2 emissions was considered as a green goal. To solve the model, an ant colony optimization (ACO) algorithm was developed. Chen et al. (2017) examined a closed-loop supply chain with information symmetry. In order to study the selling price of products, the game theory approach was used. Moreover, the wholesale and retail prices as well as the amount of storage in each warehouse were determined in terms of information symmetry.

Adding the category of reverse logistics to supply chain management has led to the creation of the concept ‘closed-loop supply chain’. In a closed-loop supply chain, in addition to the management of the flow of products from suppliers to customers and the flow of information from customers to suppliers, the flow of materials returned from customers to the different echelons of the supply chain is managed.

Ghavamifar et al. (2018) presented a multi-objective two-level mathematical model for designing a closed-loop supply chain network in competitive conditions. This supply chain was considered to be reliable, and the risks of disruptions were minimized. To solve this mathematical model, a hybrid method based on Banders decomposition was applied. Amiri et al. (2018) optimized a supply chain network design problem in competitive conditions by considering the coverage radius to meet customer demand. In this regard, an exact search method was devised and implemented. Mahmoodi (2019) considered an agile supply chain and developed a multi-objective mathematical model for its network. The objectives of this mathematical model included the reduction of the total costs and the total chain risk and the increase of the supply chain flexibility. Moreover, the NSGA-II algorithm was used to solve the mathematical model.

In competitive conditions, Wang et al. (2020) designed a multi-product and multi-period supply chain. The goal was to gain more market share for the chain. Accordingly, supply chain profit was defined based on the market share, and the objective function of the mathematical model was considered as profit maximization. The SA and PSO algorithms were used to solve this mathematical model.

The application of reverse logistics in waste collection is largely reported in the literature. Babaee Tirkolaee et al. (2021) proposed a fuzzy chance-constrained programming model for medical waste management. Alinaghian et al. (2021) presented a MILP model and improved the Tabu Search (TS) algorithm for an inventory-routing problem. Aghighi et al. (2021) assessed the location and routing in a supply chain of perishable products and presented an improved version of the genetic algorithm. Khakbaz and Babaee Tirkolaee (2021) proposed a manufacturing and remanufacturing system for Waste Electrical and Electronic Equipment (WEEE). Pahlevan et al. (2021) introduced a multi-objective mathematical model for an aluminum supply chain network. They applied a multi-objective red deer algorithm and a multi-objective gray wolf optimizer to solve the proposed model.

Due to the importance of supply chains in the current competitive environment, the present study seeks to develop and assess a closed-loop supply chain in competitive conditions. The main contribution of the study is to design a closed-loop supply chain with competitive pricing based on customers' utility. Moreover, maximizing the market share is considered as the objective function of the chain.

3. Mathematical model and solution methods

The supply chain under study consists of five echelons. Three of them are in front and two in the reverse section. At the first echelon, there is a set of manufacturers. After producing the desired product, the manufacturers send the final product to the second echelon, i.e., the set of sales centers or sales agencies. At the third echelon, there are customers who make their purchases from sales centers and return a percentage of the product to the supply chain after a certain period of time. For this purpose, a number of collection centers are set at the fourth echelon of the chain. Finally, some of the recyclable products are sent to the fifth echelon of the chain, i.e., the recycling centers. In these centers, after the product is recycled, it is sent to production centers to be put in the production and distribution process again.

An important aspect of this closed-loop supply chain is the competitive environment. In a competitive environment, it is crucial to locate right sales centers because it can significantly affect customer satisfaction; a long distance of sales centers from the position of customers causes customer dissatisfaction, and, as a result, the market share is decreased. To formulate this problem, first, the degree of utility for each sales center is calculated according to the distance from customers. Then, the market share is calculated based on the degree of utility from the customers' point of view. Finally, the customers' demand is considered as a function of the market share.

