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Research paper

A tactical multi-objective multi-product green supply chain planning optimization model

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Abstract

In this paper, a Multi-objective, multi-products, and multi-period green supply chain optimization model that consider some important economic and environmental risks and their associated impacts are developed using the lexicographic procedure. Managing the impacts of both side of economic and environmental risks, maximizing opportunities' impacts and minimizing threats' impacts. Economic impacts include maximizing profit, maximizing the overall service level while minimizing the total cost, and the environmental impacts include minimizing energy consumption and minimizing CO_2 emissions from transportation operations. The model considers transportation mode selection (Heavy or light trucks). The model efficacy has been proved through results discussion. Moreover, the effect of different allowable deviation on the objectives is discussed.

Keywords: *Green Supply Chain; Multi-Objective; Production Planning; Goal Programming; Multi-Products; Risk; Transportation Modes.*

1. Introduction

A supply chain (SC) is defined as the configuration of facilities that fulfil customers' requests by providing them with products [1], [2]. Supply chain management may be defined as the coordination of different business functions within a company and across the SC with the objective of improving the SC performance and individual companies [3].
There are a lot of classical models evaluate the economic performance of the supply chain without considering environmental awareness. Nowadays, it is necessary to incorporate environmental thinking into SC management [4] as there are some risks with negative impacts which may threaten the environment when supplying any project or customer with the required goods. The new regulations regarding carbon tax in most countries has created a challenge to reduce CO_2 emissions in business operations. According to the report of the International Energy Agency (2009), the annual CO_2 emission from transport activities accounts for approximately 30% global share [5] which can be considered as a risk with a considerable harmful impact on the environment.
The environmental costs affect the SC performance and therefore cannot be ignored [4]. Greening SC activities have many benefits like resources saving, energy consumption reduction, and waste and pollution reduction.
An optimization model to select transportation modes, minimizing total costs in addition to the effects of CO_2 emissions on environmental has been suggested by Le and Lee [5]. Hoen et al. [6], Demir et al. [7], and Lin et al. [8] studied green transportation, Jain et al. [9] and Xie [10] focused on consumption of energy. In addition, other works that may be referred to are concerning supplier selection [11, 12], integrated modelling approaches [13, 14], and/or empirical case studies [15], [16]. Fan Wang et al [17] studied an SCND problem with environmental concerns but they considered a single period model without inventory stored in each facility.
Supply chains were optimized with the general objective to minimize total costs [18]. Sustainability issues are becoming more prevalent and environmental concerns are required to be addressed [19], [20].
The lexicographic technique has been used by some researchers like Sawik [21] who solved the multi-period production scheduling problem using it. Also, Mavrotas, [22]; Pishvaee et al. [23] also used the lexicographic procedure to find the Pareto frontier extreme points.
The ε-constraint method is used by other researchers. Guillén et al. [24] developed a multi-objective model to solve the problem of SC design taking into account the NPV, demand satisfaction, and financial risk. Altiparmak et al. [25] formulated a multi-objective MINL model for a single product supply chain network design (SCND). Liu and Papageorgiou [26] studied the production, distribution, and capacity planning of SCs using a multi-objective MILP formulation.
Al-e- Hashem et al. [13] studied a stochastic green SC problem, which contained multi-product, multi-transportation mode, multi-plant, multi-period, and limitations of CO_2 emissions.
In this study, a multi-period multi-objective multi-product green SC location allocation optimization model that consider some important economic and environmental risks and their associated impacts are developed using the lexicographic procedure. In other words, managing the impacts of both side of economic and environmental risks, maximizing opportunities' impacts and minimizing threats' impacts. Economic impacts include maximizing profit, maximizing Overall Service Level (OSL) while minimizing the total cost, and the environmental impacts include minimizing energy consumption and minimizing CO_2 emissions from transportation operations. The model considers transportation mode selec-

tion (Heavy or light trucks). The very popular environment index CO_2 emission only consider as the only environmental influence which can be measured easily. This work is an extension of the work done by M. S. Al-Ashhab et al. [27].

There are many problems have been tackled in this developed model at the same time; location and allocation of the suppliers and customer; optimizing production planning considering multi-objectives taking the beginning and ending inventories into account.

The system consists of three potential suppliers serve the facility to serve three customers/distributor as shown in Fig. **1**.

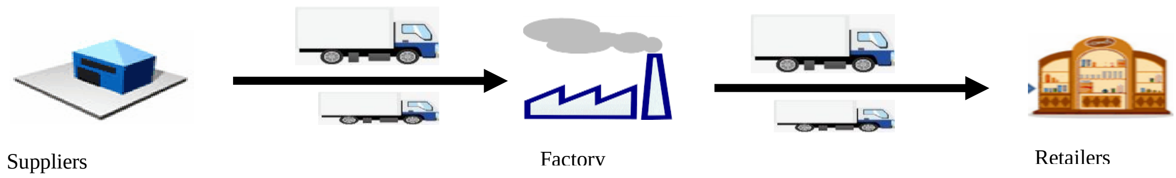

Fig. 1: Supply Chain Diagram.

