INDIAN JOURNAL OF
ENGINEERING

19(51), 2022

Modelling and Solving a Sustainable, Robust Multi-Period Supply Chain Network for Perishable Products

Mohamed Sayed Al-Ashhab[1,2], Naji Aldosari[1*]

To Cite:
Al-Ashhab MS, Aldosari N. Modelling and Solving a Sustainable, Robust Multi-Period Supply Chain Network for Perishable Products. *Indian Journal of Engineering*, 2022, 19(51), 184-195

Author Affiliation:
[1]Department of Mechanical Engineering, College of Engineering and Islamic Architecture, Umm Al-Qura University, Makkah, Saudi Arabia.
[2]Design & Production Engineering Department Faculty of Engineering, Ain-Shams University, Cairo, Egypt

***Corresponding Author**
Design & Production Engineering Department Faculty of Engineering, Ain-Shams University, Cairo, Egypt

Peer-Review History
Received: 14 March 2022
Reviewed & Revised: 15/March/2022 to 27/April/2022
Accepted: 27 April 2022
Published: 29 April 2022

Peer-Review Model
External peer-review was done through double-blind method.

DISCOVERY
SCIENTIFIC SOCIETY

ABSTRACT

In this paper, a robust mathematical model was developed to optimize production, distribution, and inventory planning for a perishable supply chain consisting of three factories, one warehouse, and three retailers to maximize profit. The proposed Fig. 1model was formulated using mixed-integer linear programming and solved using XpressIVE. The model considers the disruption of factory capacity due to uncertain interruptions. In addition, it deals with a sustainable supply chain network and interruptions that affect factory capacity while maintaining the FIFO inventory policy to maximize the network's overall profit and reduce the amount of expired products to reduce the environmental impact. The model successfully handles the problem of designing and planning a long-term supply chain network for perishable products. The capability and accuracy of the model were verified by solving several scenarios. The effect of the minimum and maximum expected values of the interruption was studied. It may be concluded that the robust SCN design is affected mainly by the value of the maximum expected interruption. The design and performance of the SCN are affected by the capacity disruption of the factories, and the model succeeded in designing and planning the SCN under all conditions.

Keywords: Supply Chain; Perishable; Robust; MILP; XpressIVE

1. INTRODUCTION

Sustainable supply chain design (SSCD) has three pillars: economic, environmental, and social. Organizations are now attempting to strike a balance between the triple bottom line of sustainability (TBLs) [1], [2]. The term "sustainable" was coined at the end of the 1980s, and the term "development" was coined to address economic, social, and environmental concerns [3]. In today's world, sustainability is a major factor in a variety of businesses. However, few mathematical models combine the economic and social consequences of environmental factors and the supply chain [1].

For perishable goods, Jiang et al. [4] considered the carbon footprint when designing the SSCN. They created a bi-objective mathematical model to determine the best partner selection strategy, technology, and transportation method, as well as raw material and recovery material supply. In the sphere of the global food system, Rohmer et al. [5] offered a design approach that included both cost and environmental objectives. Yakavenka et al. [6] created a multi-objective model for perishable food SSCD. Their suggested model helps in the selection of transportation modes, routes, facility sites, and related product flows. Eskandari Khanghahi et al. [7] created a model of multi-objective functions for the blood supply chain that took sustainability into account.

To choose acceptable suppliers in the field of pharmaceutics, Halim et al. [8] and Tavakkoli Moghaddam et al. [9] established a mathematical model for the reverse supply chain of perishable foodstuffs, which they used for a meat product manufacturing company. Varsei and Politkovskay [10] created a multi-objective model to design a long-term wine supply chain. Zahiri et al. [11] proposed a multi-objective sustainable model for constructing a pharmaceutical supply chain structure that takes strategic and tactical actions into account.

Alashhab and Mlybari [12] developed a robust green supply chain network planning optimization model that considers possible risks to identify the production, inventory, and shipping methods. Jouzdani et al. [13] developed a dynamic SCND that takes into account traffic congestion and demand uncertainty. They used a case study to demonstrate the applicability of their concept in the dairy business. Pishvaee et al. [14] presented a case study of an accelerated Benders decomposition technique for sustainable supply chain network design in an uncertain supply chain for medical needles and syringes.

