A Novel Optimization Technique for Integrated Supply Chain Network in Industries - a Technical Perspective

Rohit Kaushik, Hossein Shokri Garjan and Divya Singh

April 25, 2021

A Novel Optimization Technique for Integrated Supply Chain Network in Industries - A Technical Perspective

Dr. Rohit Kaushik
Department of Electronics and Communication Engineering,
Institute of Information Technology
Noida,India
rohit.kaushik@glbitm.ac.in

Hossein Shokri Garjan
Department of Industrial Engineering,
Babol Noshirvani University of Technology
Babol,Iran
hossein.shokri@nit.ac.ir

Dr.Divya Singh
Department of Civil Engineering,Indian Institute of Technology Roorkee
New Delhi, India
divya1784@rediffmail.com

Abstract

Supply chain (SC) management is an integral part of the technological advancement of industries nowadays. This study designed and presents an optimization model for the inventory-location technical problems in an SC network. The model considers carbon emission and perishable products and formulated a novel model based on the mixed-integer linear programming concept. The proposed model aimed at minimizing the total costs in the network. The solution of the model obtained using the GAMS optimization package. The results show that an optimal solution is reachable within a reasonable time with the presented mathematical model.

Keywords*: Supply Chain Network, Carbon Emission, Perishable Products, Mathematica Model.*

1. Introduction

A Supply Chain (SC) is a network of processes whose ultimate goal is to provide commodities and services to customers [1, 2, 16-20]. The main purpose of the SC can be considered to optimize the performance of the desired chain.

On the other hand, the SC is exposed to various risks that these problems affect the efficiency of the chain components and the whole chain [3, 21-28]. This problem is highlighted when the SC is related to perishable products, which doubles the importance of this issue. As you know, the life of marketable products is limited, so the design and management of the SC for these products is essential [4, 5, 29-33]. Corruption of goods has several economic effects, including losses of enterprises, increased waste and pollution of the environment.

The rest of this study is as follows: Section 2 shows an overview of the existing literature relevant to the location-inventory models of the SC network. Section 3 describes the problem. The mathematical formulas are explained in Section 4. In Section 5, the computational outcomes are presented and finally numerical tests and conclusions are performed in Section 6.

2. Literature review

Paxoi et al. (2010) examined a multi-objective linear mathematical model to decrease the cost and amount of carbon dioxide emissions in forward logistics as well as to decrease SC costs in reverse logistics [1]. Verdu et al. (2010) have designed a basic model for supplying fresh and processed fruit SC with all the details [2]. Amorim et al. (2012) produce and distribute perishable products to optimize fruit freshness [3]. Amin and Zhang (2013) consider a closed-loop SC network that includes production and collection centers and multi-product demand market under conditions of uncertainty. Their mathematical model was a complex integer programming that aims to decrease whole costs [4]. Velichko (2014) presents an integrated model for decision-making in the field of fruit and vegetable service logistics [5]. Nadal Roig & Pa Aragos (2015) presented a mathematical transport model for the fruit SC in which a fruit logistics center is provided by a number of storage centers according to demand in the non-harvest season [6]. Etemadnia et al. (2015), utilizing two-level transportation options, suggested the optimal location of the wholesale facility for the fruit and vegetable SC and proposed an innovative method to achieve the results [7]. Hayast et al. (2017) investigated the issue of routing-location potential trust with limited conditions under accidental disturbance in warehouses and proposed a scenario-based mixed integer planning model to optimize warehouse locations, out-of-bounds delivery routes and support programs [8]. Yavari et al. (2019) presented a two-layer flexible closed-loop SC mathematical model for perishable products considering the risk of power outages in the grid. Their mathematical model is Mixed-Integer Linear Programming (MILP). This two-layer model includes two objective functions for each layer with defined objectives. LP metric method has been utilized to solve the multi-objective model and a case study from Kaleh company has been studied for validation [9].

