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Developing A Sustainable Bi-Objective, Multi-Item, And Multi-Product Supply Chain Network Optimization Model For Perishable Products

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Abstract
This paper proposes a multi-item, multi-products, multi-periods, and bi-objectives sustainable supply chain network (SSCN) design and planning model for perishable products. Considering the economic, environmental, and social sustainability factors, aiming to maximize the profit and minimize the gas emission and expiration of stored products using the first in first out (FIFO) inventory strategy.
The proposed model has been formulated using mixed integer non-linear programming (MINLP) and solved by GAMS software using two different solvers; DICOPT and SCIP, to study the processing time significance in each case. The model's behavior has been verified by solving a full-capacity scenario followed by two computational case studies for various trends of demands. The results give trust in using the developed model to design and plan the SSCN. The effect of different maximum allowable deviation values on the SSCN performance and the objectives has been studied.
Keywords: Supply chain; MINLP; GAMS; multi-item; multi-product; bi-objectives; and perishable products.

1 Introduction

Due to the significant effect of perishable products on the environment, it is necessary to incorporate a sustainability study with the design of the perishable supply chain network. Sustainability generally includes economic, environmental, and social aspects. The main objective of SSCN design and planning is to balance the different objectives of maximizing economic performance and minimizing environmental and social impacts [1].
Products are considered perishable if at minimum, one of the following requirements occurs: a decrease in their worth, deterioration in their physical condition, and a possible reduction in functionality in the future [2]. Its applications represent various industries including food, blood and pharmaceuticals, where perishable products are extremely important [3].
According to the solution approach, to solve SSCN design, exact methods were used, including heuristics plus metaheuristics, Linear programming (LP), and Non-Linear Programming (NLP) [4]. Other approaches were used, such as genetic algorithm (GA)[5]–[9], particle swarm optimization (PSO) [5], simulated annealing (SA) [10], and meta-heuristic algorithms based on Pareto solutions [3], [7], [11]. Various methods used for multi-objective models, such as the weighted sum of objectives method [12], epsilon-constraint method [13], metaheuristics [14], and Multi-Criteria Decision Analysis (MCDA) [15], were reviewed by Eskandarpour et al. [16].
Several researchers in their model used the multi-objective solution approaches. To solve the models, these approaches were developed based on the augmented constraint method [17]–[20]. Other researchers applied the ε-constraint method [21], [22], a solution approach based on Lagrangian relaxation and ε-constraint to solve their model [23]. Also, the weighted sum method and the goal programming method have been used in some models [24], [25].
The production planning process has a high impact on the profit, gas emissions, and overall service level of the customers. So, this process is essential to ensure a high-profit level and a service level [26]. Researchers consider the importance of other objectives, such as environmental or economic impact, having bi-objective models that consider both objectives, in which environmental consequences are designed to reduce CO_2 emissions [1].

The SCM challenges become more difficult due to considering the qualities of perishable products [28]. The design and planning of the perishable product SCN are rarely considered [29].
Table 1 shows relevant researches on the SSCN design for perishable products.

Moreover, supply chain management (SCM) is a process that efficiently incorporates various phases of the supply chain to provide end users with the required number of products at the appropriate time [27].

Table 1: SSCN network design and planning literature

Author	Multi-item	Multi-product	Multi-period	Multi-customer	Objective Functions					Application
					S/ B/ M	Economic	Environmental	Social	Other	
M. S. Al-Ashhab et al. [30]			✓		S					General
Dwivedi et al. [9]				✓	S	✓	✓			Agro-food
Jiang et al. [31]	✓		✓	✓	B	✓	✓			Beverage
Rohmer et al. [32]		✓		✓	B	✓	✓			Food
Eskandari-khanghahi et al. [33]			✓	✓	M	✓	✓	✓	✓	Blood
Patidar et al. [34]				✓	S	✓				Agro-food
Tavakkoli Moghaddam et al. [35]			✓	✓	M	✓	✓		✓	Meat
S., Paydar [36]		✓			M	✓	✓	✓	✓	General
Zahiri et al. [11]		✓	✓	✓	M	✓	✓	✓	✓	Pharma.
M. S. Al-Ashhab et al. [1]			✓	✓	S	✓				General
Al-Ashhab & Alanazi [37]	✓	✓	✓	✓	S	✓				General
Munshi et al. [38]			✓	✓	M	✓	✓	✓		General
Our	✓	✓	✓	✓	B	✓	✓	✓		General

S: Single objective, **B**: Bi-objectives, **M**: Multi-objectives

- The quantities of items supplied to factories, the optimal number of units produced in each period then transferred from factories to the warehouse and from the warehouse to customers, taking into account the perishability of the product.
- Inventory management is based on the ages of products in the inventory.
- Implementation of the FIFO strategy in managing inventory to minimize the expiration of products.

This model is an extension of the models proposed by Al-Ashhab & Alanazi [37] and Munshi et al. [38], by adding the gas emissions minimization objective in addition to the profit maximization.

The proposed SCN includes three potential suppliers, three potential manufacturers, one warehouse, and three customers, as shown in Fig. 1. The flow of the model, which represents the relationship between the different facilities, is shown in Fig. 2.

Referring to literature review, it is obvious that there is no research concerned with the objectives of maximizing the profit, minimizing the gas emissions, and avoid expiration of products. So, the authores decided to develop a multi-item, multi-products, multi-periods, and bi-objectives SSCN design and planning model for perishable products. Considering the economic, environmental, and social sustainability factors, aiming to maximize the profit and minimize the gas emission and expiration of stored products using the first in first out (FIFO) inventory strategy.

2 Problem Description

The targets of this model are to determine:

- The optimal design for the SSCN.
- Achieving maximum possible profit while minimizing the environmental impact of the production processes.

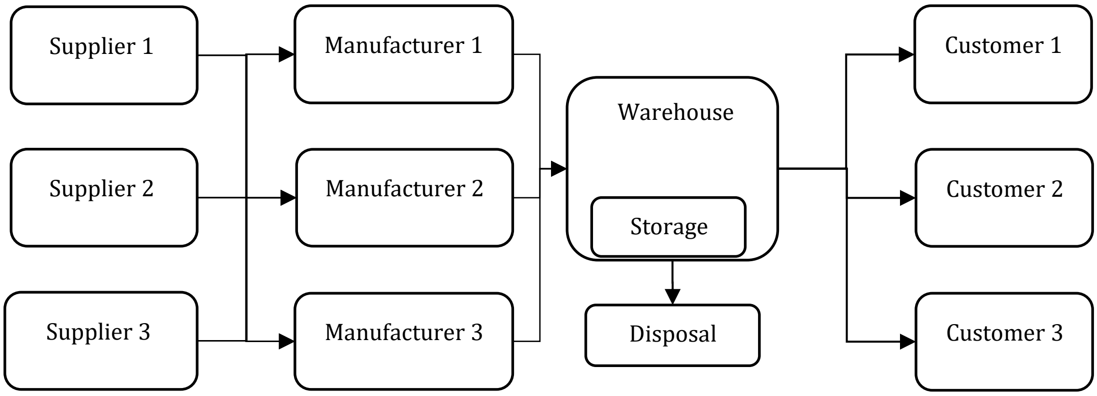


Fig. 1 The proposed supply chain network design.

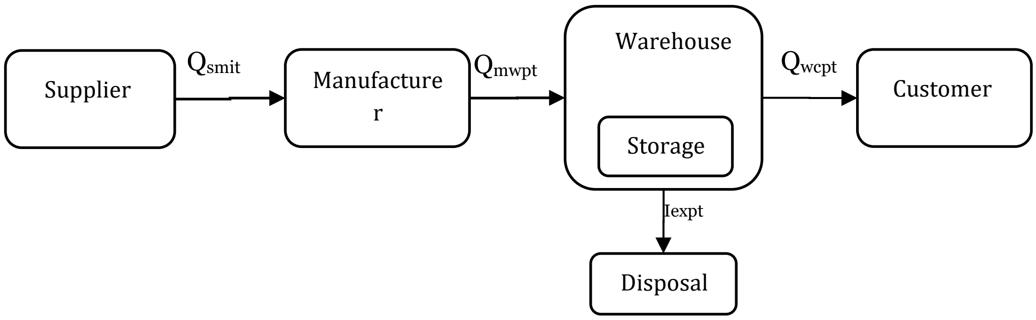


Fig. 2 Flow of materials and products

- A: ages of products.
- T: number of periods.

Indices:

- a ϵ A: Index of age of product
- t ϵ T: Index of planning periods
- i ϵ I : Index of items
- p ϵ p: Index of products
- s ϵ s: Index of potential locations of suppliers
- m ϵ M: Index of potential locations of manufacturers
- w ϵ W: Index of potential locations of warehouse
- c ϵ C: Index of potential customer locations

Parameters:

- D_{cpt}: Demand of customer *c* for product *p* in period *t*.
- SL: Shelf life duration of product *p* after its production.
- C_{sit}: Capacity of supplier *s* for item *i* in period *t*.