For the perishable food supply from a single manufacturer with a single warehouse, a proposed solution was to apply Monte Carlo simulation to the perishable inventory routing problem (PIRP) [15]. The sustainable supply chain problem regarding the behavior of demand and the number of locations was examined by Al-Ashhab et al. [16], who determined that the final objective was to keep up with the demands of the retailer while using minimum travel between the warehouse and the retailer. To solve the supply chain problem, they used the nonlinear generalized reduced gradient solver, which considers the perishable product in multi-periods and prevents the expiry of the product.

Several studies have shown that hierarchical production planning is a useful strategy to deal with the difficulties associated with multilevel production planning and scheduling issues that arise in real-world systems [1]. Yakavenka et al. [6], and [17] have used multi-criteria decision-making (MCDM) techniques. Repoussis and Gounaris [18], and Ferguson and Koenigsberg [19] have addressed a variety of assumptions about the industrial environment. When it comes to production planning in the face of uncertainty, Thiel [20] offers an in-depth look at mathematical models to do so.

Mohammadi et al. [21] addressed the dynamic multilevel lot size issue in a broad product design with single and multiple limiting resources, as well as time frames. Kim and Bell [22] looked at the difficulties associated with planning multi-item, multilevel backlog production and found them to be very difficult. Lim and Shanthi Kumar [23] developed a multilevel lot size difficulty model with backlogs to simulate capacity-constrained multilevel lot size problems with backlogs. Chan [24] investigated multi-product, multi-period, and multi-stage production planning using sequence-dependent settings in a multi-product, multi-period environment.

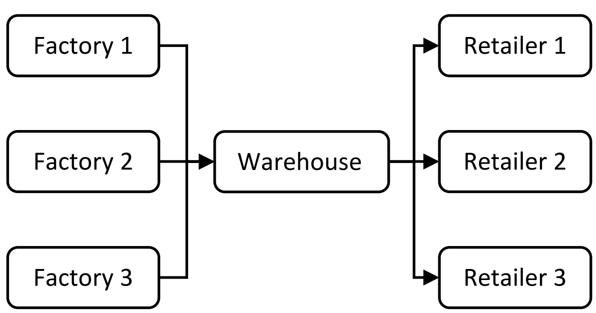

Fig. 1 The general structure of the proposed supply

In this research, the authors have decided to develop a robust supply chain network model considering perishable products using mixed-integer linear programming that integrates both financial and environmental measures for designing and planning a supply chain network. This is carried out in consideration of the uncertain interruption of machines. The main objective of the model is to maximize profit by maximizing the total revenue and minimizing the total cost (including expiration costs) to prevent the expiration of perishable products and to protect the environment. The proposed supply chain network is shown in Fig. 1.

The following assumptions have been considered:

The supply chain is a single product.

The retailer's demand is known.

The shelf life of products is known and limited.

The first products produced are issued first, according to FIFO inventory management.

There is no initial inventory.

The expired products are considered waste and disposed of.

The inventory is kept only in the warehouse.

Backlog is allowed, and the unsatisfied demand through one period can be satisfied in any of the following periods.

2. RESEARCH SIGNIFICANCE

The proposed model helps supply chain managers to design and plan a robust SCN of the perishable products to assure sustainability by maximizing the total profit and avoiding the expiration of products to save environment taking into account the uncertainty of production capacity due to the uncertain interruption in the working environment. The work done in this scope is very rare as presented in the literature review.

3. MODEL FORMULATION

The indices, parameters, and variables used in the proposed model are:

Indices

t	Index of planning periods (t = 1, …, T)
a	Index of the ages of products (a = 1, …, A)
f	Index of potential factories (f = 1, …, F)
r	Index of potential retailers (r = 1, …, R)

Parameters

SL	The product's shelf-life
D_{rt}	The demand of a retailer (r) in period (t)
$CapM_{mt}$	The capacity of a factory (f) in period (t)
$CapW_t$	The capacity of a warehouse in period (t)
Upper	The maximum expected value of interruption
Lower	The minimum expected value of interruption
pr	Price per unit
TC	Transportation cost per unit per distance
DMW_m	Distance between a factory (f) and a warehouse
DWC_c	Distance between a warehouse and a retailer (c)
IHC	Inventory holding cost per unit per period
EC	Expired cost per unit
SC	Shortage cost per unit
MC	Material cost per unit
PC	Production cost per unit
C	Fixed cost

Variables

QFW_{ft}	Quantity of units transferred from a factory (f) to a warehouse in a period (t)
QWC_{ct}	Quantity of units transferred from a warehouse to a retailer (r) in a period (t)
I_{at}	Inventory of the age (a) at the end of a period (t)
$Iexp_t$	Expired inventory at the end of a period (t)
Interruption	The percentage of the outage time to the total planned time (uncertain)
X_f	The binary variable equals 1 if a factory (f) is established; 0 otherwise

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

Z Total profit

3.1. Objective Function

The profit of the supply chain network is maximized using the economic goal function provided in Eq (1).