Imran et al. (2020) presented an inventory routing model that was multi-objective and multi-cycle for perishable products at undisclosed costs. On the other hand, reducing the cost of CO2 emissions is also considered in this model. Their mathematical model is MILP. A multi-objective fuzzy programming approach was used to solve the model [10]. Tirkalai et al. (2019) presented a mathematical model for the problem of routing perishable vehicles. Their mathematical model is MILP. Their goal is to decrease the cost of the entire SC. First, the model was linearized, then it was solved, and on the other hand, the robust model planning approach was used [11]. Mousavi et al. (2017) considered a multi-objective mathematical model of novelization and location of the center for perishable products in the food SC taking into account carbon dioxide emissions. Their mathematical model is MILP. Therefore, NSGA.II method was used to solve the model [12]. Dai et al. (2018) presents a mathematical model for the SC location problem, whose mathematical model is MILP. Their goal is to decrease the whole cost of inventory. To solve the model, the methods of hybrid genetic algorithm were used along with hybrid neighborhood search [13]. Tirkalai et al. (2019) considered a multi-objective mathematical model that includes two-level green routing for perishable products. The volume of the intended warehouse type is average. Their mathematical model is MINLP. Both of their objective functions are of the minimization type. The proposed solution for this Epsilon model is constraint [14]. Buicki et al. (2020) examine an integrated three-objective model of inventory, location, and routing. Their mathematical model is MILP. All three objective functions are of the minimization type. Genetic algorithms and particle swarm optimization have been used to solve the model [15].

3. Problem description

There is a three-tier SC network that includes factories, retailers, and warehouses. The purpose of the suggested model is to reduce the whole cost. Whole costs include maintenance costs, warehouse ordering costs, fixed costs, shipping costs, perishable commodities, loss cost. The goals and decisions pursued in this article include the following.

Determining the location and number of factories and warehouses, assigning retailers to warehouses and allocating warehouses to factories, and inventory control decisions for each warehouse.

SC network designed for perishable products such as meat, vegetables, human blood, medicine, flowers, etc. has been proposed and designed.

On the other hand, this network has been affected by various factors such as storage capacity and carbon emissions.

According to the studies reviewed in the proposed model, there is no control over the purchase costs.

Therefore, in order to save on purchase costs and investigate the issue in the real world, the maximum capital is considered so that the purchase costs do not exceed this amount of capital.

The assumptions of the proposed model are as follows.

- Determining fixed costs for warehouses and factories.
- Shipping costs are considered according to the distance traveled, the volume and amount of perishable products and the shipping unit.
- Retailers must specify at least one warehouse so that if supply exceeds demand or vice versa, the cost of fines will increase.
- Inventory costs that occur only in warehouses include maintenance costs and ordering costs . The optimal order quantity is equal to the economic order quantity .Perishable products also have different maintenance and ordering costs.
- Perishable products spoil only when transferred from warehouse to retailers and no damage occurs at other times.If the time required to transport the following corrupt materials from the warehouse to the retailers is more than the critical time, the request will be rejected.
- Warehouse capacity is limited. On the other hand, the SC is limited by crane emissions.
- There is no shortage of product and delivery time for warehouses

Indices:

P	Set of Perishable product ($p \in P$)
R	Set of retailers ($r \in R$)
U	Set of industrial units ($u \in U$)
W	Set of warehouses ($w \in W$)

Parameters:

FC_u	Fixed annual cost for factory u
FC_w	Fixed annual cost for warehouse w
L_p	Cost of loss per unit of perishable product p
di_{uw}	Factory distance u to warehouse w
d_{wr}	Warehouse distance w to retailer r
f_{uw}	Cost of purchasing perishable product p for warehouse w from factory u
f_{rw}	Cost of purchasing perishable product p for retailer r from warehouse w
x_r	Maximum capital (each retailer r)
c_p	Perishable product transport unit p
O_{wp}	The cost of warehouse ordering w for perishable product p
h_{wp}	Warehouse maintenance cost w for perishable product p
CT_p	The time of the critical of perishable product p to be disposed of.
D_{rp}	Annual demand for perishable product p for retailers r
h_{rp}^{s}	Cost of perishable product p damage due to oversupply of demand for retailers r
h_{rp}^{d}	Cost of perishable product p due to demand greater than supply to retailer r
δ_{wrp}	Perishable rate of perishable product p from warehouse w to retailer r
wc_w	Annual warehouse capacity limit w
car	Annual carbon emissions limit
sp	Vehicle speed
λ	Reliability level of carbon emissions limits
θ	Confidence level of capacity constraints