In addition to the assumptions mentioned in [27], the following assumptions are considered:

1) Vehicles are divided into heavy and light trucks.
2) All shipments should have the full load of the used truck.
3) Each truck should serve only one distributor at the same time.
4) The amount of CO_2 emission depends on the weight of the shipment and the distance travelled in addition to the truck type.
5) The model considers five objectives; maximizing both profit and OSL while minimizing total cost, CO_2 emissions and fuel consumption

2. Model formulation

In addition to the sets, parameters and variables mentioned in [27], the model involves the following sets, parameters and variables:

Sets:

M: Set of trucks, indexed by m

Parameters:

$CAPTM_m$: carrying capacity of truck m (kg/truck)

FC_{mt}: fuel consumption of truck m per km in period t (gallon/km)

GE_{mt}: gas (CO_2) Emissions of truck m per km in period t (ton/gallon)

FP_{mt}: fuel price of truck mode m per gallon in period t ($/gallon)

TC_{mt}: transportation cost of the transportation mode per kilometer in period t ($/km)

Decision Variables:

N_{msft}: The total number of mode m shipments from supplier s to the facility in period t

N_{mfct}: The total number of mode m shipments from the facility to customer c in period t

2.1. Model objectives

There are five objectives have been considered through this developed model:

- Profit
- Overall service level
- Fuel consumption
- CO_2 emissions
- Total cost

2.1.1. Profit objective

The profit is defined as by total revenue after subtracting the total cost. The total revenue may be calculated as in Equation 1.

$$\text{Total Revenue} = \sum_{c\in C}\sum_{p\in P}\sum_{t\in T}(Qfc_{cpt} + Ifc_{cpt})\, Bf_p\, P_{pct} \tag{1}$$

2.1.2. Overall service level objective

$$\text{CustomerServiceLevel}_c = \sum_{p\in P}\sum_{t\in T}(Qfc_{cpt} + Ifc_{cpt}) * Bf_p * W_p \Big/ \sum_{p\in P}\sum_{t\in T} DEMAND_{cpt} * W_p \tag{2}$$

2.1.3. Fuel consumption objective

The fuel consumed by all trucks in transporting raw material from all suppliers to the facility and from the facility to all customers is calculated by Equation 3.

$$\sum_{t\in T}\sum_{s\in S}\sum_{m\in M} N_{msft}\, FC_{mt}\, D_{sf} + \sum_{t\in T}\sum_{c\in C}\sum_{m\in M} N_{mfct}\, FC_{mt}\, D_{fc} \tag{3}$$

2.1.4. Gas emissions objective

The amount of CO_2 emitted by all trucks in transporting raw material from all suppliers to the facility and from the facility to all customers is calculated by Equation 4. Gas emissions per unit distance depend on the age or certification standard of the vehicle/engine, as well as driving conditions. But it is assumed to be constant in this model.

$$\sum_{t\in T}\sum_{s\in S}\sum_{m\in M} N_{msft}\, GE_{mt}\, D_{sf} + \sum_{t\in T}\sum_{c\in C}\sum_{m\in M} N_{mfct}\, GE_{mt}\, D_{fc} \tag{4}$$

2.1.5. Total cost objective

The total cost is the summation of fixed, material, manufacturing, non-utilized capacity, back-ordering, transportation, and inventory holding costs calculated as shown in Equations (5-11).

1) Fixed Cost

$$\text{Fixed cost} = FCf \tag{5}$$

2) Material costs

$$\text{Materialcost} = \sum_{s\in S}\sum_{t\in T} Q_{sft}\, B_s\, MatCost_{st} + \sum_{p\in P} IIf_p\, W_p\, MatCost_{s1} - \sum_{p\in P} FIf_p\, W_p\, MatCost_{sT} \tag{6}$$

3) Manufacturing costs

$$\text{Manufacturing costs} = \sum_{c\in C}\sum_{p\in P}\sum_{t\in T} Q_{fcpt}\, Bf_p\, MH_p\, Mc_t + \sum_{p\in P}\sum_{t\in T} Iff_{pt}\, Bf_p\, MH_p\, Mc_t + \sum_{p\in P} IIf_p\, MH_p\, Mc_1 - \sum_{p\in P} FIf_p\, MH_p\, Mc_T \tag{7}$$

4) Non-Utilized capacity cost (for the facility)

$$\sum_{t\in T}((\mathrm{CAPH}_{ft})\,L_f - \sum_{p\in P}\sum_{c\in C}(Q_{fcpt}\,Bf_p\,MH_p) - \sum_{p\in P}(Iff_{pt}\,Bf_p\,MH_p))\,NUCCf \quad (8)$$