Profit = Total revenue—Total costs

Total costs include fixed, production, material, transportation, holding, expiration, and shortage costs

The suggested model's objective function is as follows:

$$Z = \sum_{r}\sum_{t} QWR_{rt}\, pr - \sum_{f} FC\, X_{m} - \sum_{m}\sum_{t} QFW_{ft}\,(PC + MC) - \sum_{f}\sum_{t} QFW_{ft}\, TC\, DFW_{f} - \sum_{r}\sum_{t} QWR_{rt}\, TC\, DRW_{r} - \sum_{a}\sum_{t} I_{at}\, IHC - \sum_{t} Iexp_{t}\, EC - \sum_{r}\sum_{t} SC\left(\sum_{1}^{t} D_{t} - \sum_{1}^{t} QWR_{t}\right) \quad (1)$$

The objective function may be broken down as follows:

The sales revenue is calculated using Eq. (2) by multiplying the number of units transferred from the warehouse to the retailers in all periods by the unit price.

$$Sales\ revenue = \sum_{r}\sum_{t} QWR_{rt}\, pr \quad (2)$$

The fixed cost of the factory is calculated using Eq. (3) by multiplying the fixed cost per factory by a binary decision variable Xf that equals 1 if a factory is established at the candidate location f and 0 otherwise, as presented in Eq. (4).

$$Fixed\ cost\ of\ the\ factories = \sum_{f} FC\, X_{f} \quad (3)$$

$$X_{f} = \begin{cases} 1\ If\ a\ factory\ (f)\ is\ established \\ 0\ otherwise \end{cases} \quad (4)$$

The production cost is equal to the number of units transferred from the factory to the retailers (r) during all periods (t) multiplied by the production cost per unit, as presented in Eq. (5)

$$Production\ cost = \sum_{f}\sum_{t} QFW_{ft}\, PC \quad (5)$$

The cost of the material is equal to the number of units transferred from the factory to the warehouse during all periods multiplied by the cost of the material per unit, as presented in Eq. (6).

$$Material\ cost = \sum_{f}\sum_{t} QFW_{ft}\, MC \quad (6)$$

The transportation cost is calculated using Eq. (7) by multiplying the number of units moved from each facility by the transportation cost per unit distance and the distance between them.

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

$$Transportation\ cost = \sum_f \sum_t QFW_{ft} * TC\ DFW_f + \sum_r \sum_t QWR_{rt}\ TC\ DRW_r \tag{7}$$

Multiply the remaining inventory in all periods by the unit inventory holding cost to obtain the inventory holding cost, as presented in Eq. (8).

$$Inventory\ holding\ cost = \sum_a \sum_t I_{at}\ IHC \tag{8}$$

The expiration cost is calculated using Eq. (9) by multiplying the expired inventory at the end of all periods by the unit expiration cost.

$$Expiration\ cost = \sum_t Iexp_{slt}\ EC \tag{9}$$

The difference between the cumulative demand and the cumulative received amounts of each retailer is multiplied by the unit shortage cost per period to compute the shortage cost as presented in Eq. (10).

$$Shortage\ cost = \sum_r \sum_t SC \left(\sum_1^t D_t - \sum_1^t QWR_t \right) \tag{10}$$

[1] **Constraints**

The model constraints are presented in this section.

Balancing Constraints

$$I_{at} = \sum_{f \in F} QFW_{ft} - \sum_{r \in R} QWR_{rt} \qquad t = 1, \qquad a = 1 \tag{11}$$

$$I_{at} = QFW_t - \ max \left\{ \left(\sum_1^t QWR_t \right) - \sum_{a=1}^{S-1} I_{a,t-1}, 0 \right\}, t = 2, \ldots, T, a = 1 \tag{12}$$

$$I_{at} = max \left\{ I_{a-1,t-1} - max \left\{ \left(\sum_{r \in R} QWR_{rt} \right) - \sum_{j=a}^{S-1} I_{j,t-1}, 0 \right\}, 0 \right\}, t = 2, .., T, a = 2, \ldots, S \tag{13}$$

The equivalence of the inventory balance in the warehouse is ensured. The number of units transferred in the first period from the factory to the warehouse matches the number of units transferred from the warehouse to the retailer, in addition to the inventory as presented in Eq. (11).

