E-ISSN: 2717-2937 | P-ISSN: 2783-1337

International Journal of Research in Industrial Engineering

IJRIE

www.riejournal.com

Int. J. Res. Ind. Eng. Vol. 12, No. 4 (2023) 375–387.

Paper Type: Research Paper

Development a Forward-Reverse Network Optimization Model with Delay Reduction and Multistage Fuzzy Demand Satisfaction Policy

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Citation:

Torkian, V., Shojaie, A. A., & Boyer Hassani, O. (2023). Development a forward-reverse network optimization model with delay reduction and multistage fuzzy demand satisfaction policy. *International journal of research in industrial engineering, 12*(4), 375-387.

Received: 04/03/2023 Reviewed: 06/04/2023 Revised: 11/05/2023 Accepted: 10/06/2023

Abstract

Supply chain management is a process in which a number of organizations work together as a supply chain until the raw materials reach the manufacturer and finally, a valuable product is provided to the end consumer. With the increase in population and the increase in environmental sensitivities, the forward-reverse supply chain has attracted a lot of attention, which pursues goals such as optimization, customer satisfaction, responding to their needs in the shortest time with the lowest cost and high quality. In this paper, a forward- reverse multi-product and multi-period network is designed under the condition of uncertainty in the demand parameter. The purpose of the proposed model is to maximize profit by considering customer satisfaction simultaneously and reducing delay and the fuzzy approach has been used to solve the model under conditions of uncertainty. The proposed model is mixed-integer linear programming and for its validation and applicability, it has been solved by GAMS software, a numerical example using simulated data in deterministic and uncertain state. The results of the analysis of the numerical example show that the show that with increasing uncertainty in the demand parameter, the optimal value of the objective function decreases.

Keywords: Forward-reverse supply chain, Demand satisfaction, Delay reduction, Fuzzy.

1 | Introduction

A supply chain consists a network of organizations and facilities that work in tandem to transform raw materials into finished products for customers and fulfills the demands of customers and satisfies the customer [1], [2]. Supply chain management serves manufacturing industries to create a low cost program that guarantees the productivity and success of companies [3]. The forward supply chain starts from the supplier and during that, the manufactured product reaches the final customer. The reverse supply chain starts from the final customer and during that the returned product from the customer is either sent to the market through the process of reproduction or removed from the chain.

By remanufacturing and recycling products that have expired, the structure of supply chain networks has changed and closed-loop supply chains are gaining popularity [4], [5]. Product recovery includes reproduction, reuse and recycling. Remanufacturing is the process of disassembly of the collected

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https://doi.org/10.22105/riej.2023.388330.1371

product and the manufacturer can choose to repair or remanufacture. Reuse is a process that repairs defective parts or removes healthy parts from a product that has failed and uses it in a product that has defective parts [6]. Simultaneous attention of scheduling the production and distribution and assigning delivery times could lead to reduced costs and as a result increase in profit [7]. Due to their complex nature, supply chains face a high degree of uncertainty that can affect the quality of their performance such as uncertainty in purchasing, processing, market and other stages of the closed loop supply chain which has greatly increased the complexity of remanufacturing and reduced the efficiency of the process, hindering the sustainable development of industries and the the economy becomes cyclical [8], [9]. In recent years, a large number of companies, in addition to economic goals, have followed the goals of meeting the needs of customers in the design of the supply chain network [10]. Customer satisfaction is a key factor in the formation of customers' future purchase intention. Every customer has expectations, if the services provided are less than their expectations, it leads to their dissatisfaction [11], [12]. Generally, there are two different demand satisfaction policies: 1) satisfying the entire demand for retailers [13]-[15], and 2) satisfying a proportion of demand and dismissing the rest as lost sales or the fulfilling the remaining demand is delayed [16], [17].

In forward-reverse supply chain design, most of the presented models consider minimizing purchase costs, inventory costs, and ordering costs, and a dyadic network structure that mainly includes manufacturers, distributors or retailers. Rarely do we find studies that have been conducted in the analysis of CLSC with network structure, in which multiple factors are coordinated and consider maximum profit and demand satisfaction at the same time. Based on mentioned points, purpose of this paper to consider the development of a closed loop supply chain model in which the demand parameter is considered non-deterministic. The strength of the presented model is considering the goal of profit maximization, which is considered in this goal of satisfying demand and reducing delay. In this research, our customers are retailers, which are considered to be maximum three modes to satisfying their demand, depending on the type of product. For example, retailer 1 in two stages, retailer 2 in three stages and retailer 3 in one stage, its demand is fulfilled. *Table 1* shows steps to meet demand. The policy of satisfying the demand is to meet the demand of retailers and includes lost sales and delays.