The following assumptions are considered for the mathematical model

- Customers' demands are known.
- Gas emissions amount depends on the production hours.
- Each product consists of multiple items.
- All products have a limited shelf life.
- The first products produced are issued first as an inventory strategy.
- There is no initial inventory.
- Expired products are treated as waste and discarded.
- The capacities of all facilities are known and limited.
- The backlog is allowed.

The model involves the following sets, parameters, and decision variables:

Sets:

- S, M, and W : potential locations of suppliers, manufacturers, and warehouses.
- C: set of customers.
- I: number of items.

- Q_{mwpt}: Number of batches of product *p* transferred from the manufacturer *m* to warehouse *w* in period *t*.
- Q_{wcpt}: Number of batches transferred from the warehouse *w* to customer *c* for the product *p* in period *t*.
- I_{pat}: Inventory of product *p* of age *a* at the end of period *t*.
- Iex_{pt}: Stock expired at the end of period *t*.
- L_s: Binary variable equals one if the supplier *s* is established; 0 otherwise.
- L_m: Binary variable equals one if the manufacturer *m* is established; 0 otherwise.
- L_w: Binary variable equals one if the warehouse *w* is established; 0 otherwise.
- GER: Gas emission rate

3.1 Objective Functions

The model's objectives are to maximize the supply chain's profit and minimize or eliminate gas emissions (GE). The profit equals the net revenue which is calculated by subtracting the total cost from the total revenue. Gas emissions and total revenue can be calculated from Eq. (1) and Eq. (2), respectively.

$$\mathrm{GE} = \mathrm{GER} * \sum_{m\in M}\sum_{p\in P}\sum_{t\in T} Q_{mwpt}B_{mp}\, MH_p \qquad (1)$$

$$\text{Total revenue } = \sum_{c\in C}\sum_{p\in P}\sum_{t\in T} Q_{\mathrm{wcpt}}\, B_{wp} \mathrm{P}_{\mathrm{pt}} \qquad (2)$$

Total cost = fixed costs + material costs + manufacturing costs + non-utilized capacity costs + shortage costs + transportation costs + inventory holding costs + expired costs.

Eq. (3) represents the total costs which include all different terms of cost, then Eqs. from (4) until (11) represent each of them individually.

- CM_{mt}: Capacity of raw material of the manufacturer in period *t*.
- CH_{mt}: Capacity in production hours of the manufacturer *m* in period *t*.
- C_{wt}: Capacity of warehouse *w* in period *t*.
- M_{sit}: Material cost per unit of item *i* supplied by supplier *s* in period *t*.
- MC_{mt}: Manufacturing cost per hour for manufacturer *m* in period *t*.
- MH_p: Manufacturing hours of the product *p*.
- TC: Transportation cost per unit per kilometer.
- DS_{sm}: Distance of supplier *s* to manufacturer *m*.
- DS_{mw}: Distance from manufacturer m to warehouse *w*.
- DS_{wc}: Distance of warehouse *w* to the customer *c*.
- $F_{s,m,w}$: Fixed cost of location *s*, *m*, and *w*.
- W_i: Weight of item *i*.
- R_{pi}: Quantity required for item *i* for product *p*.
- W_p: Weight of product *p*.
- P_{pt}: Unit price of product p in period *t*.
- EC_p: Expired cost for product *p*.
- SC_p: Shortage cost of product *p*.
- IC_p: Cost of inventory maintenance per unit per period.
- N: Cost of non-utilized manufacturing capacity per hour of the manufacturer.
- B_{si}: Batch size of item *i* transferred from supplier *s*.
- B_{mp}: Batch size transferred from manufacturer *m* for product *p*.
- B_{wp}: Batch size transferred from warehouse *w* for product *p*.
- Decision Variables:
- Q_{smit}: Number of batches of items *i* transferred from suppliers s to manufacturer *m* in period *t*.

$$\begin{aligned}\text{Total Costs} = {} & \sum_{s\in S} F_s\, L_s + \sum_{m\in M} F_m\, L_m + F_w + \sum_{s\in S}\sum_{m\in M}\sum_{i\in I}\sum_{t\in T} Q_{\mathrm{smit}}\, \mathrm{B_{si}}\, \mathrm{M_{sit}} + \sum_{m\in M}\sum_{p\in P}\sum_{t\in T} Q_{\mathrm{mwpt}}\mathrm{B_{mp}}\, \mathrm{MH_p}\, \mathrm{MC_{mt}} \\ & + \left[\sum_{m\in M}\sum_{t\in T} CH_{mt}\, L_m - \sum_{m\in M}\sum_{p\in P}\sum_{t\in T} Q_{\mathrm{mwpt}}\mathrm{MH_p}\right] N + \sum_{p\in P}\sum_{c\in C}\sum_{t\in T}\left[\sum_{1}^{t} D_{cpt} - \sum_{1}^{t} Q_{wcpt}\right] SC_p \\ & + \sum_{s\in S}\sum_{m\in FM}\sum_{i\in I}\sum_{t\in T} Q_{smit}\, B_{si}\, W_i\, TC\, DS_{sm} \\ & + \sum_{m\in M}\sum_{p\in P}\sum_{t\in T} Q_{mwpt}B_{mp}W_p \mathrm{TC}\ \mathrm{DS_{mw}} + \sum_{c\in C}\sum_{p\in P}\sum_{t\in T} Q_{wcpt}B_{wp}W_p \mathrm{TC}\ \mathrm{DS_{wc}} + \sum_{p\in P}\sum_{a}^{SL-1}\sum_{t\in T} I_{pat}\, IC_p \\ & + \sum_{p\in P}\sum_{a=SL}\sum_{t\in T} I_{pat}EC_p \end{aligned} \qquad (3)$$

$$\text{Material Costs} = \sum_{s\in S}\sum_{m\in M}\sum_{i\in I}\sum_{t\in T} Q_{\mathrm{smit}}\, \mathrm{B_{si}}\, \mathrm{M_{sit}} \qquad (5)$$

$$\text{Fixed Costs} = \sum_{s\in S} F_s\, L_s + \sum_{m\in M} F_m\, L_m + F_w \qquad (4)$$

to the sum of the amounts directed to the warehouse.

$$\sum_{m\in M}\sum_{p\in P} Q_{mwpt}\, W_p \le C_{wt}\ , \forall t = 1 \tag{15}$$

Eq. (15) ensures that the quantities transported to the warehouse cannot override the warehouse capacity in the first period.

$$\sum_{m\in M}\sum_{p\in P} Q_{mwpt}\, W_p + \sum_{p\in P}\sum_{a}^{SL-1} I_{p,a,t-1} W_p \le C_{wt}\ , \forall t = 2,\dots,T \tag{16}$$

Eq. (16) ensures that the sum of quantities of products transported to the warehouse in each period in addition to the remaining from the previous period cannot exceed the warehouse capacity.

$$Q_{wcpt} \le D_{cpt}, \forall t = 1, \forall p \in P, \forall c \in C \tag{17}$$

Eq. (17) ensures that the sum of the delivery to each customer in the first period cannot exceed the sum of the demand in the current period.

$$Q_{wcpt} \le \sum_{1}^{t} D_{cpt} - \sum_{1}^{t-1} Q_{wcpt}\ , \forall t = 2, \dots, T, \forall c \in C, \forall p \in P \tag{18}$$

Eq. (18) states that for each product, the sum of deliveries to customers does not exceed the sum of the current period's demand and the previous cumulative shortages.

$$Iexp_{pt} = 0, \forall t \le SL - 1, \forall p \in P \tag{19}$$

Eq. (19) guarantees that no expired stock exists before the shelf-life period is reached.

$$Iexp_{pt} = I_{pat}, \forall t \ge SL\ , \forall a = SL, \forall p \in P \tag{20}$$

Eq. (20) ensures that only after the shelf life is reached the expired inventory appears.

$$I_{pat} \ge\ 0, \forall a \in A, \forall t \in T, \forall p \in P \tag{21}$$

Eq. (21) confirms that for all ages and in all periods, the inventory cannot have a negative value.

$$I_{pat} = 0, \forall t < a, \forall a \in A, \forall p \in P \tag{22}$$

Eq. (22) ensures that when the age is greater than the period, the inventory is equal to zero.