5) Back-ordering cost (for customers)

$$\sum_{p\in P}(\sum_{c\in C}(\sum_{t\in T}(\sum_{1}^{t}\mathrm{DEMAND}_{cpt} - \sum_{1}^{t}(Q_{fcpt} + Ifc_{cpt})\,Bf_p))\,SCPU_p \quad (9)$$

6) Transportation costs

$$\sum_{s\in S}(\sum_{t\in T}\sum_{m\in M}N_{msft}\,Tc_{mt}\,D_{sf}) + \sum_{c\in C}(\sum_{t\in T}\sum_{m\in M}N_{mfct}\,Tc_{mt}\,D_{fc}) \quad (10)$$

7) Inventory holding costs

$$\sum_{p\in P}IIf_{pt}\,Bf_p\,W_p\,HC + \sum_{p\in P}\sum_{t=1}^{T-1}Rf_{pt}\,Bf_p\,W_p\,HC \quad (11)$$

2.2. Constraints

There are two categories of constraints have been taken into consideration in this model to ensure flow balancing and capacity limits

2.2.1. Balancing constraints

$$\sum_{s\in S}Qsf_t B_s = \sum_{c\in C}\sum_{p\in P}Qfc_{cpt}Bf_pW_p + Iff_{pt}Bf_pW_p, \forall t\in T \quad (12)$$

$$Iff_{p1}Bf_p + IIf_p = Rf_{p1}B_{fp} + \sum_{c\in C}Ifc_{cp1}Bf_p, \forall p\in P \quad (13)$$

$$Iff_{pt}Bf_p + Rf_{p(t-1)}Bf_p = Rf_{pt}Bf_p + \sum_{c\in C}Ifc_{cpt}Bf_p, \forall t\in 2\to T, \forall p\in P \quad (14)$$

$$Rf_{pT}Bf_p = FIf_p, \forall p\in P \quad (15)$$

$$(Qfc_{cpt} + Ifc_{cpt})Bf_p \le \mathrm{DEMAND}_{cpt} + \sum_{1\to t}\mathrm{DEMAND}_{cp(t-1)} - \sum_{d\in D}(Qfc_{cp(t-1)} + Ifc_{cp(t-1)})Bf_p, \forall t\in T, \forall c\in C, \forall p\in P \quad (16)$$

Constraint (12-16) ensures flow balancing of materials and products.

2.2.2. Capacity constraints

$$Qsf_t\,B_s \le CAP_{st}\,L_s, \forall t\in T, \forall s\in S \quad (17)$$

$$\sum_{s\in S}Qsf_t\,B_s \le CAPMf_t\,L_f, \forall t\in T \quad (18)$$

$$(\sum_{c\in C}\sum_{p\in P}Qfc_{cpt}\,Bf_p + \sum_{p\in P}Iff_{pt}\,Bf_p)\,MH_p \le CAPHf_t\,L_f, \forall t\in T \quad (19)$$

$$Qsf_t\,B_s = \sum_{m\in M}(CAPTM_m\,N_{msft}), \forall s\in S, \forall t\in T \quad (20)$$

$$(\sum_{p\in P}Qfc_{cpt} + \sum_{p\in P}If_{cpt})\,Bf_pW_p = \sum_{m\in M}(CAPTM_m\,N_{mfct}), \forall c\in C, \forall t\in T \quad (21)$$

$$\sum_{p\in P}Rf_{pt}Bf_pW_p \le CAPFS_t\,L_f, \forall t\in T \quad (22)$$

Constraint (17-19) ensures that all facilities work within their limited capacities.
Constraint (20) ensures the equality of the total weight of materials transported from each supplier at any period and the capacities of the used trucks
Constraint (21) ensures that the total weight of products transported from the facility and its store to any customer at any period is equal to the capacities of the used trucks
Constraint (22) ensures that the residual inventory at the facility store does not exceed its storing capacity at each period.

3. Model verification

3.1. Model inputs

To verify the solving capability of the model the following example is solved, and the results are analyzed. The assumed demands are shown in Table 1 while Table 2 represents other parameters. The five objectives are arranged as follows: Profit, total cost, OSL, CO_2 emissions and fuel consumption without any allowable deviation for all of them.

Table 1: Demand of the Three Customers of Products Over 6 Periods

Period		1	2	3	4	5	6
Customer 1	Product 1	0	8500	4500	7500	3500	8500
	Product 2	5500	0	4500	7500	3500	8500
	Product 3	5500	8500	0	7500	3500	8500
Customer 2	Product 1	5500	8500	4500	0	3500	8500
	Product 2	5500	8500	4500	7500	0	8500
	Product 3	5500	8500	4500	7500	3500	0
Customer 3	Product 1	5500	8500	4500	7500	0	8500
	Product 2	5500	8500	0	7500	3500	8500
	Product 3	0	8500	4500	7500	3500	8500