Table 1. The Satisfaction demand modes for the example.

Retailer	Modes to Meet Demand		
1	140	120	80
2	120	100	
3	150		
4	60	50	90

This paper is organized as follows: literature review and mathematical modeling is presented in Sections 2 and 3. In Section 4, we summarize the basic concepts of fuzzy logic and introduce its computational procedure. In Section 5, in order to demonstrate the applicability and validation of the proposed model, a numerical example is solved and the computational process details are expressed. Finally, in Section 6 conclusion and suggests future is expressed.

2 | Literature Review

Most of the studies conducted in the field of logistics network design include different facility location models using mixed-integer linear programming. The common goal of these models is cost minimization and profit maximization. Below are some of the things done in this field.

2.1 | Supply Chain Network Design

Ramezani et al. [18] presented a multi-objective probabilistic model for the problem of integrated logistics network design, under conditions of uncertainty, in which the objectives of the model are considered to be profit maximization, customer responsiveness, and quality. Bushuev et al. [19] in

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research entitled improving supply chain delivery performance for several delivery time distributions, investigated the changes of delivery time distribution parameters on the expected cost of untimely delivery. They presented strategies to improve delivery performance by using mean and variance of delivery time distribution for distribution. Hong et al. [20] developed the problem of designing a supply chain network including production, distribution and customer centers. The proposed model minimizes the total fixed costs of center establishment and transportation costs with the aim of customer satisfaction. In order to solve the proposed model, they used the optimization algorithm of ants. Shojaie et al. [21] presented a novel optimization model based two meta heuristics of PSO and SA then the facility lauout problems is solved by using the modified algorithm manufacturer in other hand, Shojaie et al. [22] presented a research wprk on solving a bi-objective flexible flow shop problem with transporter preventive maintenance planning by NSGA II and MOPSO. Zhu et al. [23] presented a three-stage supply chain with asymmetric information under uncertainty with several suppliers and one. Zaid et al. [24] investigated the role of Supply Chain Integration (SCI) including suppliers, customers and internal integration in creating customer loyalty. The research conducted showed that SCI has a significant direct impact on operational performance and customer satisfaction. The results of the analysis also provided information that operational performance and customer satisfaction can mediate the effect of SCI. Salmannejad et al. [25] proposed a mixed integer linear programming model for medical management and information flow. The objectives of the proposed model are to minimize the cost of purchase, maintenance, manpower and drug expiration and to minimize drug shortages. The results of solving the model showed that the decisions related to the purchase and procurement of drugs have a great impact on the lack of drugs and the control of various costs related to drug inventory in this hospital.

2.2 | Supply Chain Network Design

Zhao et al. [26] considered a two-step, fuzzy closed-loop supply chain. In this model, price-dependent demand and coordination in a CLSC under balanced and unbalanced information have been investigated. Kim et al. [27] proposed a deterministic mixed integer optimization model to deal with the uncertainty of recycled products and customer demand in a closed-loop supply chain. The proposed model considers the uncertainty in the budget to reflect the uncertainty in the mathematical model. Pant et al. [28] designed a closed loop supply chain network to minimize the total cost including four parts (suppliers, manufacturer, distribution center and customer) in the direct direction and six parts (collection center, repair center, reconditioning center, separation center, destruction center and secondary market) in the opposite direction. A mixed linear programming model is developed to solve the proposed network. Mahmoodirad et al. [29] considered multi-state demand satisfaction in a closed-loop supply chain and then solved it in a fuzzy environment using trapezoidal fuzzy parameters. Sonu Rajak et al. [30] investigated a multi-objective mixed integer linear programming approach to minimize environmental impacts and maximize product net profit to transform a traditional linear supply chain into a closed-loop supply chain to achieve sustainability and thereby satisfy sustainable development goals. Safaei et al. [31] investigated a multi-layered mixed integer linear programming model considering factories' vehicles and transport companies' leased vehicles to minimize the costs of a multi-period, multi-layer closed-loop supply chain network. In the proposed model, the demand for products is estimated using the time series model of automatic regressive integrated moving average to reduce the shortage that may occur in the entire supply chain network. Numerical results showed that the proposed model is closer to the real situation and can achieve a reasonable solution in terms of service level, shortage, etc. Zhang et al. [32] investigated in research aimed at recycling defective recycled products and waste recycled products in order to calculate the total profit in a two-channel closed loop supply chain and compare it with inconsistent models. The results of the research showed that the proposed coordinating mechanism in price discounts to retailers leads to the improvement of the financial performance of the supply chain.