Constraints (12) and (13) are used to determine how much inventory is left in the warehouse after each period. They ensure that units are handled by the FIFO inventory policy. Under a FIFO inventory policy, the oldest inventory, or inventory of the highest age, is used first to meet demand, followed by the inventory of intermediate age. Ultimately, demand is met by the inventory of the freshest units, i.e., inventory of the lowest age.

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

$$Iexpt = 0 \;\forall\, t < SL \tag{14}$$

$$Iexpt = Iat \;\forall\, t \geq SL, a = SL \tag{15}$$

Constraint (14) determines the inventory that has expired, and it ensures that no product will expire before its shelf life expires. Constraint (15) determines that the expired inventory could only appear once the shelf life has been reached.

Capacity Constraints

$$QFW_{ft} \leq CapF_{ft} * \left(1 - Interruption_{ft}\right) * X_f \;\forall\, f, t \tag{16}$$

$$lower \leq Interruption_{ft} \leq \text{Upper} \;\forall\, f, t \tag{17}$$

Constraints (16) and (17) ensure that the number of units transferred from factories does not exceed the capacity of the factories calculated and that the interruption does not exceed the upper and lower rates of interruption.

$$\sum_{r\in R} QWR_{rt} \leq Drt_t, t = 1 \tag{18}$$

$$QWR_{rt} \leq \sum_{t=1}^{t} Drt - \sum_{t=1}^{t-1} QWR_{rt}, t \geq 2 \tag{19}$$

Constraint (18) ensures that the number of units transferred from the warehouse to the retailers during the first period does not exceed the amount of demand of the retailers in the first period.

Constraint (19) ensures that the number of units transferred from the warehouse to the retailers during the periods does not exceed the difference between the cumulative demand of all retailers and the cumulative quantity transferred for each period from the warehouse to the retailers.

$$\sum_{f\in F} QFW_{f1} \leq CapW_1 \;\forall\, f, t = 1 \tag{20}$$

$$\sum_{f\in F} QFW_{ft} + \sum_{a=1}^{SL-1} I_{a,t-1} \leq CapW_t \;\forall\, f, t > 1 \tag{21}$$

Constraint (20) ensures that the number of units transported from the factory to the warehouse during the first period does not exceed the warehouse capacity.

Constraint (21) ensures that the overall number of items entering the warehouse in each period, as well as products left over from the previous period, does not exceed the prespecified capacity of the warehouse.

$$QFW_{ft}, QWR_{rt}, I_{at}, Iexp_t \geq 0, \forall\, f, r, a, t \tag{22}$$

$$X_f \in \{0,1\}, \forall\, f \tag{23}$$

Constraint (22) prevents the quantities from taking negative values, and constraint (23) ensures that X_f is binary.

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

4. RESULTS AND DISCUSSIONS

In this section, the effect of the minimum and maximum expected values of interruption on the network performance will be studied. In addition, we will study the effect of the capacity disruption on the supply chain network's design, planning, and expected profit. The model parameters are assumed as presented in Table .

Table 1 Working parameters

Parameter	Value
Shelf life	3 (period)
$CapF_{ft}$	6000 (unit)
$DFW_{1,2,3}$ & $DWR_{1,2,3}$	200, 300, 400 (km)
$CapW_t$	100,000 Unit
IHC	3 (USD/unit/t)
EC, MC and PC	10 (USD/unit)
SC	5 (USD/unit)
FC	4000 (USD/unit)
TC	USD/unit)
PR	(USD/UNIT)

4.1. Studying the Effect of the Minimum and Maximum Expected Value of Interruption

The objective of this experiment is to study the variability range in the effect of the minimum and maximum expected values of possible interruptions on the different cost elements. For these test problems, all the parameters are kept fixed, with interruption as the only variable. The range of the minimum and maximum expected values of possible interruptions is assumed to be from zero to 0.8 with a step of 0.2. The resulting incomes and costs of these experiments are presented in Fig. 2. It may be concluded that the performance of the network is affected mainly by the maximum value of the expected interruption.