The assumptions of the proposed mathematical model are summarized as follow:.
- The number of customers is constant and definite.
- Each sales center in the supply chain has a specific utility for customers.
- Each customer has a specific purchasing power.
- The amount of customer demand depends on the advantage of the chain over other competitors
- The location of the manufacturers is fixed at the beginning of the planning.
- The optimal locations of sales centers, collection centers and recycling centers should be determined.
- Production, shipping costs and inventory of products are fixed and definite.
- In a competitive environment, it is possible for any other competitor to enter the market.
- The supply chain is limited in terms of production and storage capacity.
- The objective is to increase the profits as well as the market share.

Indices

i	Index of production center
j	Index of customers
k	Index of potential points for collection centers
l	Index of potential points for recovery centers
n	Index of potential points for sales centers

Parameters

bc_k	Cost of collection and separation for one unit of goods in collection center *k*
br_l	Recycling cost of a unit of goods in recycling center *l*
ω_j	The amount of products returned to the collection centers from customer *j*
cp_{in}	Cost of transferring a unit of goods from production center *i* to sales center *n*
cc_{jk}	Cost of transferring a unit of goods from customer *j* to collection center *k*
cr_{ld}	Cost of transferring a unit of goods from collection center *k* to recycling center *l*
cw_{li}	Cost of transferring a unit of goods from recycling center *l* to production center *i*

pr_i	Production cost of one unit of goods in production center *i*
pw_i	Reproduction cost of one unit of goods in production center *i*
dis_{jn}	Distance between customer *i* and potential sales center *n*
fr_l	Fixed cost of establishing recycling center *l*
fc_k	Fixed cost of establishing collection center *k*
fb_n	Fixed cost of establishing sales center *n*
D_j	Total demand of customer *j* (divisible among all the competitors)
β_i	Capacity of production center *i*
γ_k	Capacity of collection center *k*
μ_l	Capacity of recycling center *l*

Decision variables

xi_{in}	Amount of the products transferred from production center *i* to sales center *n*
xj_{jk}	Amount of the products transferred from customer *j* to collection center *k*
xk_{kl}	Amount of the products transferred from collection center *k* to recycling center *l*
xl_{li}	Amount of the products transferred from recycling center *l* to production center *i*
yb_n	Binary variable equal to 1 if sales center *n* is established
yc_k	Binary variable equal to 1 if collection center *k* is established
yr_l	Binary variable equal to 1 if recycling center *l* is established
P_n	Selling price of the product in sales center *n*
d_{jn}	Amount of the demand of customer j for sales center *n*
U_{jn}	Utility of sales center *n* for customer *j*

Mathematical formulation

$$\begin{aligned} MAX\ Z_1 = \sum_n \sum_j P_j d_{jn} - \\ \{\sum_k fc_k yc_k + \sum_l fr_l yr_l + \sum_n fb_n yb_n \\ + \sum_i \sum_n (pr_i + cp_{in}) xi_{in} + \sum_j \sum_k \left(bc_k + cc_{jk}\right) xj_{jk} \\ + \sum_k \sum_l (br_l + cr_{kl}) xk_{kl} + \sum_i \sum_l (cw_{li} + pw_i) xl_{ki}\} \end{aligned} \tag{1}$$