3 | Defining the Research Problem

The network proposed in this research is an integrated forward-reverse network with non-deterministic demand that has four levels in the forward direction (suppliers, plants, distributors and retailers) and three levels in the reverse direction (collection centers, recycling and destruction). In the forward flow, first the production centers receive the raw materials they need from the suppliers. The final products made in the production centers are sent to the distribution centers, then the products are sent to the retail centers according to the demand of the retailers. In the reverse direction, retailers send a percentage of defective and unusable products to collection centers, then the products are transferred from collection centers to recycling centers. In the recycling centers, the parts of the products are separated and those parts that can be used are sent to production centers for re-production, and those parts that are unusable are transferred to destruction centers for disposal.

3.1 | Assumptions

The following assumptions are made in the network proposed configuration:

I. The model is designed for multi-product, multi-level and multi-period model. In which the demand parameter is considered under uncertainty conditions.
II. Demand satisfaction policies include meeting the demand of retailers and they can supply all these products from a distribution center or any of them from separate distribution centers.
III. Binary variable is considered for retailer demand, so that if a retailer's demand is fulfilled, the value is one, otherwise it is zero.

3.2 | Mathematical Model

The network proposed can be formulated as a mixed-integer linear programming model. Indices, decision variables and model parameters are presented as follows:

Sets

g	Index of mode satisfaction g = 1, …, G.
j	Set of products j = 1, …, J.
i	Set of parts i = 1, …, I.
o	Set of plant o = 1, ..., O.
m	Set of collection center m = 1, 2, …, M.
n	Set of distributor n = 1, ..., N.
l	Set of recycle center l =1, ..., L.
k	Set of suppliers k = 1, …, K.
h	Set of disposal center h = 1, ..., H
t	Set of time periods t =1, …., T.
r	Set of retailer r =1, …, R.

Parameters

$\tilde{D}_{jrgt}$	Demand for the product j the retail center r for satisfaction mode g in period t.
D_{pjrt}	Sale price of each unit of product j at retailer center r in period t.
Q_{ij}	Units of part i in product j.
MC_{jm}	Operational cost of each unit of product j at collection center m.
MP_{jo}	Operational cost of each unit of product j at plant center o.
MD_{jn}	Operational cost of each unit of product j at distribution center n
RC_{il}	Operational cost for recycled of parts i at recycling center l
WDC_{ih}	Operational cost for destruction of parts i at disposal center h.

PR_{it}	Profit by recycling of parts i in period t.
PC_{ik}	Cost of purchasing parts i from suppliers k.
SC_{jm}	Set-up cost of collection center m for product j.
SR_{il}	Set-up cost of recycling center l for parts i.
SU_{jn}	Set-up cost of distribution center n for product j.
SX_{ih}	Set-up cost of disposal center h for parts i.
SO_{jo}	Set-up cost of plant center o for product j.
ST_{jr}	Set-up cost of retailer center r for product j.
TCO_{jon}	Transportation cost for each unit of product j from plant o to distribution center n.
TCD_{jml}	Transportation cost for each unit of product j from collection center m to recycling center l.
TCR_{ilo}	Transportation cost for each unit of parts i from recycling center l to plant center o.
TCK_{ilh}	Transportation cost for each unit of parts i from recycle center l to disposal center h.
TCM_{jnr}	Transportation cost for each unit of product j from distribution center n to retailer center r.
TCU_{iko}	Transportation cost for raw material i from supplier k to plant center o.
TCN_{jmr}	Transportation cost for each unit of product j from retailer center r to collection center m.
λ_i	Maximum percentage of part i recycled.
CU_{jmt}	Capacity of collection center m for product j in period t.
CR_{ilt}	Capacity of recycle center l for parts i in period t.
CD_{jnt}	Capacity of distribution center n for product j in period t.
CG_{iht}	Capacity of disposal center h for parts i in period t.
CP_{jot}	Capacity of plant center o for producing product j in period t.
CM_{jrgt}	Capacity of retailer center r for product j for each satisfaction mode g in period t.
$M1_{ij}$	Conversion rate of the product j to the raw materials or parts i.
TCR_{ilo}	Cost of transporting parts i from recycling center l to plant center o.
TCK_{ilh}	Cost of transporting parts i from the recycling center l to the disposal center h.
TLSjrt	Cost of lost sales per unit of product j retailer center r in period t.
TXIikot	Delivery time of parts i from supplier k to plant center o in period t.
TXPjont	Delivery time of product j from plant center o to distribution n in period t.
TXN_{jnrt}	Delivery time of product j from distributor n to retailer r in period t.
MXIikt	Return parts i to supply center k in period t.
MXPjot	Return product j to production center o in period t.
MXNjnt	Return product j to distribution center n in period t.
$TBmax_{jont}$	Maximum time allowed to receive product j from plant center o by distributor n in period t.
$TOmax_{jnrt}$	Maximum time allowed to receive product j from distributor n by retailer center r in period t.
$TAmax_{ikot}$	Maximum time allowed to receive parts i from supplier k by plant center o in period t.