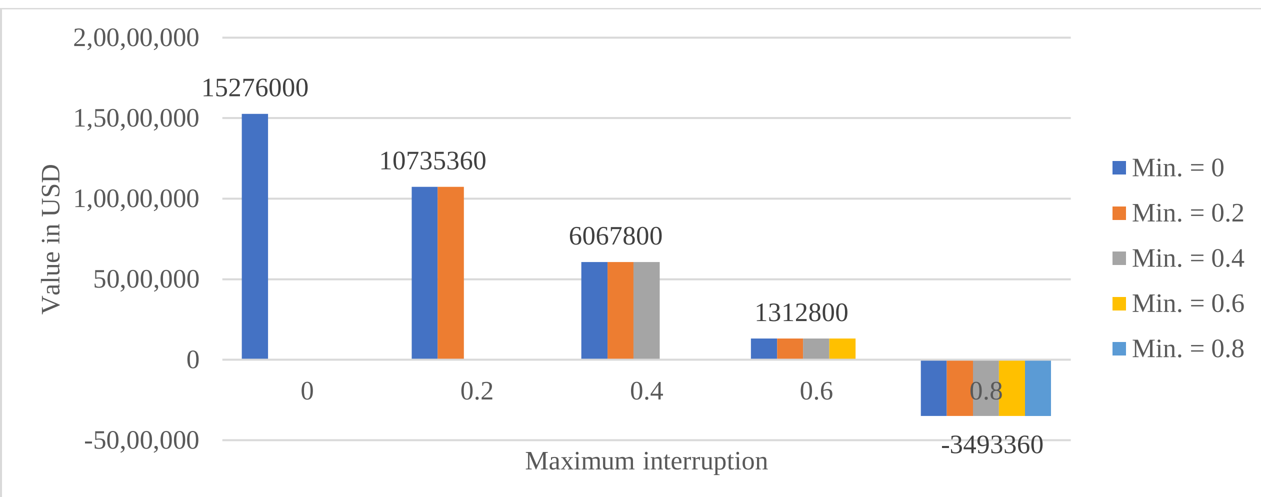

Fig. 2. The effect of the minimum and maximum expected interruption on the profit.

4.2. Studying the Effect of The Capacity Disruption on the SCN Design and planning

In this section, the effect of the capacity disruption on the design and planning of the SCN is studied. All parameters were kept constant as shown in Table 2 except for the maximum percentage of interruption.

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

Table 2 The optimal robust SCN design and plan at different interruption rates for the first scenario.

Interruptions	Demand	Produced F1	Produced F2	Produced F3	Delivered	Shortage
0	6	6	0	0	6	0
0.2	6	4.8	1..2	0	6	0
0.4	6	3.6	2.4	0	6	0
0.6	6	2.4	2.4	1.2	6	0
0.8	6	1.2	1.2	1.2	3.6	2.4

As shown in Table it may be noticed that at zero interruption, the capacity of only one factory is enough to fulfil all retailers' demands. While at the interruption rates of 0.2 and 0.4, the capacity of the factories decreases to 4800 and 3600 units per period respectively, so the first factory produces at its full capacity and the second factory opens to satisfy the extra amount of demand. There is no need for a third factory.

At an interruption rate of 0.6 and 0.8, the capacity of the factories decreases to 2400 and 1200 units per period respectively, so the first and second factories produce at their full capacity and the third factory opens to satisfy the extra amount of demand.

From this study, it may be concluded that the interruption ratio has an obvious effect on the design and performance of the SCN.

4.3. Studying the Effect of the Capacity Disruption on the SCN Performance

In this section, the effect of the capacity disruption on the SCN performance; quantities delivered, stored, and shortages is studied at different value of interruption rates. The demand of all retailers at all periods are as shown in Table .

Table 3 Retailer's demand (in Thousands)

Period	1	2	3	4	5	6
Demand	2	4	6	8	10	12
Period	7	8	9	10	11	12
Demand	12	10	8	6	4	2

As shown in Table , at an interruption rate of 0.2, the capacity of the factories decreases to 14,400 units per period. The demand exceeds the total capacity in all periods except the first two periods in which the SCN retains some inventory to satisfy some of the extra demand in the next periods, according to the excessive increase in demand compared to the SCN's capacity, the shortage quantities increase gradually during the last periods.

Table 4 The optimal robust plan of the SCN at an interruption rate of 0.2.