Table 2: List of Input Parameters and Their Respective Values

No.	Input parameter	Value	Unit	No.	Input parameter	Value	Unit
1	S and C	3	--	14	MCft	10	$/hr
2	P	3	--	15	MHp	1, 2, 3	hrs
3	IIfp	500, 1000, 1500	Unit	16	MCft	10	$/hr
4	FIfp	1000, 1500, 2000	Unit	17	NUCCf	5	$/hr
5	Ppct	100, 150, 200	$/Unit	18	SCPUp	5, 10, 15	
6	W1,2,3	1, 2, 3	Kg	19	HC	3	$/kg. period
7	MH1,2, 3	1, 2, 3	Hrs	20	Bs	100	Unit

8	CAPst	50,000	Kg	21	Bfp	10	Unit
9	CAPHft	120,000	Hrs	22	FCmt	0.02, 0.01	gallon/km
10	CAP-Mft	100,000	Kg	23	GEmt	3, 2	g/km
11	CAP-FSft	20,000	Kg	24	TCmt	0.3, 0.2	$
12	CAP-TM_m	300, 200	Kg/truck	25	FC	50,000	$
13	MatCost	10	$/kg				

3.2. Results and discussion

The model is solved using Xpress-MP 7.9 software on an Intel® Core™ i3-2310M CPU @2.10 GHz (3 GB of RAM). The resulted optimal SCND is shown in Fig. **2**. According to the optimum network, the facility has to contract only the first and second suppliers to get the required materials to achieve minimum transportation cost. The quantities of products delivered to each customer in the planning horizon are shown in Table 3. The values of the five objectives mentioned in the previous section are 29526609 $, 12781641$, 97%, 4414099 lbs and 29427$ respectively

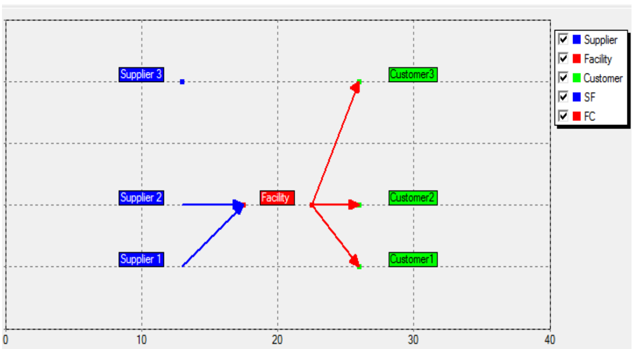

Fig. 2: The Optimal Supply Chain Network Design.

Table 3: Quantities of Products Delivered to Each Customer in All of the Six Periods

		Period					
		1	2	3	4	5	6
Customer 1	Product 1	0	8500	4500	7500	3500	8500
	Product 2	5500	0	4500	7500	3500	8500
	Product 3	5500	8500	0	7500	3500	8500
Customer 2	Product 1	5500	500	12500	0	3500	8500
	Product 2	5500	0	13000	7500	0	8500
	Product 3	5500	8500	4500	7500	3500	0
Customer 3	Product 1	5500	2500	10500	7500	0	8500
	Product 2	5500	8500	0	7490	3510	8495
	Product 3	0	8500	4500	840	10160	2670

All customers are served with different service levels as shown in Fig. **3**. It can be noticed that the service level of the third customer is the lowest because of its distance to the facility.

Fig. 3: The Resulted CSL of the Customers.

Flow balancing of weights through the first three periods are verified as shown in Figures 4a while flow balancing of weights through the last three periods are verified as shown in Figure 4b.

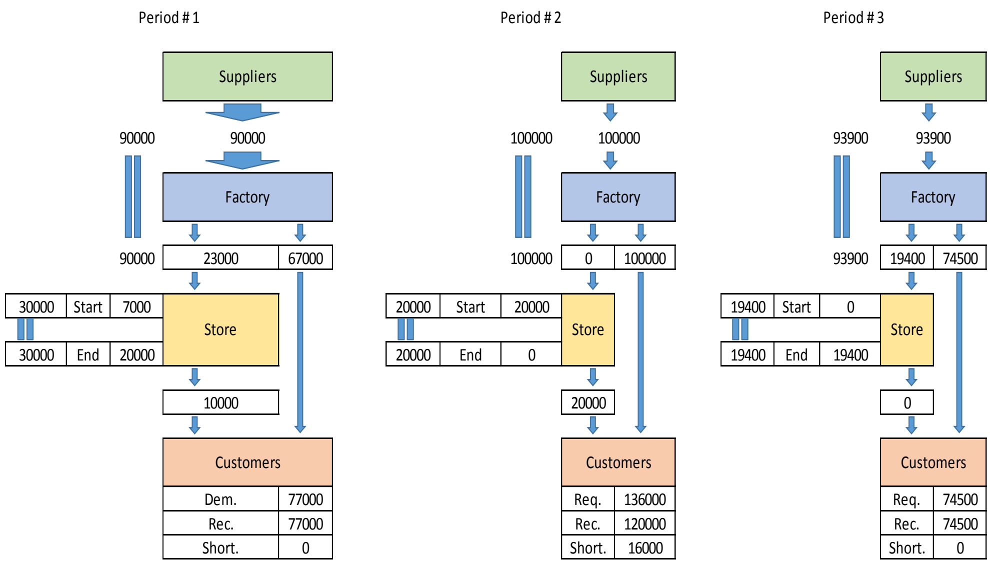

Fig. 4: A) Flow Balancing of Weights during the First Three Periods.