$$MAX\ Z_2 = \sum_j \sum_n |U_{jn}| \tag{2}$$

$$subject\ to$$

$$\sum_i xi_{in} \geq d_{jn} \quad \forall j, n \tag{3}$$

$$\sum_k xj_{jk} \geq \omega_j \quad \forall j \tag{4}$$

$$\sum_j xj_{jk} = \sum_l xk_{kl} \quad \forall k \tag{5}$$

$$\sum_n xi_{in} \leq \beta_i \quad \forall i \tag{6}$$

$$\sum_j xj_{jk} \leq \gamma_k yc_k \quad \forall k \tag{7}$$

$$\sum_k xk_{kl} \leq \mu_l yr_l \quad \forall l \tag{8}$$

$$U_{jn} = \left(-P_n - dis_{jn}\right) yb_n \quad \forall j, n \tag{9}$$

$$d_{jn} = D_j e^{u_{jn}} yb_n \quad \forall j, n \tag{10}$$

$$\sum_k xj_{jk} \leq \sum_n d_{jn} \quad \forall j \tag{11}$$

$$\sum_{k} xk_{kl} = \sum_{i} xl_{li} \qquad \forall l \tag{12}$$

$$\sum_{l} xl_{li} \leq \beta_i \qquad \forall i \tag{13}$$

$$yc_k, yr_l, yb_n \in \{0,1\} \tag{14}$$

$$xi_{ij}, xj_{jk}, xk_{kl}, xl_{li} \geq 0 \tag{15}$$

Eq. (1) is the first objective of the model is to maximize the total profit of the supply chain. This profit is derived from the gap between the revenue and the total costs. The total costs of the supply chain include production costs, processing costs at collection and recycling centers, and transmission costs throughout the closed-loop supply chain.

Eq. (2) expresses the second objective which is to maximize the total utility of the supply chain. This relationship also indicates the maximum market share. Indeed, the higher the value of the sales centers from the customers' point of view, the more they want to buy from those centers. Therefore, the maximum amount of the market share is obtained by this objective function. Eq. (3) states that the total amount of the products delivered to each sales center should be greater than the demand created for that center.

Eq. (4) states that the total amount of the products delivered to collection centers should be greater than or equal to each customer's returned products. In fact, this constraint emphasizes that the defective products discarded by customers should reach the collection centers. Eq. (5) shows the balance of the materials in each collection center. This is because the amount of the products collected in a collection center should be equal to that of the products sent from the same center to the recycling centers. Eq. (6) states that the total amount sent from each producer cannot exceed its maximum capacity.

Eq. (7) states that, if a collection center is established, customers' products can be sent to it up to its maximum capacity. Eq. (8) states that a recycling center can be established, and recyclable items can be sent to it. Eq. (9) calculates the utility created in terms of the selling price as well as the distance to different sales centers. Eq. (10) calculates the amount of demand for each sales center according to its utility.

Eq. (11) states that the amount of the products which the customer returns to the collection centers is less than that of the products which it initially receives. Eq. (12) states that the amount of the products reaching each recycling center should be equal to that of the products which go to the production centers from that recycling center. Eq. (13) states the remanufacturing capacity of each production center. Finally, Eqs. (14) and (15) show the kind of decision variables.

3.1. Multi-objective optimization

In terms of the number of objective functions and optimization criteria, optimization problems can be divided into two types including single-objective optimization problems and multi-objective optimization problems. In the first type, the goal of solving the problem is to improve a single Performance Index (PI), the minimum or maximum value of which fully reflects the quality of the response obtained. However, in some cases, it is not possible to find a feasible solution to the optimization problem by relying on one indicator (Deb, 2014). In this type of problems, several objective functions or PIs have to be defined.

At the same time, their values are all optimized. In the case of multi-objective optimization, it is necessary to consider all the objectives simultaneously. For this purpose, this research makes use of goal programming and LP-metric.

3.2. LP-metric method

In the LP-metric method, the total power of relative deviations from optimal values is minimized. For a problem with *n* objective functions, the optimal value of each function must be obtained independent of the *n*-1 of the other objective functions. The GAMS software serves the purpose. In the optimal solution achieved separately for each of these *n* objectives, the constraints are constant and unchanged. The objective functions that are closer to their optimal values are more desirable. So, an objective function that involves the benefits of all the *n* objective functions should be sought for so as to bring them all closer to their optimal values. To this end, the sum of the relative deviations of the objectives from their optimal values must be minimized. The objective function in question is as follows (Goli et al., 2019):

$$Min\ Z = \left[\sum_{i=1}^{n} \left(\frac{f_i^* - f_i}{f_i^*}\right)^p\right]^{\frac{1}{p}} \tag{16}$$

where, $f_i^*$is the optimal value of the i^{th} objective function independent of the other objectives, and P is an adjustable parameter for which the values 1, 2 and 3 are suggested.

3.3. Goal programming

Linear goal programming is one of the basic techniques to make models in which the decision-maker seeks to achieve several goals simultaneously. Goal programming, like other methods, can be formulated in linear or nonlinear mathematical models. (Chen et al., 2017).