Decision variables

LS_{jrt}	Amount of lost sales of product j at retail center r in period t.
P_{jot}	Amount of product j to be produced at plant o in period t.
C_{jmt}	Amount of product j at collection center m in period t.
S_{ikt}	Amount of purchased parts i from the supplier k in period t.
B_{jnt}	Amount of product j at distribution center n in period t.

Y_{ilt}	Amount of parts i at recycling center l in period t.
DR_{jr}	Amount of product j retailer center r in period t.
W_{ith}	Amount of parts i destroyed at the destruction center h in period t.
TU_{jnrt}	Amount of product j transported from the distribution center n to the retailer center r in period t.
TC_{jmrt}	Amount of product j transported from the retailer center r to the collection center m in period t.
X_{ikot}	Amount of parts i transported from the supplier k to plant o in period t.
TR_{jont}	Amount of product j transported from the plant o to distribution center n in period t.
TL_{jmlt}	Amount of product j transported from the collection center m to recycling center l in period t.
F_{ilot}	Amount of parts i transported from the recycling center l to plant o in period t.
E_{iht}	Amount of parts i transported from the recycling center l to disposal center h in period t.
A_{jmt}	Binary variable equal to 1 if collection centers m is established for product j in period t, otherwise 0.
V_{ilt}	Binary variable equal to 1 if recycle center l is established for parts i in period t, otherwise 0.
U_{jnt}	Binary variable equal to 1 if distribution center n is established for product j in period t, otherwise 0.
RH_{iht}	Binary variable equal to 1 if disposal center h is established for parts i in period t, otherwise to 0.
GH_{jot}	Binary variable equal to 1 if plant o is established for product j in period t, otherwise to 0.
BH_{grjt}	Binary variable equal to 1 if demand of retailer r is satisfied in mode g in period t, otherwise to 0.
CH_{jrt}	Binary variable equal to 1 if retailer r established for product j in period t, otherwise 0.
TA_{ikot}	Time of receipt of parts i from supplier k by plant center o in period t.
TB_{jont}	Time of receipt of product j from plant center o by distribution center n in period t.
TO_{jnrt}	Time of receipt of product j from distribution center n by retailer center r in period t.