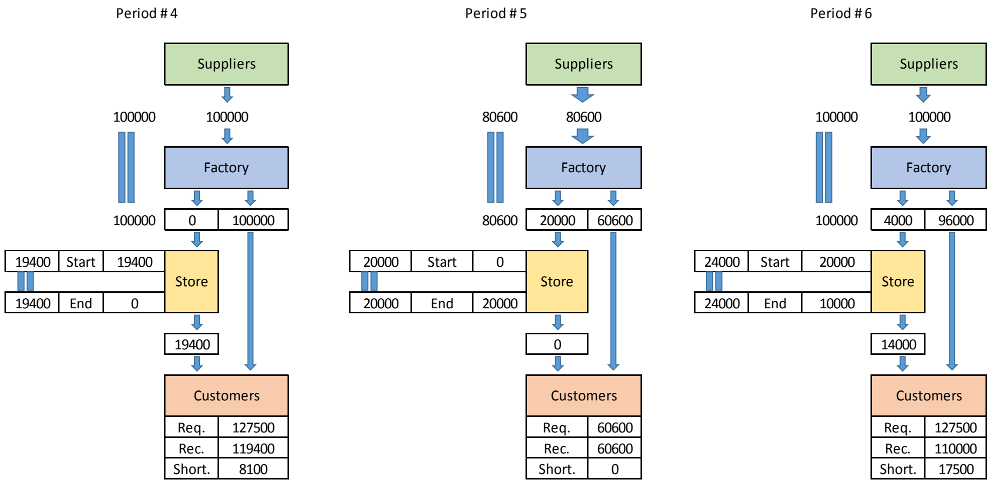

Fig. 4: B) Flow Balancing of Weights during the Last Three Periods.

The tactical plan obtained from the model is illustrated in Figure 5. Where the total demand for the first period is totally satisfied and an extra inventory of 13,00 0kg is added to the initial inventory of 7000 kg to increase the residual inventory of the first period to 20,000 kg which is used to reduce the shortage of the second period of demand 136,000 kg which exceeds the facility capacity to 16,000 kg instead of 36,000 kg. In the third period of low demand, the demand and the backorder of 16,000 kg are satisfied, and an amount of 19,400 kg is stored to reduce the potential shortage of the fourth period which is totally satisfied during the fifth period in addition to storing of 20,000 kg to satisfy both final inventory and the excess demand of the sixth period. Regarding this plan, the accuracy and logicality of the results have been verified.

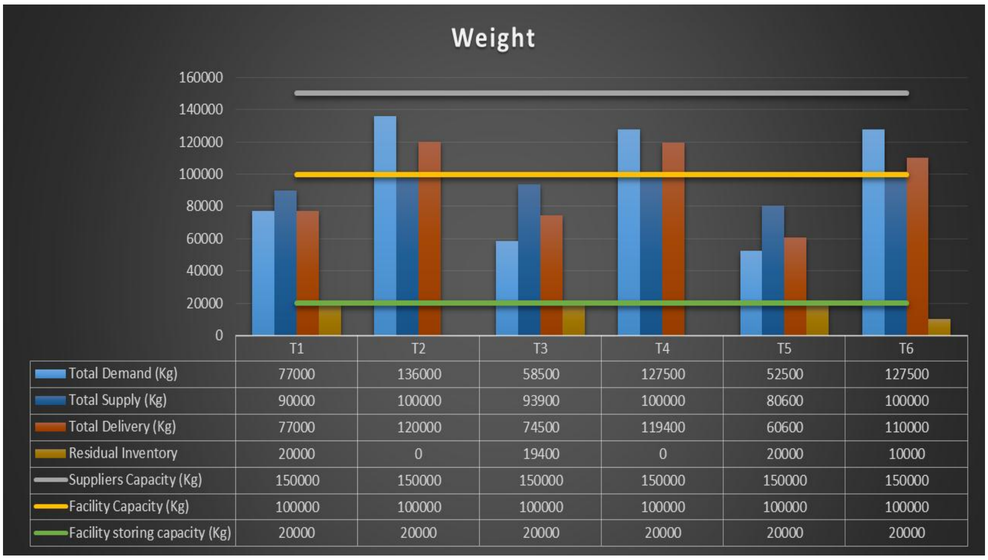

Fig. 5: Relationship between the Demand, Supply, Residual and Delivered to the Customer and All Echelons Capacities.