γ	Capability level of capital constraint

Decision variables:

ED_{rp}^{d}	Excess demand for perishable product p for retailer r
Z_{rp}^{s}	Excess supply of perishable product p for retailer r
Y_{uwp}	The amount of perishable product p from factory u to warehouse w
Y_{wrp}	Amount of perishable product p from warehouse w to retailer r
η_w	$\begin{cases}1 & \text{If warehouse w is open}\\ 0 & \text{Otherwise}\end{cases}$
β_u	$\begin{cases}1 & \text{If factory u is open}\\ 0 & \text{Otherwise}\end{cases}$

4. Mathematical model

$$\begin{aligned}\min TC = &\sum_{p\in P}\sum_{w\in W}\sqrt{O_{wp}h_{wp}\frac{\sum_{u\in U}Y_{uwp}}{2}}+\sum_{w}FC_w\eta_w\sum_{u}FC_u\beta_u\\ &+\sum_{w\in W}\sum_{r\in R}\sum_{p\in P}Y_{wrp}C_p di_{uw}+\sum_{u\in U}\sum_{w\in W}\sum_{p\in P}Y_{uwp}C_p di_{uw}\\ &+\sum_{w\in W}\sum_{r\in R}\sum_{p\in P}Y_{wrp}(1-\delta_{wrp})L_p+\sum_{r\in R}\sum_{p\in P}Z_{rp}^{s}h_{rp}^{s}\sum_{r\in R}\sum_{p\in P}ED_{rp}^{d}h_{rp}^{d}\end{aligned} \tag{1}$$

$subject\,to:$

$$\sum_{r\in R}Y_{wrp}=\sum_{u\in U}Y_{uwp} \qquad \forall w,p \tag{2}$$

$$Y_{wrp}\left(\frac{di_{wr}}{sp}-CT_p\right)\le 0 \qquad \forall w,r,p \tag{3}$$

$$\left(\sum_{p\in P}\sum_{u\in U}Y_{uwp}\le wc_w\eta_w\right)\ge\theta \qquad \forall w \tag{4}$$

$$\left(\left(\sum_{p\in P}\sum_{w\in W}\sum_{r\in R}Y_{wrp}di_{wr}+\sum_{p\in P}\sum_{u\in U}\sum_{w\in W}Y_{uwp}di_{uw}\right)\le car\right)\ge\lambda \tag{5}$$

$$\left(\left(\sum_{p\in P}\sum_{u\in U}\sum_{w\in W}Y_{uwp}di_{wr}+Y_{wrp}di_{uw}\right)\le x_r\right)\ge\gamma \qquad \forall r \tag{6}$$

$$\eta_w,\beta_u\in\{0,1\} \qquad \forall w,u \tag{7}$$

$$Y_{wrp},Y_{uwp},Z_{rp}^{s},ED_{rp}^{d}\ge 0 \qquad \forall w,r,p \tag{8}$$

Equation (1) represents the objective function that seeks to decrease the costs of the entire location-inventory SC network. Constraint (2) relates to the balance of retailers and warehouses. Constraint (3) indicates that the perishable product will be damaged if the time required to deliver the perishable product from the warehouse to the retailer exceeds the critical time. Constraint (4) indicates that $(\sum_{p\in P}\sum_{u\in U}Y_{uwp}\le wc_w\eta_w)$ it is equal to or greater than the confidence level. Constraint (5) states that less than the $(\sum_{p\in P}\sum_{w\in W}\sum_{r\in R}Y_{wrp}di_{wr}+\sum_{p\in P}\sum_{u\in U}\sum_{w\in W}Y_{uwp}di_{uw})$ confidence level λ is given. Constraint (6) indicates that $(\sum_{p\in P}\sum_{u\in U}\sum_{w\in W}Y_{uwp}di_{wr}+Y_{wrp}di_{uw})\le x_r)$ it is equal to or greater than the confidence level. Constraints (7) and (8) indicate that the variables Y_{wrp},Y_{uwp} are positive and the variables η_w,β_u are binary.