$$I_{pat} = \sum_{m\in M} Q_{mwpt} - \sum_{c\in C} Q_{wcpt},\ \ \forall t = 1, \forall a = 1, \forall p \in P \tag{23}$$

$$\text{Manufacturing Costs} = \sum_{m\in M}\sum_{p\in P}\sum_{t\in T} Q_{mwpt}\, B_{mp}\, MH_p\, MC_{ft} \tag{6}$$

$$\text{Non-Utilized Manufacturing Capacity Cost} = \left[\sum_{m\in M}\sum_{t\in T} CH_{mt} L_m - \sum_{m\in M}\sum_{p\in P}\sum_{t\in T} Q_{mwpt} MH_p\right] N \tag{7}$$

$$Shortage\ Cost = \sum_{p\in P}\sum_{c\in C}\sum_{t\in T}\left[\sum_{1}^{t} D_{cpt} - \sum_{1}^{t} Q_{wcpt}\right] SC_p \tag{8}$$

$$\text{Transportation Costs} = \sum_{s\in S}\sum_{m\in M}\sum_{i\in I}\sum_{t\in T} Q_{smit}\, B_{si}\, W_i\, TC\, DS_{sm} + \sum_{m\in M}\sum_{p\in P}\sum_{t\in T} Q_{mwpt} B_{mp} W_p TC\ DS_{mw} + \sum_{c\in C}\sum_{p\in P}\sum_{t\in T} Q_{wcpt} B_{wp} W_p TC\ DS_{wc} \tag{9}$$

$$\text{Inventory Holding Costs} = \sum_{p\in P}\sum_{a}^{SL-1}\sum_{t\in T} I_{pat}\, IC_p \tag{10}$$

$$\text{Expired Costs} = \sum_{p\in P}\sum_{a=SL}\sum_{t\in T} I_{expt} EC_p \tag{11}$$

3.2 Constraints

$$\sum_{m\in M} Q_{smit}\, B_{si} \le C_{sit} L_s, \forall i \in I, \forall t \in T, \forall s \in S \tag{12}$$

Eq. (12) states that all suppliers provide items of materials within their limited capacities.

$$\sum_{s\in S}\sum_{i\in I} Q_{smit}\, B_{si}\, W_i \le CM_{mt} L_m, \forall t \in T, \forall m \in M \tag{13}$$

Eq. **Error! Reference source not found.** ensures that from all suppliers, the sum of material flow in each period that enters the factory does not exceed the material capacity of the manufacturer.

$$\sum_{p\in P} Q_{mwpt} B_{mp}\, MH_p \le CH_{mt}\, L_m,\ \ \forall t \in T, \forall m \in M \tag{13}$$

Eq. (13) ensures that for all products manufactured in the factory to be delivered to each warehouse, the sum of manufacturing hours in each period does not exceed its manufacturing capacity hours.

$$\sum_{s\in S} Q_{smit} B_{si} = \sum_{p\in P} Q_{mwpt} B_{mp}\, R_{pi}, \forall i \in I, \forall t \in T, \forall m \in M \tag{14}$$

Eq. (14) shows that the amount of materials from all suppliers delivered to the manufacturers is equal

Fig. 3. The model has been developed and verified considering multi-items, multi-products, and a single-objective of maximizing the profit.

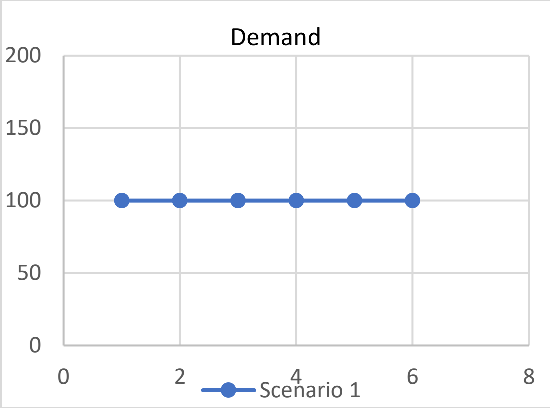


Fig. 3 Demand scenario for full capacity

4.1 Multi-Items Multi-Products and Single-Objective (MIMPSO) with full capacity

The model used for verification is solved using GAMS software and runs on an Intel ® Core™ i7-7500U CPU @ 2.70 GHz (8 GB of RAM). The parameters used for the case study model are shown in Table 2.

$$I_{pat} = \sum_{m\in M} Q_{mwpt} - \max\left[\left[\sum_{c\in C} Q_{wcpt} - \sum_{a=1}^{SL-1} I_{pa,t-1}\right], 0\right], \forall t = 2, \dots, T, \forall a = 1, \forall p \in P \quad (24)$$

$$I_{pat} = \max\left[I_{p,a-1,t-1} - \max\left[\sum_{c\in C} Q_{wcpt} - \sum_{a}^{SL-1} I_{pa,t-1}, 0\right], 0\right], t = 2, \dots, T, a = 2, \dots, A, \forall p \in P \quad (25)$$

Eqs. (23), (24), and (25) guarantee that the demand is satisfied first through the oldest age's stock products in the warehouse's inventory and then from the stock of the following age until the stock of the youngest age is reached.

4 Model Verification

The full capacity scenario was assumed and solved to verify the performance of the model, as shown in

Table 2: The parameters assumed for the case study model used for verification.

No.	Input parameter	Value	Unit	No.	Input parameter	Value	Unit
1	S and M	3	–	19	Msit 1,2	1, 2, 3	$/kg
2	W	1	–				
3	C	3	–	20	MHp 1,2	1, 2	Hrs
4	I	2	–	21	MCmt 1,2,3	10	$/hr
5	P	2	–	22	SL	3	hrs
6	A	3	–	23	TC	0.002	$/Km
7	T	6	–	24	Ds1m	50, 75, 100	Km
8	Fs and Fm	10000,15000 ,20000	$	25	DSs2m	75, 50, 75	Km
9	Fw	10000	$	26	DSs3m	100, 75, 50	Km
10	Wi 1,2	1	Kg	27	DSmw	100, 50, 150	Km
11	Wp 1,2	3, 6	Kg	28	DSwc	100,50, 150	Km
12	Rip1	1, 2	Kg/unit	29	Bsi	1	Unit
13	Rip2	2, 4	Kg/unit	30	Bmp	1	Unit
14	Ppt	100, 150	$/Unit	31	Bwp	1	Unit
15	ECp 1,2	1, 2	$/Unit	32	CSit 1,2	60000	Kg
16	SCp 1,2	5, 10	$/period	33	CMmt 1,2,3	6000	Kg
17	ICp 1,2	1,2	$/kg period	34	CHmt 1,2,3	6000	Hrs
18	N	3	$/hr	35	Cwt	60000	unit

4.2 Results and analysis for the full capacity production scenario

Fig. 4 shows the optimal supply chain network for the full capacity case study; one supplier only supplied materials for all manufacturers.

The current case represents MIMPSO considering the production with the full capacity situation regardless the customer demand, so that storage and expiration for products are expected to occur in all three ages. Accordingly, the verification and results analysis should give trust in using the model.

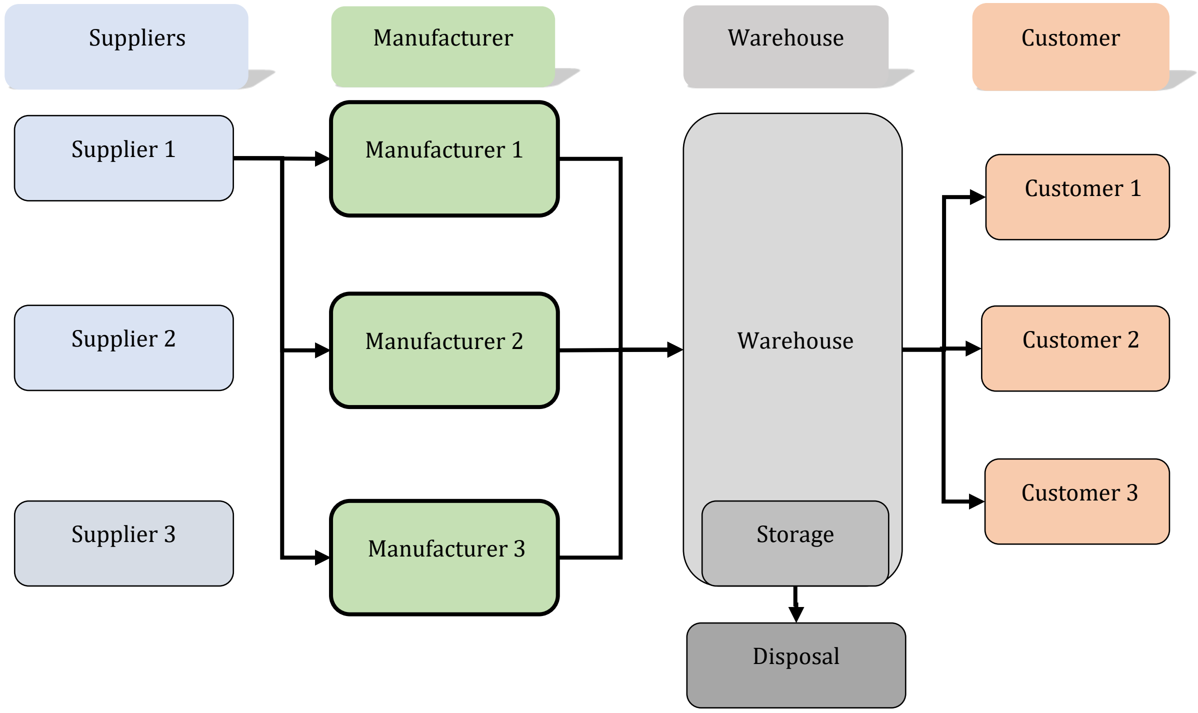
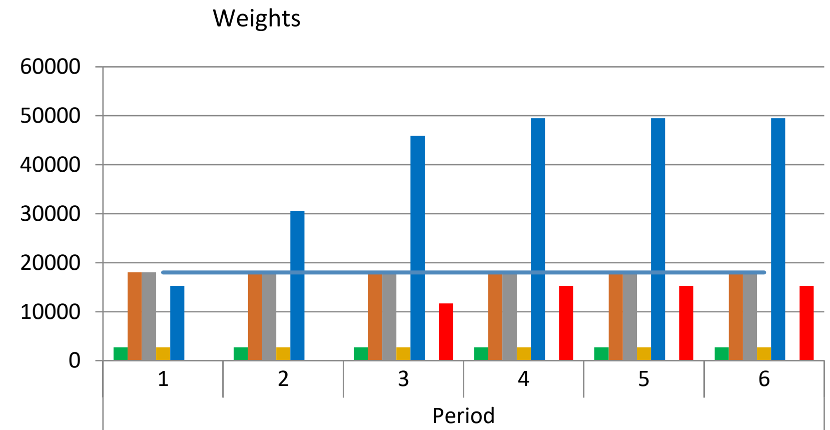