Table 4: Number of Shipments of Both Transportation Modes in the Six Periods

Period	Transportation from suppliers to the facility						Transportation from the facility to customers					
	Mode 1			Mode 2			Mode 1			Mode 2		
	S1-F	S2-F	S3-F	S1-F	S2-F	S3-F	F-C1	F-C2	F-C3	F-C1	F-C2	F-C3
1	0	0	0	200	250	0	1	0	1	136	165	81
2	0	0	0	250	250	0	0	0	0	167	178	255
3	1	0	0	218	250	0	1	0	0	69	212	90
4	0	0	0	250	250	0	0	0	0	225	162	210
5	0	0	0	153	250	0	0	1	1	105	94	101
6	0	0	0	250	250	0	0	1	1	255	126	166

The numbers of shipments of both transportation modes are presented in Table 4 where it is noticed that the heavy truck mode is used mostly in all shipments because of its low cost regardless its CO_2 emissions since the first governing objective was the profit in this example.

4. Computational results and analysis

In this section, the effect of objectives priorities on the value of each of them are studied and analyzed. The five cases of different arrangements and the corresponding results are presented in Table 5.

Table 5: The Five Arrangements and Their Corresponding Results

	Case 1		Case 2		Case 3		Case 4		Case 5	
	T	Values	T	Values	T	Values	T	Values	T	Values
1	P	29497182	CE	3000	TC	11171735	OSL	97	FC	15
2	CE	7356831	P	-13940030	P	10988267	P	29497182	P	-13940030
3	TC	12811068	TC	13940030	OSL	51	TC	12811068	TC	13940030
4	OSL	97	OSL	0	CE	3423274	CE	7356831	OSL	0
5	FC	36830	FC	15	FC	17137	FC	36830	CE	3000

T: Target, P: Profit, TC: Total Cost, OSL: Overall Service Level, FC: Fuel Consumption, and CE: CO_2 Emissions

The results of each objective in the five arrangements are shown in Figure 6. Figure 6a shows that the same maximum values of the profit have been gotten when giving the priority to both profit and OSL where they are consistent objectives while its minimum values have been gotten when giving the first priority to CO_2 emissions or fuel consumption where both of them are inconsistent objectives with the profit.

Figure 6b shows that the total cost has gotten its optimal (minimum) value in the second case since it took the first priority while its worse values, as well as the profit and OSL (as shown in Figure 6c), have happened in the two cases of giving the first priority to CO_2 emissions or fuel consumption where the fuel consumption and gas emissions had given the first priorities.

Figures 6d and 6e show that both objectives of fuel consumption and CO_2 emissions are minimized to zero when any one of them take the priority because of production stopping where they have bad values when both profit and OSL take the priority.