In this research, in order to implement the goal programming approach, first, the mathematical model is solved as a single-objective one and $f_i^*$is determined. Next, the number of the negative deviations from each objective function is calculated. Finally, the total deviations are minimized. In these cases, Eqs. (17)-(19) are used in the mathematical model.

$$Min\ Z_{GP} = d_1^- + d_2^- \quad (17)$$

$$z_1 + d_1^- - d_1^+ = f_1^* \quad (18)$$

$$z_2 + d_2^- - d_2^+ = f_2^* \quad (19)$$

4. Numerical results

4.1. Model verification

In this section, in order to evaluate the efficiency and performance of the proposed model and to comparatively study the applied method, five random problems with different dimensions (small, medium, large) have been designed. Ten random instances are also executed in each test problem. The sizes of the designed test problems are given in Table 1. Moreover, the values of the parameters are presented in Table 2.

Table 1. Data of the test problems

Indices	Test problem 1		Test problem 2		Test problem 3		Test problem 4		Test problem 5	
Number of production centers $\lvert i\rvert$	2	3	6	7	8	9	10	11	12	13
Number of customers $\lvert j\rvert$	5	6	15	16	20	21	25	26	30	31
Number of collection centers $\lvert k\rvert$	3	4	5	6	7	8	8	9	10	11
Number or recovery centers $\lvert l\rvert$	3	4	5	6	7	8	8	9	10	11
Number of selling centers $\lvert n\rvert$	3	4	5	6	7	8	8	9	10	11

As shown in Table 2, the values of the related parameters are generated in a uniform distribution. The corresponding calculations have been done with the GAMS 23.6 software and the BARON solver on a laptop with Intel Core i5 3GB RAM. To validate the proposed model, the first test problem is optimized once with the first objective and once with the second objective. The results are presented in Table 3. It should be noted that the time limit of 3600 seconds is considered to solve the problems.

Table 2. Values of the parameters in each test problem

Parameter	Value	Parameter	Value
cp_{in}	~U(2,6)	br_l	~U(11,17)
cc_{jk}	~U(3,5)	ω_j	~U(2,6)
cr_{ld}	~U(2,5)	fc_k	~U(100,200)
cw_{li}	~U(3,4)	fb_n	~U(70,130)
pr_i	~U(10,25)	fr_l	~U(80,150)
dis_{jn}	~U(400,600)	β_i	~U(100,200)
D_j	~U(4,8)	γ_k	~U(80,160)
bc_k	~U(10,15)	μ_l	~U(80,160)

Table 3. The results of optimizing the first test problem

Test problem 1	Net profit	Total utility	Solving time	Number of established selling centers	Number of established collection centers	Number of established recovery centers
Optimizing first objective	8.28931E+11	1026.785	22.923	1	1	1
Optimizing second objective	1.01864E+9	45483.172	123.40	1	1	1

For a better understanding of the proposed model, the optimal solution of the first test problem when solving the first objective is schematically displayed in Figure 1.