Fig. 4 Optimal supply chain network of the full capacity scenario



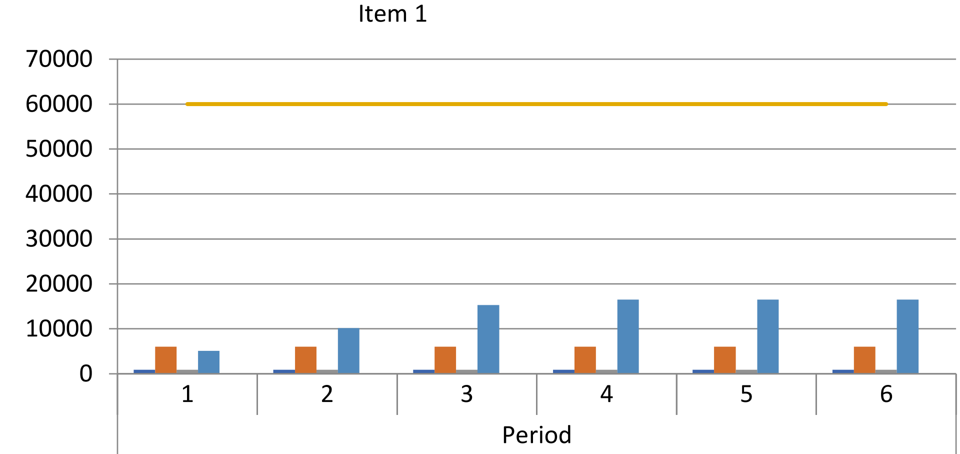
	1	2	3	4	5	6
Total Demand (kg)	2700	2700	2700	2700	2700	2700
Total Supply (kg)	18000	18000	18000	18000	18000	18000
TotalDeleviry to Mnufacturer (kg)	18000	18000	18000	18000	18000	18000
Total Delivery to Customer (kg)	2700	2700	2700	2700	2700	2700
Inventory (kg)	15300	30600	45900	49500	49500	49500
Shortage (kg)	0	0	0	0	0	0
Iexpt (kg)	0	0	11700	15300	15300	15300
Manufacturer Capacity (kg)	18000	18000	18000	18000	18000	18000

Fig. 5 Flow of products (by weight) in all periods (full capacity scenario)

the first period and some of them have been in the third period (when they reached shelf life, age = 3). Fig. 6 and Fig. 7 represent that the required weight of the first and second items are 900 Kg and 1800 kg, respectively, which are less than the suppliers' capacity for each item. So that, in all periods, the suppliers can fulfill all demands without shortages.

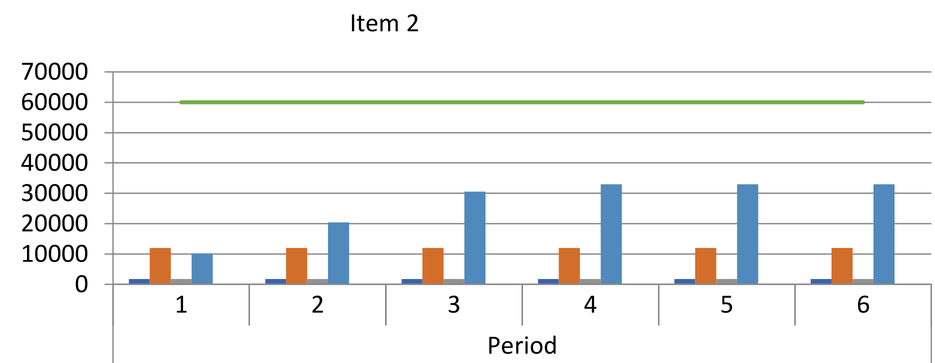
According to Fig. 5, 2700 kg are required for all periods, which is less than the manufacturing capacity in all periods, so the factory fulfilled all demands without any shortage.

The products delivered by the manufacturers to the warehouse were at full capacity in all periods, exceeding the demands in all periods, which led to the storage of the products in the warehouse from



	1	2	3	4	5	6
Demand	900	900	900	900	900	900
Supplied	6000	6000	6000	6000	6000	6000
Delivered	900	900	900	900	900	900
Inventory	5100	10200	15300	16500	16500	16500
shortage	0	0	0	0	0	0
Supplier Capacity	60000	60000	60000	60000	60000	60000

Fig. 6 The relationship between the demand and the quantities delivered of the first item (full capacity scenario)



	1	2	3	4	5	6
Demand	1800	1800	1800	1800	1800	1800
Supplied	12000	12000	12000	12000	12000	12000
Delivered	1800	1800	1800	1800	1800	1800
Inventory	10200	20400	30600	33000	33000	33000
shortage	0	0	0	0	0	0
Supplier Capacity	60000	60000	60000	60000	60000	60000

Fig. 7 The relationship between the demand and the quantities delivered of the second item (full capacity scenario)

products stored in each period relevant to each age for the first and second products. That will lead to the following verification analysis.

Table 3 represents the total production plan for the first and second products from the manufacturer to the warehouse, while Table 4 represents the

Table 3: The relationship between the weights of demand, delivered quantities, inventory, and shortage of the product in all periods

		Total Demand	Total supply	Total Delivery to Manufacturer	Total delivery to the customer	Manufacturer Capacity	Inventory	Shortage
Period	1	2700	18000	18000	2700	18000	15300	0
	2	2700	18000	18000	2700	18000	30600	0
	3	2700	18000	18000	2700	18000	45900	0
	4	2700	18000	18000	2700	18000	45900	0
	5	2700	18000	18000	2700	18000	49500	0
	6	2700	18000	18000	2700	18000	49500	0
		16200	108000	108000	16200	108000	240300	0

Table 4: The inventory for the products of various ages for all periods

Period	Inventory						W_{iwc}
	P_1			P_2			
	a_1	a_2	a_3	a_1	a_2	a_3	
1	0	0	0	2550	0	0	15300
2	0	0	0	2850	2250	0	30600
3	0	0	0	2850	2850	1950	45900
4	0	0	0	2850	2850	2550	49500
5	300	0	0	2700	2850	2550	49500
6	0	0	0	3000	2700	2550	49500
	300	0	0	16800	13500	9600	
	240300						

In period #3, for the first product: the warehouse received (300) products that will be delivered to customers, and no products will be stored as (a1).

For the second product: the warehouse received 2850 products, 300 products to be delivered to customers from the stored products (a2), which will become 1950 products to be stored as (a3) "expired" and the newly received products to warehouse 2850 products will be stored as (a1), and 2850 products in (a1) will be stored as (a2).

In period #4, for the first product: the warehouse received (300) products that will be delivered to customers, and no products will be stored as (a1).

For the second product: the warehouse received 2850 products, 300 products to be delivered to customers from the stored products (a2), which will become 2550 products to be stored as (a3) "expired" and the newly received product to the warehouse 2850 products will be stored as (a1), and 2850 products at (a1) will be stored as (a2).

Knowing that the demand for each product at each period is 300 products and the delivered products are 2700 kg

In period #1, for the first product: the warehouse received (300) products that will be delivered to customers, and no products will be stored as (a1).