5. Computational results

The number of factories, warehouses and retailers is 4, 5, 10, respectively. Table 1 calculates the problem variables, such as the number of perishable products sent from factories to warehouses and from warehouses to retailers.

Table 1. Results of Gams software

Decision variables	The value of indices	RESULT
Y_{uwp}	$w\in\{1,\dots,5\}$ $r\in\{1,\dots,10\}$ $p\in\{1,2\}$	20
X_{jik}	$u\in\{1,\dots,4\}$ $w\in\{1,\dots,5\}$ $p\in\{1,2\}$	10
y_j	$p\in\{1,2\}$	1
y_p	$u\in\{1,\dots,4\}$	1
Z_{ik}^{d}	$r\in\{1,\dots,10\}$ $p\in\{1,2\}$	3
Z_{ik}^{s}	$r\in\{1,\dots,10\}$ $p\in\{1,2\}$	5

6. Conclusion

In this paper, a three-tier location-inventory model in the SC is investigated that aims to decrease whole costs at different levels of the chain. By adding the assumption of capital constraints, more adaptation is created among the designed model and real problems, which is solved using GAMS software.

The effects of different factors on whole costs are as follows: According to the results, with increasing demand, the whole cost increases. (Figure 1) Decreasing the number of retailers and increasing the number of factories and warehouses will reduce whole costs. There is an inverse relationship among health rates and whole costs. Because the higher the health rate, the lower the cost of lost products. As can be seen in Table 2, changes in critical times and confidence levels of storage capacity limits, carbon emission limits, and capital constraints cause changes in whole costs. As critical times increase, whole costs decrease because they reduce the cost of losses. Warehouse capacity constraints, carbon constraints and capital constraints do not have a significant impact on whole costs unless they are at a certainty level. In determining their amounts, it should be noted that the cost of losses does not increase because then the whole costs will increase.

For future works, the interested researchers can add sustainable and resilient concepts to the proposed model. Additionally, we recommended extremely that scholars develop hybrid meta-heuristic algorithms and compared them with the suggested algorithm in this paper. Finally, to cope with uncertain parameters, techniques such as fuzzy, robust, stochastic, etc. can be used.

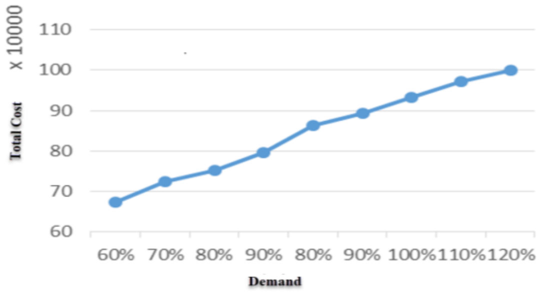

Figure1. Relationship among whole cost and demand

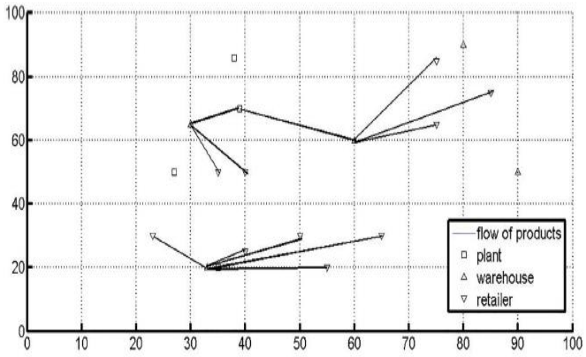

Figure 2. Location SC network - inventory

Table 2. Examination of samples with critical time and different confidence levels

T_k	55%	
	Whole Cost	Solving Time (s)
40	690767/303	0:00:00/303
50	690762/254	0:00:00/311
60	690746/190	0:00:00/309