Period	Demand	Produced	Delivered	Inventory a1	Inventory a2	Inventory a3	Inventory	Shortage	Profit (USD)
1	6	14.4	6	8.4	0	0	8.4	0	10,735,36
2	12	14.4	12	10.8	0	0	10.8	0	
3	18	14.4	18	7.2	0	0	7.2	0	
4	24	14.4	21.6	0	0	0	0	2.4	
5	30	14.4	14.4	0	0	0	0	18	
6	36	14.4	14.4	0	0	0	0	39.6	
7	36	14.4	14.4	0	0	0	0	61.2	
8	30	14.4	14.4	0	0	0	0	76.8	

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

9	24	14.4	14.4	0	0	0	0	86.4
10	18	14.4	14.4	0	0	0	0	90
11	12	14.4	14.4	0	0	0	0	87.6
12	6	14.4	14.4	0	0	0	0	79.2

At an interruption rate of 0.6, the capacity of the factories decreases to 7200 units per period. The demand exceeds the total capacity in all periods except the first period in which the SCN retains some inventory to satisfy some of the extra demand in the next periods, as shown in Table 5. According to the excessive increase in demand compared to the SCN's capacity, the shortage quantities increase gradually during the last periods.

Table 5 The optimal robust plan of the SCN at an interruption rate of 0.6.

Period	Demand	Produced	Delivered	Inventory			Inventory	Shortage	Profit (USD)
				a1	a2	a3			
1	6	7.2	6	12	0	0	12	0	
2	12	7.2	8.4	0	0	0	0	3.6	
3	18	7.2	7.2	0	0	0	0	14.4	
4	24	7.2	7.2	0	0	0	0	31.2	
5	30	7.2	7.2	0	0	0	0	54	
6	36	7.2	7.2	0	0	0	0	82.8	1,312,8
7	36	7.2	7.2	0	0	0	0	111.6	
8	30	7.2	7.2	0	0	0	0	134.4	
9	24	7.2	7.2	0	0	0	0	151.2	
10	18	7.2	7.2	0	0	0	0	162	
11	12	7.2	7.2	0	0	0	0	166.8	
12	6	7.2	7.2	0	0	0	0	165.6	

The effect of interruption on the quantities delivered to retailers is presented in Fig. 3. There is a decrease in the delivered quantities due to increases in the number of interruptions.

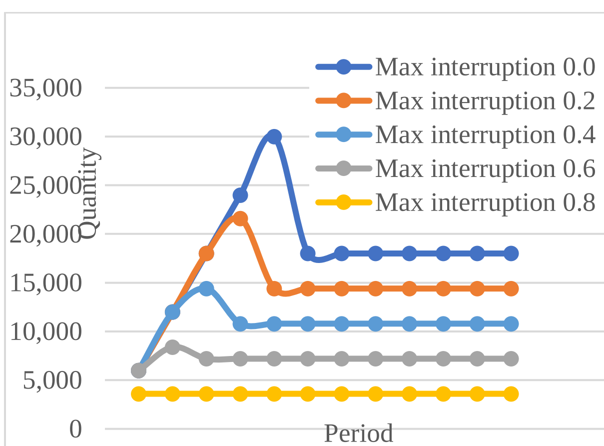

Fig. 3. Effect of interruptions on the quantities delivered to retailers.

The effect of interruptions on the residual inventory is presented in Fig. 4. The residual inventories decrease because of the increase in interruptions. The effect of interruptions on the shortage quantities is presented in Fig. 5. The shortage quantities increase because of the increase in interruptions.

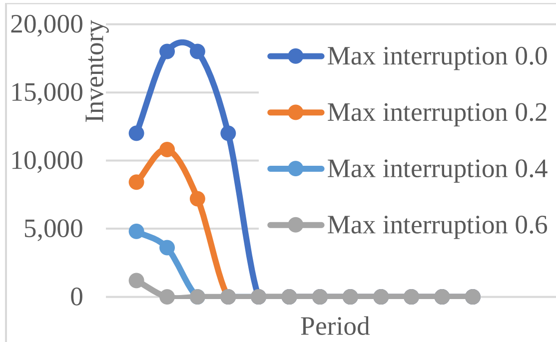

Fig. 4. Effect of interruptions on the residual inventory.

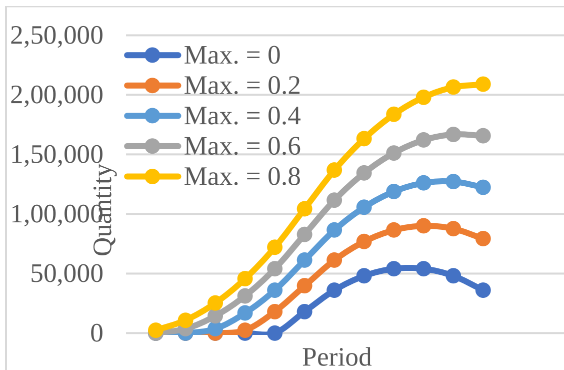

Fig.5. Effect of interruptions on the shortage quantities.