For the second product: the warehouse received 2850 products, out of them 300 products to be delivered to customers and the remaining 2550 products to be stored as (a1).

In period #2, for the first product: the warehouse received (300) products that will be delivered to customers, and no products will be stored as (a1).

For the second product: the warehouse received 2850 products, 300 products to be delivered to customers from the stored products, which will become 2250 products to be stored as (a2), and the newly received product to the warehouse 2850 products will be stored as (a1).

effects of different demand patterns on supply chain performance has been conducted.

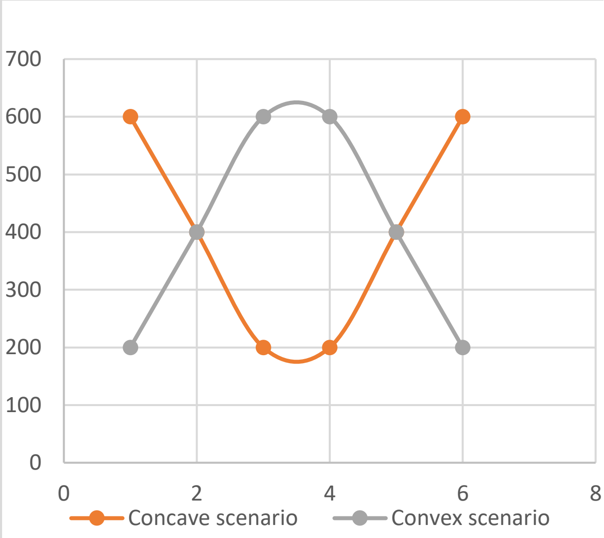


Fig. 8 Demand for concave and convex capacity scenarios

The current case represents MIMPSO considering the concave and convex demand scenarios, which have various values for the demands so that shortage will be expected in higher demand periods, and storage for products is expected to balance this shortage at lower demand periods. Accordingly, this behavior and results analysis should sustain using the model for bi-objective study.

4.3 Results and analysis for concave demand

Fig. 9 shows the optimal supply chain network for the concave demand case study; only two manufacturers received the materials from the three suppliers.

In period #5, for the first product: the warehouse received (600) products; out of them (300) products to be delivered to customers and the remaining 300 products to be stored as (a1).

For the second product: the warehouse received 2700 products, 300 products to be delivered to customers from the stored products (a2), which will become 2550 products to be stored as (a3) "expired" and the newly received product to warehouse 2700 products will be stored as (a1), and 2850 products at (a1) will be stored as (a2).

In period #6, for the first product: the warehouse received (0) products, (300) products to be delivered to customers from the stored products, and no products will be stored as (a1)

For the second product: the warehouse received 3000 products, 300 products to be delivered to customers from the stored products (a2), which will become 2550 products to be stored as (a3) "expired" and the newly received product to the warehouse 3000 products will be stored as (a1), and 2700 products at (a1) will be stored as (a2).

Accordingly, the verification and results analysis should give trust in using the model.Computational Results

Further computational case studies were implemented, which include concave and convex demand trends, as shown in Fig. 8, and with a supplier capacity of 3000 kg for each item, each period, and each product. Further analysis of the

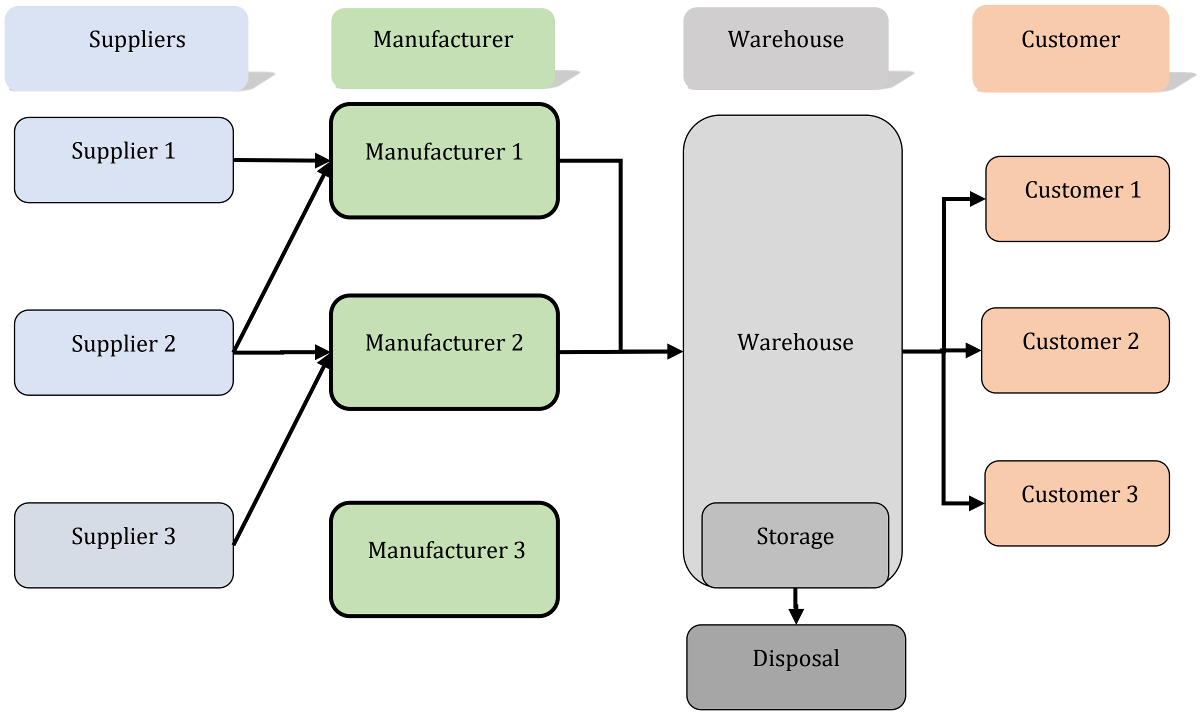
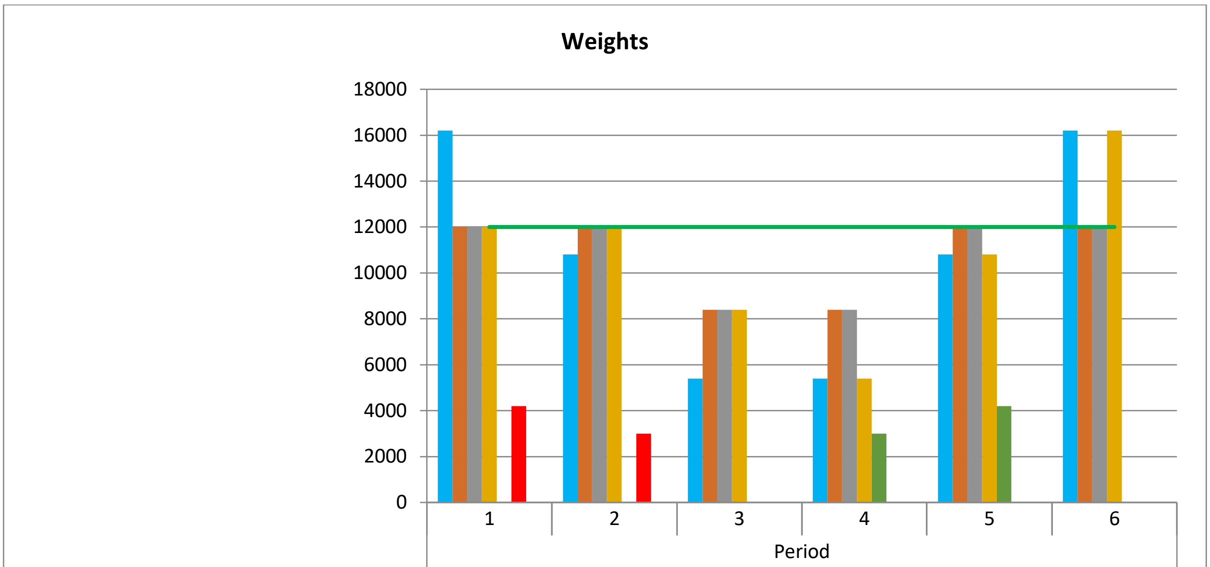