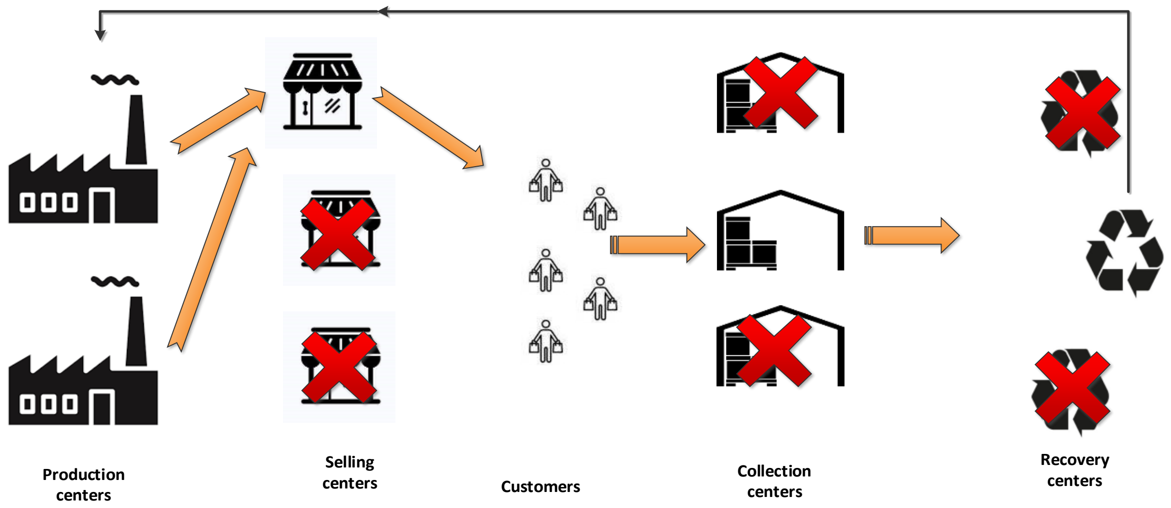

Figure 1. The scheme of the optimal network design in the first test problem

As shown in Figure 1, the output of the problem is the establishment of one unit of each facility, namely the first sales center, second collection center, and second recycling center. In order to deal with the multi-objective problem and turn it into a two-objective problem, the problem will be solved in the next section. For this purpose, all the objectives are taken into account by using the LP-metric and the goal programming methods.

4.2. Comparison of the solution methods

In this section, the sample test problems are optimized with the LP-metric method and different *P* values. As mentioned in Section 3, *P* is an adjustable parameter for which the values 1, 2, and 3 are suggested. These output values are considered for the problems presented in Table 4.

According to Table 4, the problems for the three different values of *P* are listed in order. Two problems are solved in each category, and the corresponding data are provided in the table. The second column presents the different values of *P* in the LP-metric method; $\bar{Z}$ is the values obtained by the LP-metric method, $f1$ and $f2$ represent the values in each problem category for the first and second objectives obtained by the LP-metric method, and $f1^*$ and $f2^*$ are the optimal single-objective problem-solving values separately obtained for the first and second objectives. As it can be seen, the lowest mean deviations in the LP-metric method are obtained for $P = 1$, which is calculated in the last column of Table 4. Therefore, this value of *P* is adopted as the criterion in the next calculations. Now, using the goal programming method, the output of the problem is presented in Table 5. In Table 5, Z_{GP} represents the total undesirable deviation (i.e., the goal programming objective value). After the obtained computational results are reviewed, the average values of the objective functions are compared in different methods (Figures 2-4).

Table 4. The results of implementing the LP-metric method

Test problem	P	$(\bar{Z})$	$f1$	$f2$	$f1^{*}$	$f2^{*}$	Solving time (s)	$(\bar{\bar{Z}})$
1	1	1.851	55494.804	29516.815	8.2893E+10	45483.172	23.19	0.768
2		0.296	162015.722	196808.303	2.11E+11	115527.3	64.26	
3		0.762	194158.248	280347.588	4.13E+11	226506.2	1294.5	
4		0.514	652197.16	418973.233	5.14E+11	281904.7	1952.1	
5		0.421	786935.732	588013.012	6.79E+11	372507.2	3600	
1	2	1.540	1.40821E+7	29516.800	8.2893E+10	45483.172	64.1	1.108
2		1.000	-4543.220	115557.000	2.11E+11	115527.3	86.16	
3		1.000	156009.000	225368.000	4.13E+11	226506.2	1422.16	
4		1.000	12461.400	281915.000	5.14E+11	281904.7	2194.06	
5		1.000	1512440.000	370930.000	6.79E+11	372507.2	3600	
1	3	1.506	330169.000	29516.800	8.2893E+10	45483.172	185.32	1.0786
2		1.000	-59018.600	115527.000	2.11E+11	115527.3	909.66	
3		0.996	357863.000	280348.000	4.13E+11	226506.2	2612.04	
4		0.960	258648.000	418955.000	5.14E+11	281904.7	3600	
5		0.931	792626.000	588013.000	6.79E+11	372507.2	3600	