The Effects of Interruptions on the Supply Chain Network's Profit

The effect of interruptions on the profit is presented in Fig. 6. The increase in interruptions leads to a decrease in profits in almost all cases.

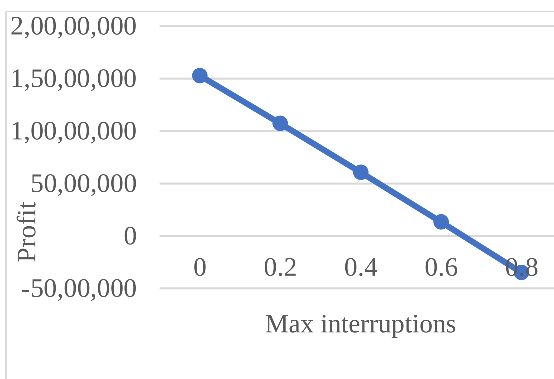

Fig. 6. Effect of interruptions on the profit.

5. CONCLUSION

The developed study models a supply chain network consisting of three echelons: number of factories, distribution warehouse, and number of retailers for perishable products in a limited multi-period time horizon. The model takes into consideration the disruption of factory capacity due to an uncertain interruption. In addition, it deals with a sustainable supply chain network and interruptions that affect factory capacity while maintaining the FIFO inventory policy to maximize the network's overall profit, reduce the amount of expired products, and reduce the impact on the environment. The model successfully handled the problem of designing and planning a long-term supply chain network for perishable products while considering inventory in the warehouse

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS

and the backlog. Moreover, a demand that is not supplied in one period can be met in succeeding periods. This aids in the prevention of product expiration by ensuring that only the appropriate quantities are generated with no waste.

The capability and accuracy of the model were verified by solving several scenarios. The effect of the minimum and maximum expected values of interruptions was studied. It may be concluded that robust SCN design is mainly affected by the maximum expected interruption. The design and performance of the SCN are affected by the capacity disruption of the factories, and the model succeeded in designing and planning the SCN under all conditions.

For future studies, we recommend considering:

- multi-products.
- multi-items.
- multi-objectives.
- the reverse logistics of the expired products; and
- stochastic demand

Acknowledgement

The authors would like to thank the Deanship of Scientific Research at Umm Al-Qura University for supporting this work by Grant Code: (22UQU4320686DSR01).

Funding

This study has received funding from Deanship of Scientific Research at Umm Al-Qura University for supporting this work by Grant Code: (22UQU4320686DSR01).

Conflict of Interest

The author declares that there are no conflicts of interests.

Data and materials availability

All data associated with this study are present in the paper.

REFERENCES AND NOTES

1. K. Govindan, A. Jafarian, and V. Nourbakhsh, "Designing a sustainable supply chain network integrated with vehicle routing: A comparison of hybrid swarm intelligence metaheuristics," Comput. Oper. Res., vol. 110, pp. 220–235, 2019.
2. Y.-C. Tsao, V. Thanh, J. Lu, and V. Yu, "Designing sustainable supply chain networks under uncertain environments: Fuzzy multi-objective programming," J. Clean. Prod., vol. 174, pp. 1550–1565, 2018.
3. F. Ciliberti, P. Pontrandolfo, and B. Scozzi, "Logistics social responsibility: Standard adoption and practices in Italian companies.," Int. J. Prod. Econ., vol. 113, no. 1, pp. 88–106, 2008.
4. Y. Jiang, Y. Zhao, M. Dong, and S. Han, "Sustainable Supply Chain Network Design with Carbon Footprint Consideration: A Case Study in China," Math. Probl. Eng., pp. 1–19, 2019.
5. S. U. K. Rohmer, J. C. Gerdessen, and G. D. H. Claassen, "Sustainable supply chain design in the food system with dietary considerations: A multi-objective analysis," Eur. J. Oper. Res., vol. 273, no. 3, pp. 1149–1164, 2019.
6. V. Yakavenka, I. Mallidis, D. Vlachos, E. Iakovou, and Z. Eleni, "Development of a multi-objective model for the design of sustainable supply chains: the case of perishable food products," Ann. Oper. Res., 2019.
7. M. Eskandari-Khanghahi, R. Tavakkoli-Moghaddam, A. A. Taleizadeh, and S. H. Amin, "Designing and optimizing a sustainable supply chain network for a blood platelet bank under uncertainty," Eng. Appl. Artif. Intell., vol. 71, pp. 236–250, 2018.
8. Halim, P. Ang, and A. Adhitya, "A decision support framework and system for design of sustainable pharmaceutical supply chain network," Clean Technol. Environ. Policy, vol. 21, no. 2, pp. 431–446, 2018.
9. S. Tavakkoli Moghaddam, M. Javadi, and S. M. Hadji Molana, "A reverse logistics chain mathematical model for a sustainable production system of perishable goods based on demand optimization," J. Ind. Eng. Int., 2018.
10. M. Varsei and S. Polyakovskiy, "Sustainable supply chain network design: A case of the wine industry in Australia," Omega, vol. 66, pp. 236–247, 2017.
11. B. Zahiri, J. Zhuang, and M. Mohammadi, "Toward an integrated sustainable-resilient supply chain: A