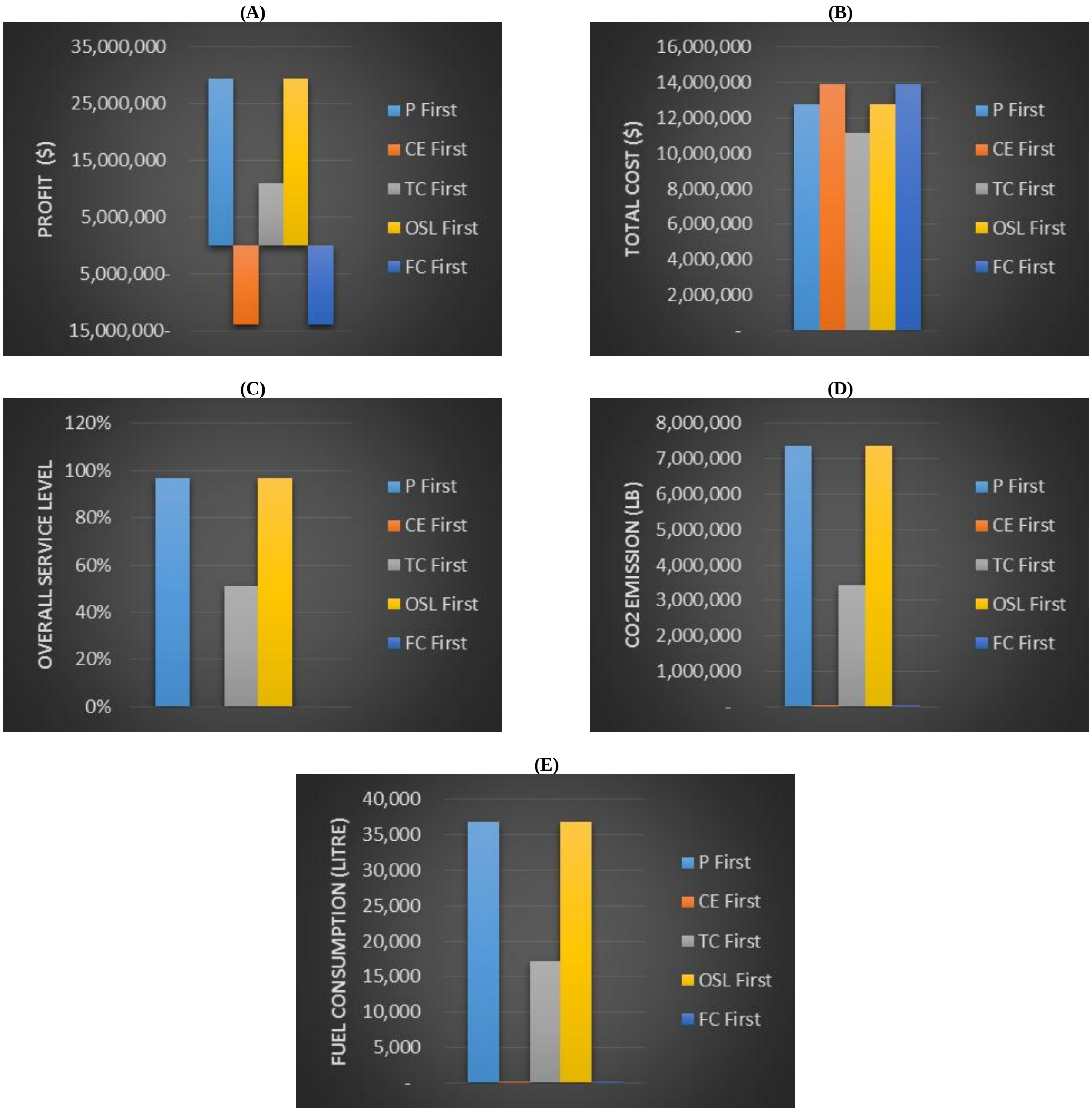

Fig. 7: Objectives' Values in the Five Cases.

In conclusion, it is not beneficial to optimize these five objectives at the same time since optimizing profit, CO_2 emissions and the total cost are enough. Giving the priority to minimizing the CO_2 emissions is not accepted practice. So, it is suggested to give the priority to increase the profit which maximizing the impact of this opportunity, the second priority to decrease the CO_2 emissions which minimizing the impact of this threat and the third priority to the total cost with certainly allowable deviation for the profit to ensure acceptable values. Decreasing the total cost will increase the profit also which maximizing the impact of this opportunity.

5. Sensitivity analysis

Through this section, the effect of changing the allowable deviation on the profit-total cost, profit-OSL and profit CO_2 emissions are presented and discussed.

The effect of allowable deviation on the profit – total cost relationship is illustrated in Figure 8 in which it may be noticed that increasing the allowable deviation reduces the profit value more than reducing the total cost. So, it is not recommended to increase the allowable deviation percentage when optimizing the profit and total cost.

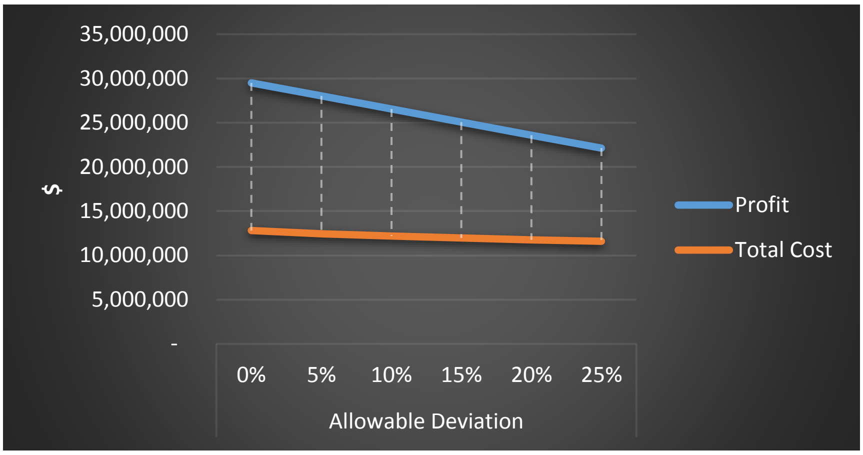

Fig. 8: The Effect of Allowable Deviation on the Profit – Total Cost Relationship.

Table **6** illustrates the effect of profit and OSL relationship in which it may be noticed that increasing the allowable deviation reduces the profit value without any effect on the OSL value. So, it is also not recommended to increase the allowable deviation percentage when optimizing the profit and OSL.

Table 6: The Effect of Allowable Deviation on the Profit – OSL Relationship

	Allowable Deviation					
	0%	5%	10%	15%	20%	25%
P	29,497,181	28,300,488	28,321,475	28,321,475	28,294,488	28,321,475
OSL	97 %	97 %	97 %	97 %	97 %	97 %

While the effect of allowable deviation on the profit – CO_2 emissions relationship is illustrated in Figure 9 in which it may be noticed that increasing the allowable deviation reduces both profit value and CO_2 emissions. So, it is recommended to adjust the allowable deviation percentage when optimizing the profit and CO_2 emissions because it has a considerable effect on both.