Table 5. The results of implementing the goal programming method

Test problem	Z_{GP}	$f1$	$f2$	$f1^{*}$	$f2^{*}$	Solving time (s)
1	8.27631E+5	54640.18	30296.06	8.2893E+10	45483.172	121.8473
2	4.27232E+6	158069	197333.8	2.11E+11	115527.3	359.19824
3	2.56632E+8	190281.2	284685.4	4.13E+11	226506.2	2274.565
4	4.32509E+7	617904.7	467549.1	5.14E+11	281904.7	3600
5	5.70672E+7	785247	646720.2	6.79E+11	372507.2	3600

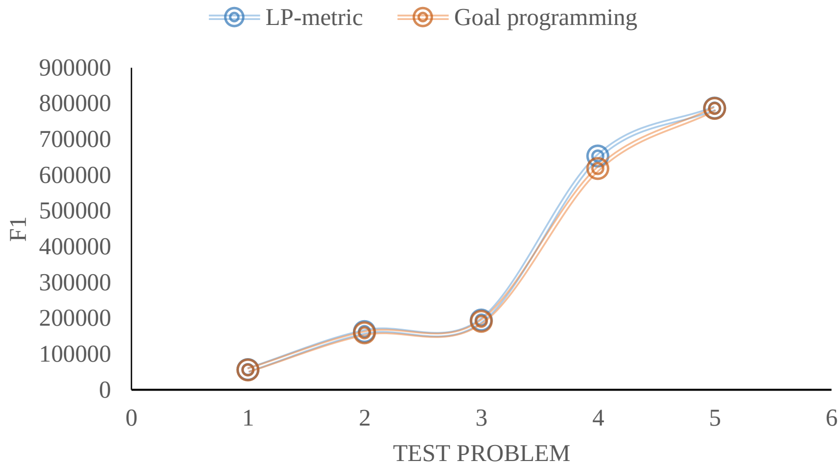

Figure 2. Comparison of different methods in terms of the first objective function

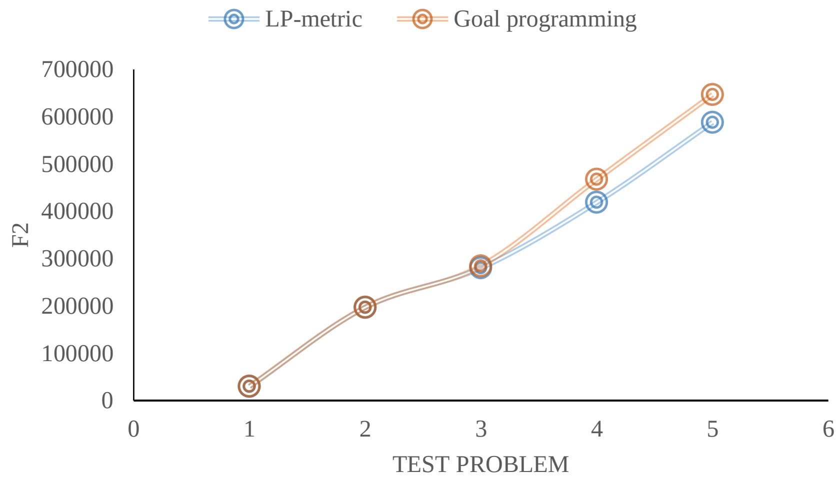

Figure 3. Comparison of different methods in terms of the second objective function

As it can be seen in Figures 2 and 3, the values of the goals obtained through different methods are very different for different problems. The differences are more visible in the goal values of the problems with larger dimensions. As in problem 4, there is a big difference between the goals. Figure 4 presents the results of comparing the solution times in different methods.