T_k	75%	
	Whole Cost	Solving Time (s)
40	690767/303	0:00:00/301
50	690755/584	0:00:00/303
60	690746/732	0:00:00/305

T_k	95%	
	Whole Cost	Solving Time (s)
40	671763/358	0:00:00/355
50	671564/144	0:00:00/313
60	670923/1	0:00:00/305

Reference:

1. Paksoy, T., E. Özceylan, and G.W. Weber. *A multi objective model for optimization of a green supply chain network*. in *AIP conference proceedings*. 2010. American Institute of Physics.
2. Verdouw, C., et al., *Process modelling in demand-driven supply chains: A reference model for the fruit industry*. Computers and electronics in agriculture, 2010. **73**(2): p. 174-187.
3. Amorim, P., H.-O. Günther, and B. Almada-Lobo, *Multi-objective integrated production and distribution planning of perishable products*. International Journal of Production Economics, 2012. **138**(1): p. 89-101.
4. Amin, S.H. and G. Zhang, *A multi-objective facility location model for closed-loop supply chain network under uncertain demand and return*. Applied Mathematical Modelling, 2013. **37**(6): p. 4165-4176.
5. VELYchKO, O., *Integrated modeling of solutions in the system of distributing logistics of a fruit and vegetable cooperative*. Verslas: teorija ir praktika, 2014. **15**(4): p. 362-370.
6. Nadal-Roig, E. and L.M. Plà-Aragonés, *Optimal transport planning for the supply to a fruit logistic centre*, in *Handbook of Operations Research in Agriculture and the Agri-Food Industry*. 2015, Springer. p. 163-177.
7. Etemadnia, H., et al., *Optimal wholesale facilities location within the fruit and vegetables supply chain with bimodal transportation options: An LP-MIP heuristic approach*. European Journal of Operational Research, 2015. **244**(2): p. 648-661.
8. Hiassat, A., A. Diabat, and I. Rahwan, *A genetic algorithm approach for location-inventory-routing problem with perishable products*. Journal of manufacturing systems, 2017. **42**: p. 93-103.
9. Yavari, M., & Geraeli, M. (2019). Heuristic method for robust optimization model for green closed-loop supply chain network design of perishable goods. *Journal of Cleaner Production*, *226*, 282-305.
10. Imran, M., et al., *Inventory routing problem in supply chain of perishable products under cost uncertainty*. Mathematics, 2020. **8**(3): p. 382.
11. Tirkolaee, E.B., et al., *A robust green traffic‐based routing problem for perishable products distribution*. Computational Intelligence, 2020. **36**(1): p. 80-101.
12. Musavi, M. and A. Bozorgi-Amiri, *A multi-objective sustainable hub location-scheduling problem for perishable food supply chain*. Computers & Industrial Engineering, 2017. **113**: p. 766-778.
13. Dai, Z., et al., *A location-inventory supply chain network model using two heuristic algorithms for perishable products with fuzzy constraints*. Computers & Industrial Engineering, 2018. **119**: p. 338-352.
14. Babaee Tirkolaee, E., S. Hadian, and H. Golpira, *A novel multi-objective model for two-echelon green routing problem of perishable products with intermediate depots*. Journal of Industrial

Engineering and Management Studies, 2019. **6**(2): p. 196-213.