Fig. 9 Optimal supply chain network of concave and convex scenarios

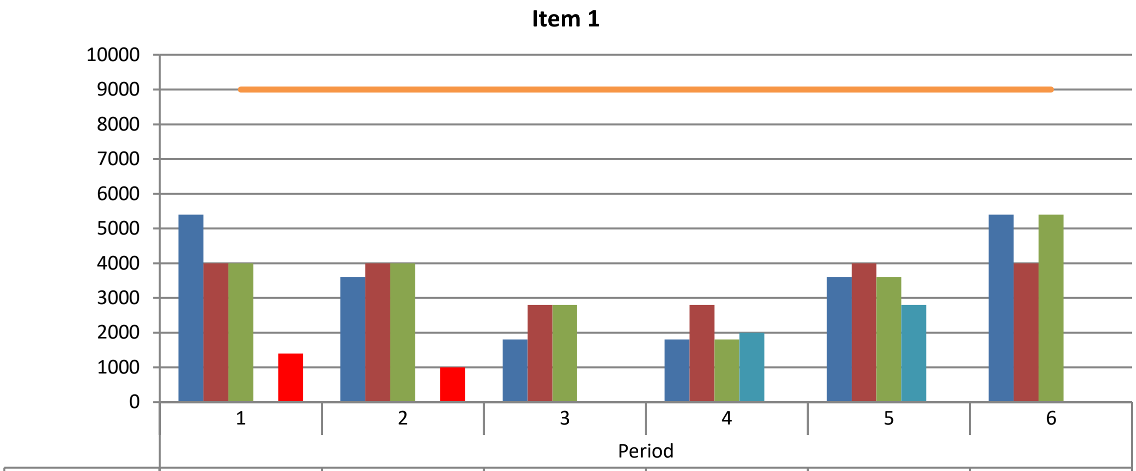


	1	2	3	4	5	6
Total Demand (kg)	16200	10800	5400	5400	10800	16200
Total Supply (kg)	12000	12000	8400	8400	12000	12000
Total Delivery to Manufacturer (kg)	12000	12000	8400	8400	12000	12000
Total Delivery to Customer (kg)	12000	12000	8400	5400	10800	16200
Inventory (kg)	0	0	0	3000	4200	0
Shortage (kg)	4200	3000	0	0	0	0
Iexpt	0	0	0	0	0	0
Manufacturer Capacity	12000	12000	12000	12000	12000	12000

Fig. 10 Product weight in all periods (concave)

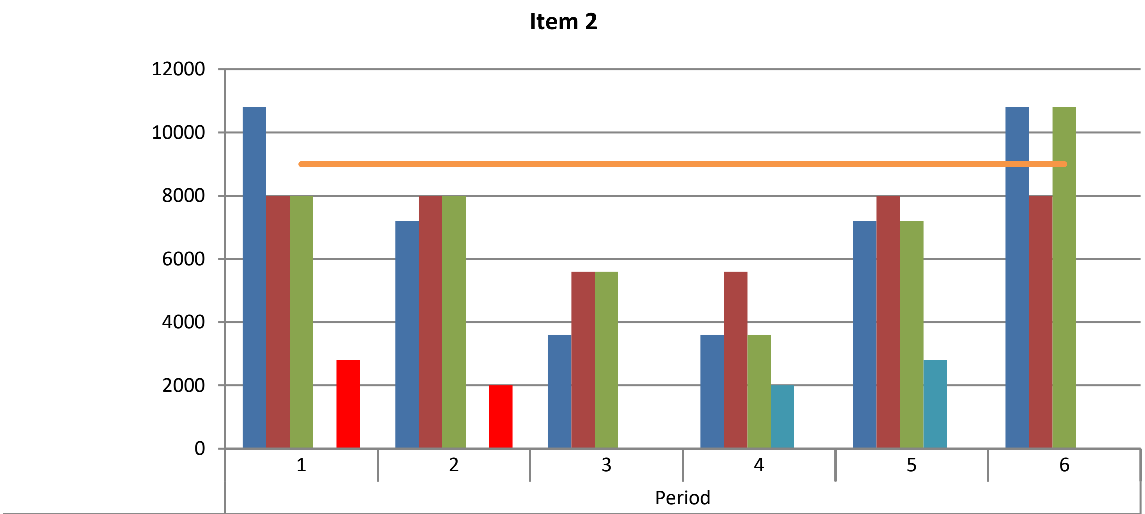
manufacturers were operated. In Fig. 11 and Fig. 12 the total material supplied to the factories were12,000 kg, so some shortage exists.

As shown in Fig. 10 in the first period, the customers' demands weights exceeded those delivered in the same period, and only two



	1	2	3	4	5	6
Demand	5400	3600	1800	1800	3600	5400
Supplied	4000	4000	2800	2800	4000	4000
Delivered	4000	4000	2800	1800	3600	5400
Inventory	0	0	0	2000	2800	0
Shortage	1400	1000	0	0	0	0
Supplier Capacity	9000	9000	9000	9000	9000	9000

Fig. 11 The relation between the demand and delivered quantities of the first item (concave)



	1	2	3	4	5	6
Demand	10800	7200	3600	3600	7200	10800
Supplied	8000	8000	5600	5600	8000	8000
Delivered	8000	8000	5600	3600	7200	10800
Inventory	0	0	0	2000	2800	0
shortage	2800	2000	0	0	0	0
Supplier Capacity	9000	9000	9000	9000	9000	9000

Fig. 12 The relation between the demand and delivered quantities of the second item (concave)

The weights required in period 5 were lower than the manufacturing capacity, so the manufacturers met the demand in the same period. There was storage for 4,200 kg to cover the high demand in period 6. The manufacturers used their full capacity The weights delivered were more than required in each of the following periods, 2, 3, and 4, to overcome the shortage in the first period and to meet the expected high demand in period 6.

demand case study; all suppliers supplied materials for only two Manufacturers.

As shown in Fig. 13, the required weights are 5400, 10800, 16200, 16200, 10800, and 5400 kg. The weights delivered were more than required in the first and second periods, and extra weights were considered as storage to fulfill the high demand in period 3 and period 4.

in period 6 and delivered 12,000 kg, and the storage weight from the previous period was used with 4,200 kg to meet the customer demand of 16,200 kg.

4.4 Results and analysis of convex demand scenario

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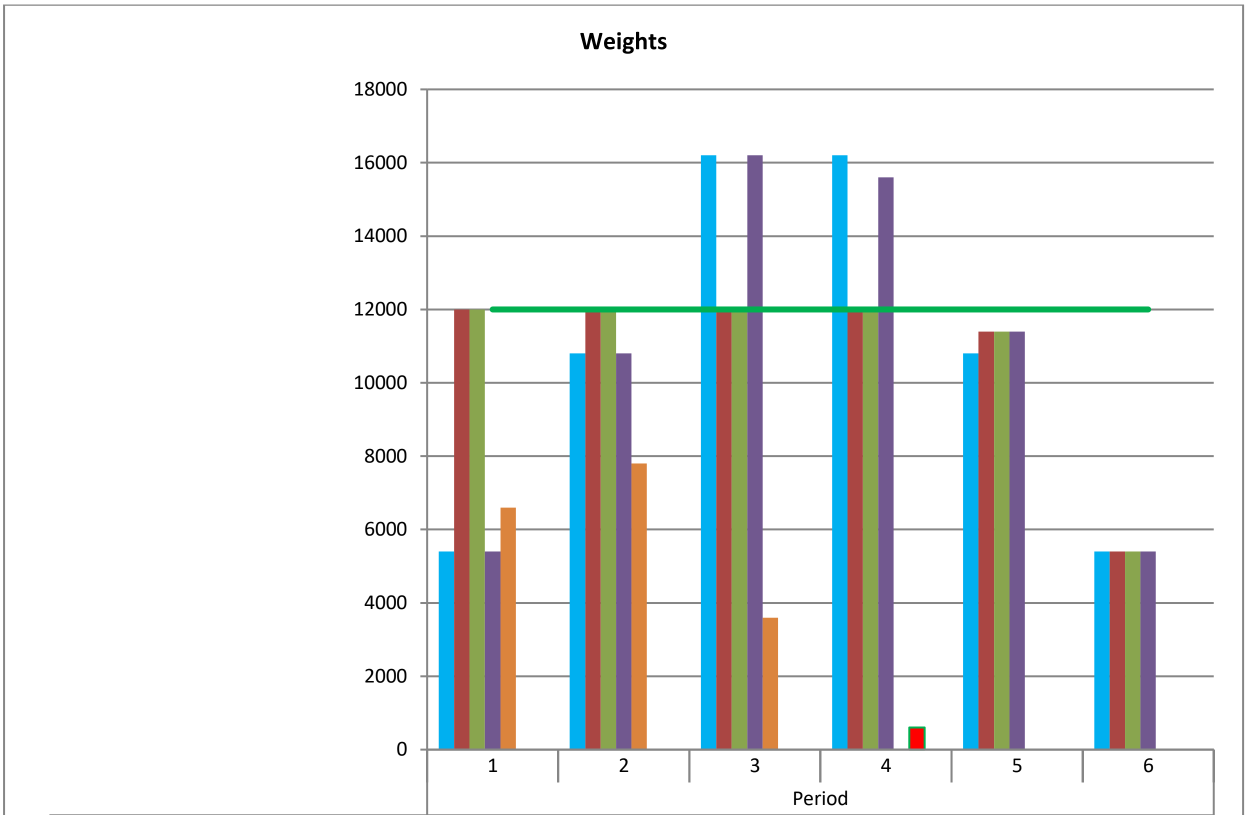