pharmaceutical case study," Transp. Res. Part E Logist. Transp. Rev., vol. 103, pp. 109–142, 2017.

12. M. S. Alashhab and E. A. Mlybari, "Developing a robust green supply chain planning optimization model considering potential risks," Int. J. GEOMATE, vol. 19, no. 73, pp. 208–215, 2020, doi: 10.21660/2020.73.52896.
13. J. Jouzdani, S. J. Sadjadi, and M. Fathian, "Dynamic dairy facility location and supply chain planning under traffic congestion and demand uncertainty: A case study of Tehran," Appl. Math. Model., vol. 37, no. 18–19, pp. 8467–8483, 2013, doi: 10.1016/j.apm.2013.03.059.
14. M. S. Pishvaee, J. Razmi, and S. A. Torabi, "An accelerated Benders decomposition algorithm for sustainable supply chain network design under uncertainty: A case study of medical needle and syringe supply chain," Transp. Res. Part E Logist. Transp. Rev., vol. 67, pp. 14–38, 2014.
15. B. S. Onggo, J. Panadero, C. G. Corlu, and A. A. Juan, "Agri-food supply chains with stochastic demands: A multi-period inventory routing problem with perishable products," Simul. Model. Pract. Theory, vol. 97, 2019, doi: 10.1016/j.simpat.2019.101970.
16. M. S. Al-Ashhab, O. M. Nabil, and N. H. Afia, "Perishable products supply chain network design with sustainability," Indian J. Sci. Technol., vol. 14, no. 9, pp. 787–800, 2021, doi: 10.17485/ijst/v14i9.24.
17. "An efficient solution method for the flexible and robust inventory-routing of red blood cells," 2018. [Online]. Available: http://www.elsevier.com/open-access/userlicense/1.0/.
18. P. P. Repoussis and C. E. Gounaris, "Special issue on vehicle routing and scheduling: Recent trends and advances," Optimization Letters, vol. 7, no. 7. 2013, doi: 10.1007/s11590-012-0603-4.
19. M. E. Ferguson and O. Koenigsberg, "How should a firm manage deteriorating inventory?," Prod. Oper. Manag., vol. 16, no. 3, 2007, doi: 10.1111/j.1937-5956.2007.tb00261.x.
20. Thiele, "Multi-product pricing via robust optimisation," J. Revenue Pricing Manag., vol. 8, no. 1, 2009, doi: 10.1057/rpm.2008.41.
21. S. Mohammadi, A. Cheraghalikhani, and R. Ramezanian, "A joint scheduling of production and distribution operations in a flow shop manufacturing system," Sci. Iran., vol. 25, no. 2E, 2018, doi: 10.24200/sci.2017.4437.
22. S. W. Kim and P. C. Bell, "Optimal pricing and production decisions in the presence of symmetrical and asymmetrical substitution," Omega, vol. 39, no. 5, 2011, doi: 10.1016/j.omega.2010.11.002.
23. E. B. Lim and J. G. Shanthikumar, "Relative entropy, exponential utility, and robust dynamic pricing," Oper. Res., vol. 55, no. 2, 2007, doi: 10.1287/opre.1070.0385.
24. H. L. Chan, "Supply chain coordination with inventory and pricing decisions," Int. J. Invent. Res., vol. 5, no. 3, 2019, doi: 10.1504/ijir.2019.10020307

ISSN 2319–7757 EISSN 2319–7765 I OPEN ACCESS