15. Biuki, M., A. Kazemi, and A. Alinezhad, *An integrated location-routing-inventory model for sustainable design of a perishable products supply chain network.* Journal of Cleaner Production, 2020. **260**: p. 120842.
16. Sahebjamnia, N., Goodarzian, F., & Hajiaghaei-Keshteli, M. (2020). Optimization of multi-period three-echelon citrus supply chain problem. *Journal of Optimization in Industrial Engineering*, *13*(1), 39-53.
17. Goodarzian, F., Hosseini-Nasab, H., Muñuzuri, J., & Fakhrzad, M. B. (2020). A multi-objective pharmaceutical supply chain network based on a robust fuzzy model: A comparison of meta-heuristics. *Applied soft computing*, *92*, 106331.
18. Fakhrzad, M. B., & Goodarzian, F. (2019). A fuzzy multi-objective programming approach to develop a green closed-loop supply chain network design problem under uncertainty: modifications of imperialist competitive algorithm. *RAIRO-Operations Research*, *53*(3), 963-990.
19. Goodarzian, F., & Hosseini-Nasab, H. (2019). Applying a fuzzy multi-objective model for a production–distribution network design problem by using a novel self-adoptive evolutionary algorithm. *International Journal of Systems Science: Operations & Logistics*, 1-22.
20. Fakhrzad, M. B., Talebzadeh, P., & Goodarzian, F. (2018). Mathematical formulation and solving of green closed-loop supply chain planning problem with production, distribution and transportation reliability. *International Journal of Engineering*, *31*(12), 2059-2067.
21. Fakhrzad, M. B., Goodarzian, F., & Golmohammadi, A. M. (2019). Addressing a fixed charge transportation problem with multi-route and different capacities by novel hybrid meta-heuristics. *Journal of Industrial and Systems Engineering*, *12*(1), 167-184.
22. Goodarzian, F., Hosseini-Nasab, H., & Fakhrzad, M. B. (2020). A multi-objective sustainable medicine supply chain network design using a novel hybrid multi-objective metaheuristic algorithm. *International Journal of Engineering*, *33*(10), 1986-1995.
23. Fakhrzad, M. B., & Goodarzian, F. (2021). A new multi-objective mathematical model for a Citrus supply chain network design: Metaheuristic algorithms. *Journal of Optimization in Industrial Engineering*, *14*(2), 127-144.
24. Goodarzian, F., Taleizadeh, A. A., Ghasemi, P., & Abraham, A. (2021). An integrated sustainable medical supply chain network during COVID-19. *Engineering Applications of Artificial Intelligence*, *100*, 104188.
25. Goodarzian, F., Shishebori, D., Nasseri, H., & Dadvar, F. (2021). A bi-objective production-distribution problem in a supply chain network under grey flexible conditions. *RAIRO-Operations Research*, *55*, S1287-S1316.
26. Goodarzian, F., Kumar, V., & Abraham, A. (2021). Hybrid meta-heuristic algorithms for a supply chain network considering different carbon emission regulations using big data characteristics. *Soft Computing*, 1-31.
27. Goodarzian, F., Hoseini-Nasab, H., & Fakhrzad, M. B. Designing a new Medicine Supply Chain Network considering production technology policy using two novel heuristic algorithms. DOI: https://doi.org/10.1051/ro/2021031
28. Goodarzian, F., Abraham, A., & Fathollahi-Fard, A. M. (2020). A biobjective home health care logistics considering the working time and route balancing: a self-adaptive social engineering optimizer. *Journal of Computational Design and Engineering*.
29. Balogun, O. S., Oguntunde, P. E., Akinrefon, A. A., & Modibbo, U. M. (2015). The comparison of the performance of ARIMA and MA model selection on road accident data in Nigeria. *European Journal of Academic*, *2*(3), 13-31.
30. Modibbo, U. M., Ali, I., & Ahmed, A. (2020). Multi-objective optimization modelling for analysing sustainable development goals of Nigeria: Agenda 2030. *Environment, Development and Sustainability*, 1-35.
31. Kamal, M., Modibbo, U. M., AlArjani, A., & Ali, I. (2021). Neutrosophic fuzzy goal programming approach in selective maintenance allocation of system reliability. *Complex & Intelligent Systems*, 1-15.
32. Modibbo, U. M., Umar, I., Mijinyawa, M., & Hafisu, R. (2019). Genetic Algorithm for Solving University Timetabling Problem. *Amity Journal of Computational Sciences (AJCS) 3 (1), 43, 50*.
33. Modibbo, U. M., Arshad, M., Abdalghani, O., & Ali, I. (2021). Optimization and estimation in system reliability allocation problem. *Reliability Engineering & System Safety*, 107620.