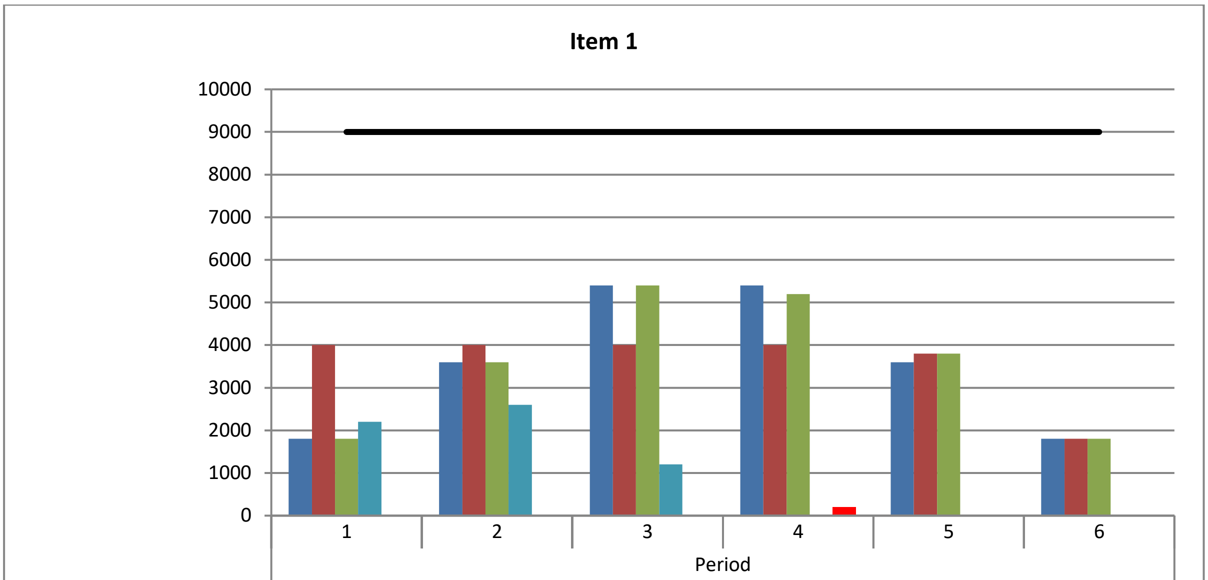
	1	2	3	4	5	6
Total Demand (kg)	5400	10800	16200	16200	10800	5400
Total Supply (kg)	12000	12000	12000	12000	11400	5400
Total Delivery to Manufacturer (kg)	12000	12000	12000	12000	11400	5400
Total Delivery to Customer (kg)	5400	10800	16200	15600	11400	5400
Inventory (kg)	6600	7800	3600	0	0	0
Shortage(kg)	0	0	0	600	0	0
Iexpt	0	0	0	0	0	0
Manufacturer Capacity (kg)	12000	12000	12000	12000	12000	12000

Fig. 13 Product weight in all periods (convex)

In period 5, the weights delivered were more than the demand to fulfill the shortage in period 4. The demand weights were less than the manufacturing capacity, which did not cause a shortage.

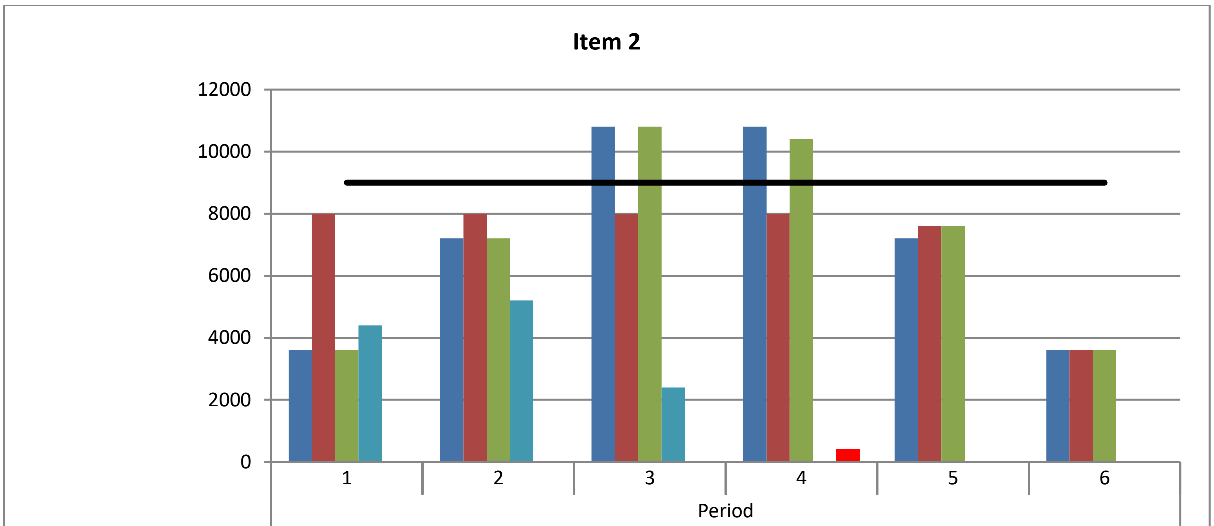
As shown in Fig.14 and Fig.15 it is noticed that the material supplied was larger than the required weights. The excess required weight was stored in the first two periods to meet later high demand.

Manufacturers used their full capacities and delivered 16,200 and 15,600 kg in period 3 and period 4, respectively, in addition to the storage weight from period 2, but 600 kg was considered a shortage in period 4 due to the high demand compared to the manufacturer and storage weights.



	1	2	3	4	5	6
Demand	1800	3600	5400	5400	3600	1800
Supplied	4000	4000	4000	4000	3800	1800
Delivered	1800	3600	5400	5200	3800	1800
Inventory	2200	2600	1200	0	0	0
Shortage	0	0	0	200	0	0
Supplier Capacity	9000	9000	9000	9000	9000	9000

Fig.14 Relation between the demand and delivered for the first item (convex)



	1	2	3	4	5	6
Demand	3600	7200	10800	10800	7200	3600
Supplied	8000	8000	8000	8000	7600	3600
Delivered	3600	7200	10800	10400	7600	3600
Inventory	4400	5200	2400	0	0	0
Shortage	0	0	0	400	0	0
Supplier Capacity	9000	9000	9000	9000	9000	9000

Fig.15 The relationship between the demand and the quantities delivered of the second item (convex)

delivered in period 5 were more than the required in this period.

The required items in period 6 were less than the capacity of the material for factories, so the suppliers satisfied demand without any shortage.

The suppliers delivered limited items in periods 3, and 4 in addition to the remaining storage, are unable to fulfill the high demand. So that shortage existed in period 4. To fulfill this shortage, the items profit and minimizing the gas emissions as the optimization objective functions (OFs). This scenario has been selected because it is a comprehensive scenario where it has both shortages and inventories. The solver used was a DICOPT solver then the SCIP solver was used for comparison reasons. All results are presented in

The results in Fig. 16 included the objective function OF1, which represents profits, and the objective function OF2, which represents gas emissions, when using different deviation values. While increasing the maximum permissible values of deviation, the profit values decrease; the gas emissions decrease as well, but the rate in the case of the OF2 is less than that with OF1.

5 Multi-Items Multi-Products And Bi-Objective (Mimpbo) "Concave Demand"

The environmental impact has been considered by adding the gas emission. The model has been developed to include multi-items multi-products and bi-Objective MIMPBO, adopting the previous concave demand scenario Table 5 maximizing the

Table 5 with various maximum deviation values.

5.1 The effect of maximum allowable deviation on supply chain objectives

The MIMPBO model was run using a DICOPT solver to study the effects of the maximum permissible deviation on the different objectives then the supply chain performances were studied. The maximum allowable deviations range from 0 to 0.5 with a step of 0.1.

Table 5: The parameters assumed for model verification in the case study.