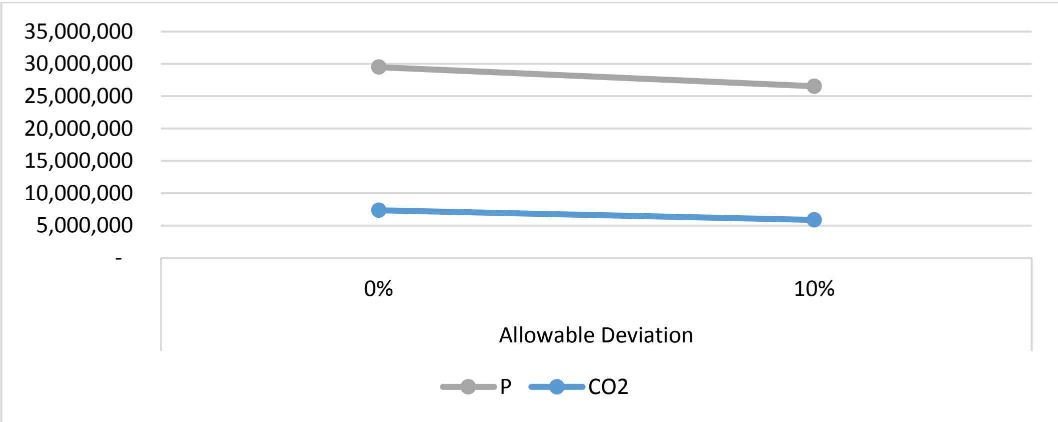

Fig. 9: The Effect of Allowable Deviation on the Profit – CO_2 Emissions Relationship.

In the same manner, the effect of allowable deviation on the profit – fuel consumption relationship as shown in Figure 10 illustrated that in which it may be noticed that increasing the allowable deviation reduces both profit value and fuel consumption. So, it is also recommended to adjust the allowable deviation percentage when optimizing profit and fuel consumption because it has a considerable effect on both.

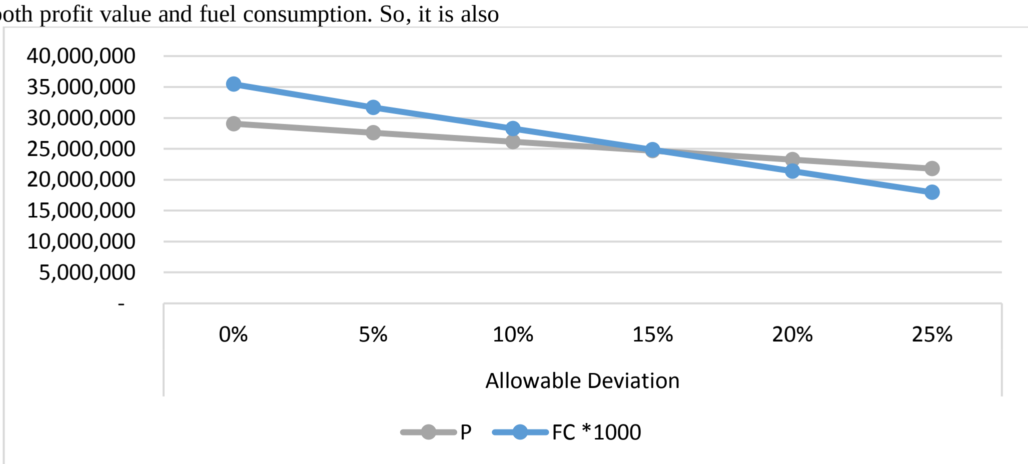

Fig. 10: The Effect of Allowable Deviation on the Profit – Fuel Consumption Relationship.

6. Conclusion

This research developed a green SCN model considering multi-commodity, multi-period and multi-objective mixed integer linear programming model. The developed model incorporated CO_2 emissions and fuel consumption during transportation processes. The model can select the transportation type (Heavy or Light truck) in addition to other planning variables to optimize five objectives; profit, total cost, overall service level, CO_2 emissions and fuel consumption those covering economic, customer satisfaction and environmental impacts.

Increasing the allowable deviation in optimizing the profit and total cost reduces rigorously the profit value while slightly affect the total cost. So, it is not recommended to increase the allowable deviation percentage when optimizing the profit and total cost. And it is strongly recommended to manipulate the total cost as a constraint, not as an objective.

When optimizing the profit and OSL it is noticed that increasing the allowable deviation reduces the profit value without any effect on the OSL value. So, it is also not recommended to increase the allowable deviation percentage when optimizing the profit and OSL.

Contrary to the above, increasing the allowable deviation in optimizing the profit and both the CO_2 emissions or fuel consumption cost reduces rigorously all of them. So, it is recommended to optimize only the profit and CO_2 emission since they affect other objectives.

The efficiency and efficacy of the developed model are verified through a general example. The model considers both initial and ending inventories for all products. The model is a general one and may be customized easily to solve many real cases. The developed model is capable to optimize production planning for multi-objectives ordered according to their priorities to the manager or planner.

It is recommended to develop the model by allowing the trucks to serve more location during the same trip.

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