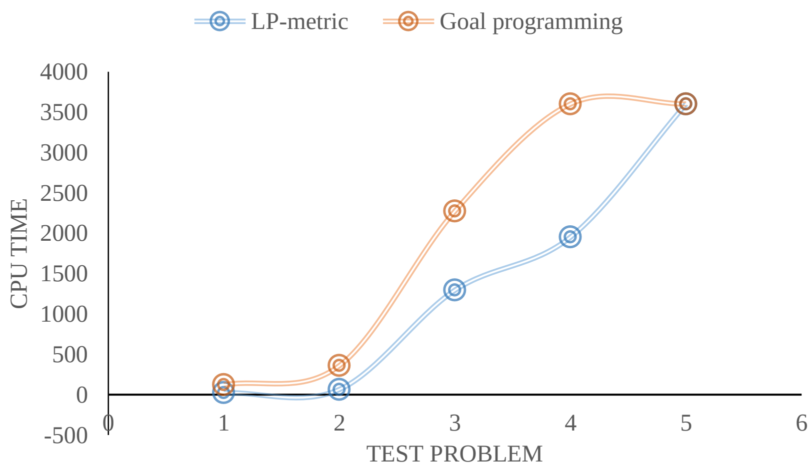

Figure 4. Comparison of different methods in terms of the CPU time

As shown in Figure 4, the goal programming method has a much longer solution time in all the problems. This is a major reason for the existence of equality constraints in the problem, which increases the complexity of the problem. To use the best method, the simple additive weighting (SAW) approach is implemented. The weight of each method is presented in Table 6. The data in the table actually refer to the optimal average values of the objectives in different issues. It should be noted that the effect of solution time on weight determination is negative because the goals are presented in their maximized state. So, it is a good manner of gaining the most weight.

Table 6. Decision matrix

Element	$f1$	$f2$	Solving time (s)
Weights	0.6	0.3	0.1
LP-metric	370160.3	302731.8	1386.81
Goal programming	361228.4	325316.9	1991.131

As Table 6 suggests, first, the values obtained in the matrix are normalized, and then the weight of each method is determined from the following equation:

Weight of each method =
(normalized mean of the first objective × weight of the first objective)
+ (normalized mean of the second objective × weight of the second objective)
- (average solving time × weight of the solving time)

Table 7. Ranking the solution methods

Methods	SAW criteria	Ranking
LP-metric	0.509018	1
Goal programming	0.490982	2

After the review of the solution methods used to solve the problem, it has emerged that the LP-metric method has the best performance. This method has proved to work the best in averagely 80% of the cases (i.e., in 4 out of 5 problems). It is, thus, suggested for parameter analysis.

4.3. Sensitivity analysis

In this section, in order to investigate the uncertainty and real conditions in the problem, a sensitivity analysis is performed on the total customers' demand (D_j) as the main parameter of the first problem. To this end, the first test problem designed in the previous section is selected. A range of changes in this parameter is tested, from a decrease of 20% to an increase of 20%. The results for each period of change are presented in Table 8. The results of the analysis are also provided in Figures 5 and 6.

Table 8. Sensitivity analysis of the demand parameter

Objectives	**Parameter changing percentage**				
	-20%	**-10%**	**0**	**+10%**	**+20%**
Z1	20183.30	55485.61	55494.80	53597.307	63801.60
Z2	21871.96	26535.6167	29516.815	35201.7536	37397.8046

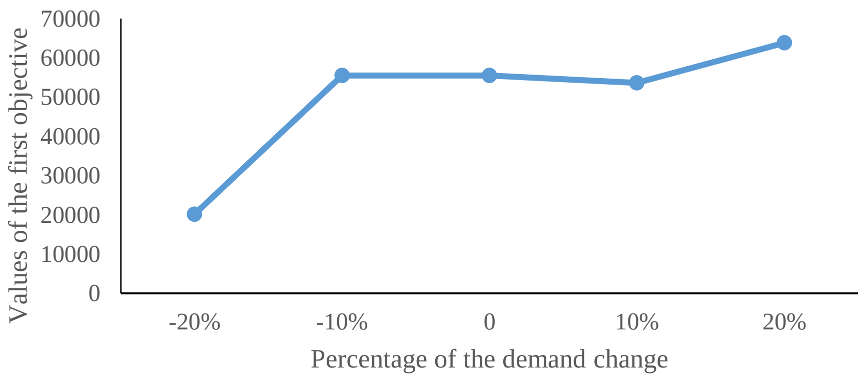

Figure 5. The values of the first objective function according to the change in the demand parameter