		Optimized Objectives Using DICOPT		Process Time (sec)		Optimized objectives Using SCIB		LS	Lm	Level	Lower
		OF1 (Profit)	OF2 (Gas Emission)	DICOPT	SCIB	OF1(Profit)	OF2(Gas Emission)	# Supplier	# Manufacturers	Min value of OF1	Min value of OF1
Deviation	0	1218470	216000	1.147	1.773	1218470	216000	1,2,3	1,2	1218470	1218470
	0.1	1096629	197560	0.972	6.448	1096629	197560	1,2,3	1,2	1096629	1096623
	0.2	974881	179560	1.019	4.375	974848	179560	1,2,3	1,2	974881	974776
	0.3	853004	162740	2.479	18.353	853003	162740	1,2,3	1,2	853004	852929
	0.4	731094	146590	1.73	17.651	731121	146590	1,2,3	1,2	731094	731082
	0.5	609314	131340	1.776	13.678	609242	131340	1,2	1,2	609314	609235

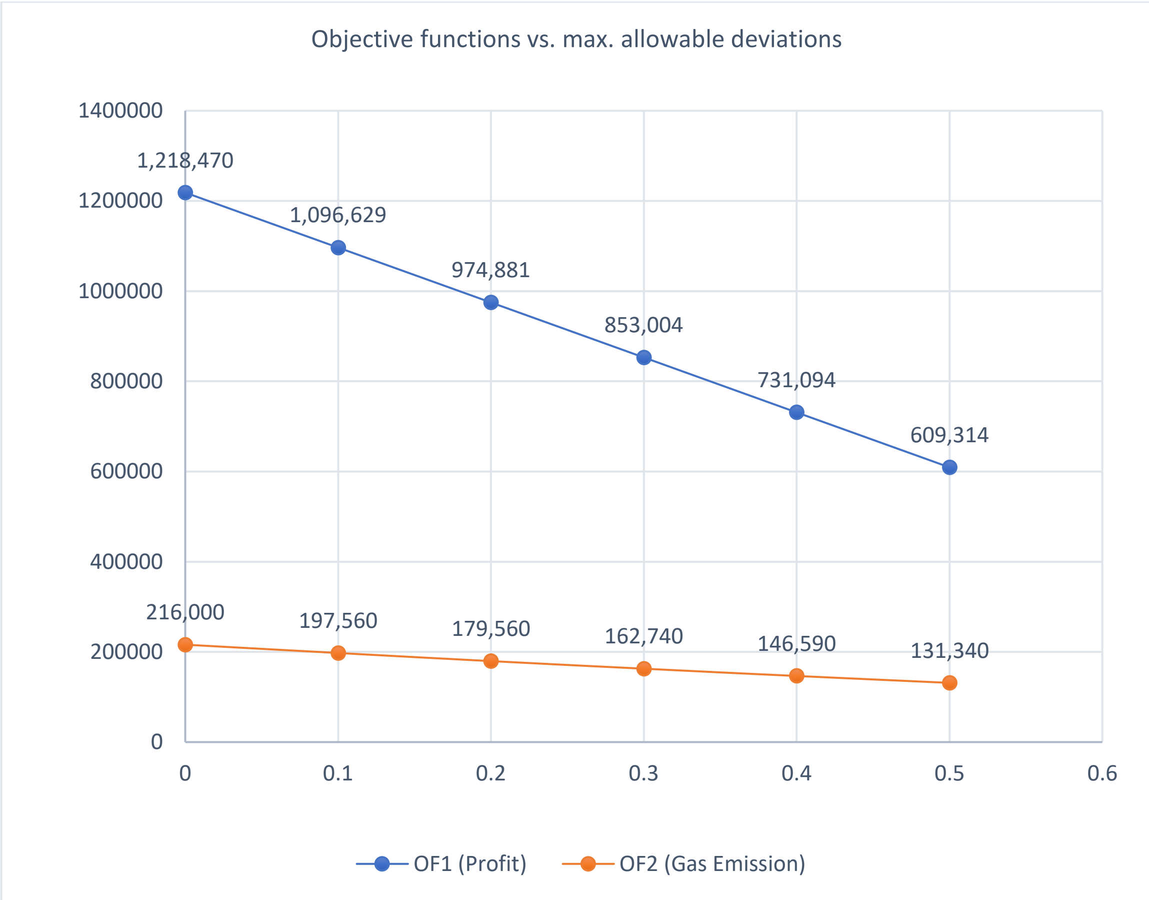


Fig. 16 The relation between the objective functions and deviations

Deviation	# Supplier (Ls)	# Manufacturers (Lm)
0	1,2,3 = (1,1,1)	1,2 = (1,1)
0.1	1,2,3 = (1,1,1)	1,2 = (1,1)
0.2	1,2,3 = (1,1,1)	1,2 = (1,1)
0.3	1,2,3 = (1,1,1)	1,2 = (1,1)
0.4	1,2,3 = (1,1,1)	1,2 = (1,1)
0.5	1,2,3 = (1,1,0)	1,2 = (1,1)

5.2 The effect of maximum allowable deviation on supply chain network design

The MIMPBO model using DICOPT solver was used to study the effect of changing the maximum permissible deviation on SCN designs. By extracting numbers of suppliers Ls and numbers of manufacturers Lm during the different values of the deviation (range from 0 to 0.5 with a step of 0.1). The results are shown in Table 6. The supply chain design was the same with deviation value ranging from (0 to 0.4) with 3 suppliers and 2 manufacturers except in deviation value of 0.5 the design became 2 suppliers and 2 manufacturers due to the fact that at this deviation the profits at the lowest values to manage to have optimum value for the gas emissions, so only 2 suppliers will be required to match with this target.

Table 6: The parameters of the network design at various values of deviation.

	Network Design

5.3 Effect of the maximum allowable deviation on the processing time of different solvers

The MIMPBO model was run with two different solvers, DICOPT and SCIP solvers, respectively, at different deviation values to measure the run time for each solver and make the required comparison. From Fig. 17, the processing time values in all cases of using the DICOPT solver were lower than the the processing time values of using the SCIP solver.

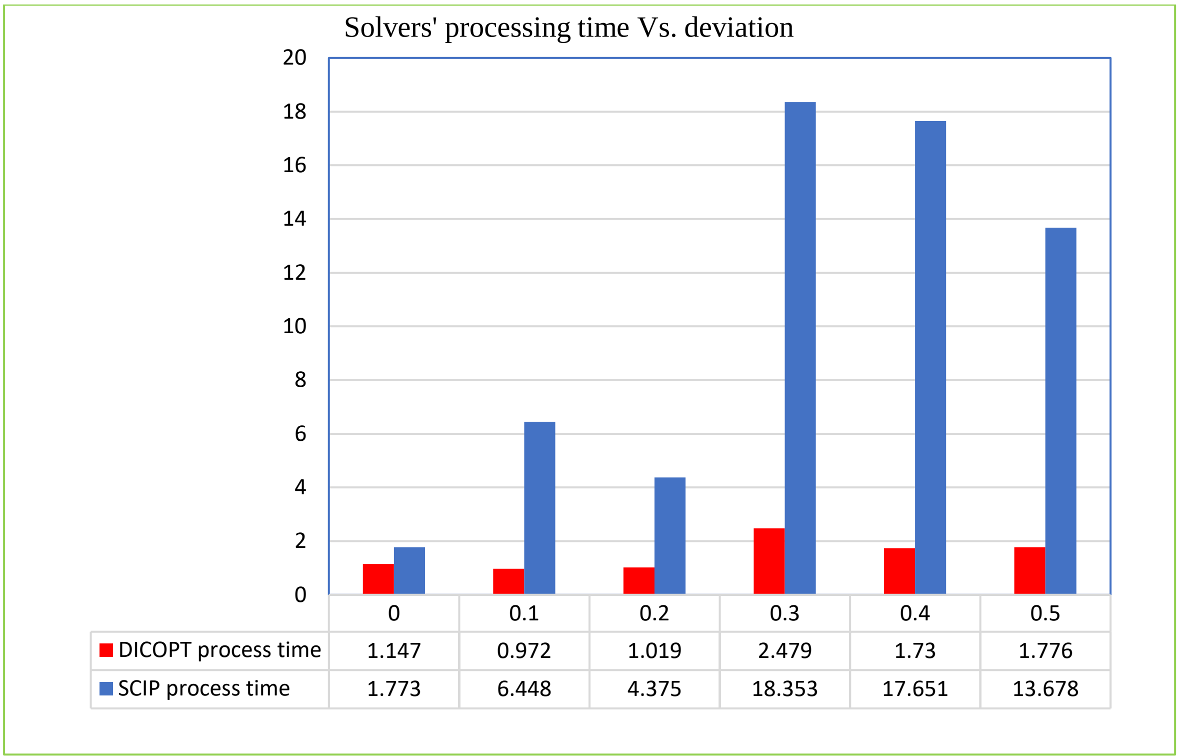


Fig. 17 The relation between solvers' processing time and deviations

6 Conclusions and recommendations

According to the research work, it is concluded that:

1. The MIMPBO model is used after implementing the required modification and verifying its accuracy. So, the developed model can be used to design and plan the supply chain networks.
2. When the objectives through the model, the economic, environment, and social aspects were satisfied.
3. The effect of using different deviation values on the design of the supply chain network was recognized.
4. The run time was studied using two different solvers, DICOPT and SCIP, at different deviation values.

It is recommended to developed to the following:

- Optimize multi-objectives, such as maximizing overall service level and minimizing total cost.
- Deal with the problem of stochastic demand.
- Consider robustness.
- The model can also be extended to consider the mode and combining it with other aspects such as vehicle route and CO2 emissions.
- Discounting the near perishable products.

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