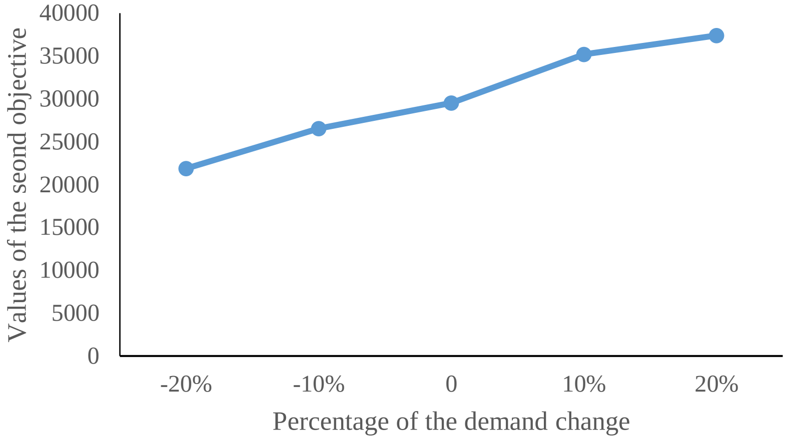

Figure 6. The values of the second objective function according to the change in the demand parameter

According to Figures 5 and 6, when the demand parameter increases, the objectives take different values. For example, in response to an increase in the demand parameter, the first objective initially decreases and then increases with a sharper slope. Such a change causes different amounts to be set for the selling price, which, in turn, changes the first objective of the problem. In response to a 10% reduction in the demand parameter, the objective declines slightly. A 20% reduction in the demand, however, makes the first objective decline with a very steep slope. The second objective is to increase the demand parameter. The variation of one is correlated to that of the other with different slopes.

5. Discussion

In this section, in order to review the results better, more details are provided. At the beginning of Section 4, a numerical example was solved, and the optimal supply chain design was determined. As shown in Figure 1, out of three sales centers, only one was established. A closer examination of the parameters reveals that each sales center, with its capacity, is able to meet the entire demand of customers. If another sales center is set up, the costs of the supply chain will be more, and, as a result, its net profit decreases. In such a case, the chain deviates from its optimal solution. The same is true of collection centers and recycling centers.

The results show that a change of demand can have sudden effects on the first objective function of the problem. Therefore, supply chain managers should seriously focus on the amount of demand and monitor the market; managing the changes in these parameters can positively affect the overall structure of the chain. Moreover, due to the multi-objective structure of the model and with regard to various factors such as competitive conditions and chain utility for customers, this research is of insights for closed-loop supply chain management in competitive conditions.

6. Conclusion

In this study, after a detailed review of the literature in the field of supply chains, a gap has been identified between research and innovation. The main contribution of this research is the consideration of demand behavior as a function of product prices in competitive conditions. On this basis, the aim of the study is set to design a closed-loop supply chain in which the price is a fundamental factor that can determine the amount of demand and, consequently, change the structure of the supply chain. Thus, a bi-objective mathematical model is presented according to the research assumptions as well as the function stating the relationship between the amount of demand and the price. The first objective is to reduce the costs and increase the chain revenue, i.e., to maximize the supply chain profits. The second objective is to focus on the market share and increase the utility of sales centers. This mathematical model has been solved with LP-metric and goal programming methods.

In a competitive environment, if a supply chain does not perform well, it cannot properly meet the needs of customers and, as a result, will be out of the competition cycle. Therefore, an important practical implication of this research is that supply chain managers should use a suitable strategy for locating, distributing and selling products in a competitive environment. It is to be noted that this research has a few limitations such as the lack of accurate environmental data to investigate the adverse effects of the chain on the environment and the limited efficiency of the GAMS software to solve the developed mathematical model.

In order to conduct such type of research in other aspects, it is suggested that problems be examined for multi-product cases and in terms of demand certainty as well as market share. To deal with uncertainty, a robust optimization approach is suggested. It is also recommended to use new multi-objective meta-heuristic algorithms such as Multi-objective Gray Wolf Optimizer (MOGWO) and Multi-objective Salp Swarm Algorithm (MOSSA) (Dhiman and Garg, 2020).

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