$$
\begin{aligned}
&\text{Max imaize} \\
&\sum_{t}\sum_{g}\sum_{r}\sum_{j}\left(DP_{jrt} * \tilde{D}_{jrgt} * BH_{jrgt}\right) + \sum_{t}\sum_{o}\sum_{l}\sum_{i}(RP)_{iot} * F_{ilot} - \sum_{t}\sum_{k}\sum_{i}(PC)_{ik} * S_{ikt} \\
&-\sum_{t}\sum_{o}\sum_{j}(MP)_{jo} * P_{jot} - \sum_{t}\sum_{n}\sum_{j}(MD)_{jn} * B_{jnt} - \sum_{t}\sum_{m}\sum_{j}(MC)_{jm} * C_{jmt} - \sum_{i}\sum_{l}\sum_{t}(RC)_{il} * Y_{ilt} \\
&-\sum_{t}\sum_{h}\sum_{i}(WDC)_{ih} * W_{iht} - \sum_{t}\sum_{o}\sum_{j}(SO)_{jo} * GH_{jot} - \sum_{t}\sum_{n}\sum_{j}(SU)_{jn} * U_{jnt} - \sum_{t}\sum_{r}\sum_{j}(ST)_{jr} * CH_{jrt} \\
&-\sum_{t}\sum_{m}\sum_{j}(SC)_{jm} * A_{jmt} - \sum_{t}\sum_{l}\sum_{i}(SR)_{il} * V_{ilt} - \sum_{t}\sum_{h}\sum_{i}(SX)_{ih} * RH_{iht} - \sum_{t}\sum_{o}\sum_{k}\sum_{i}(TCU)_{iko} * X_{ikot} \qquad (1) \\
&-\sum_{t}\sum_{n}\sum_{o}\sum_{j}(TCO)_{jon} * TR_{jont} - \sum_{j}\sum_{n}\sum_{r}\sum_{t}(TCM)_{jnrt} * TU_{jnrt} - \sum_{j}\sum_{m}\sum_{r}\sum_{t}(TCN)_{jmrt} * TC_{jmrt} \\
&-\sum_{t}\sum_{j}\sum_{m}\sum_{l}(TCD)_{jml} * TL_{jmlt} - \sum_{t}\sum_{o}\sum_{l}\sum_{i}(TCR)_{ilo} * F_{ilot} - \sum_{t}\sum_{h}\sum_{l}\sum_{i}(TCK)_{ilh} * E_{ilht} \\
&-\sum_{t}\sum_{r}\sum_{j}(TLS)_{jrt} * LS_{jrt}.
\end{aligned}
$$

The objective *Function (1)* of the proposed model includes maximizing profit and customer satisfaction. In the first row computed by multiplying amount of demand and the selling price per unit of product in binary variable for rretailer satisfaction, amount of recycled parts and profit from their recycling, amount of purchased parts and the cost of their purchase. In the second and third rows operating costs (production, distribution, collection, recycling and disposal centers) are included in each of the centers.

The fourth row is the fixed costs of setting up the facility, and the fifth and sixth rows include transportation costs between the facilities. Finally, the number of lost sales has been stated.

$$S_{ikt} = \sum_{o} X_{ikot} \quad \text{for all } i,k,t. \tag{2}$$

$$C_{jmt} = \sum_{r} TC_{jmrt} \quad \text{for all } j,m,t. \tag{3}$$

$$\sum_{o} TR_{jont} = B_{jnt} \quad \text{for all } j,n,t. \tag{4}$$

$$\sum_{m} TC_{jmrt} = \sum_{l} TL_{jmlt} \quad \text{for all } j,m,t. \tag{5}$$

$$\sum_{o} TR_{jont} = \sum_{l} TU_{jnrt} \quad \text{for all } j,n,t. \tag{6}$$

$$\sum_{o} TL_{jmlt} = \sum_{o} F_{ilot} + \sum_{h} E_{ilht} \quad \text{for all } j,l,i,t. \tag{7}$$

$$\sum_{l} E_{ilht} = W_{iht} \quad \text{for all } i,h,t. \tag{8}$$

$$\sum_{g} BH_{jrgt} = 1 \quad \text{for all } j,r,t. \tag{9}$$

Constraint (2) ensures that the number of parts purchased from the supplier is equal to the parts shipped from the supplier to the production center. *Constraints (3)* to *(8)* assure the balance flow at production, distribution, retailing, collection, recycling and disposal centers. *Constraint (9)* ensures that for each retailer, demand satisfaction is selected.

$$\sum_{m} TL_{jmlt} * M1_{ij} = Y_{ilt} \quad \text{for all } i,j,l,t. \tag{10}$$

$$\sum_{n} TU_{jnrt} + LS_{jrt} = \sum_{g} \tilde{D}_{jrgt} * BH_{jrgt} \quad \text{for all } j,r,t. \tag{11}$$

Constraint (10) shows that the number of parts in the recycling center is equal to the product of the amount of the product transported from the collection center to recycling in the conversion rate of the product to parts. *Constraint (11)* represents the amount of product shipped from the distribution center to retail and the number of lost sales is equal to the amount of retail demand for each of the states of satisfaction multiplied by zero variable and one retailer demand.

$$P_{jot} \le (CP)_{jot} * GH_{jot} \quad \text{for all } j,o,t. \tag{12}$$

$$B_{jnt} \le (CD)_{jnt} * U_{jnt} \quad \text{for all } j,n,t. \tag{13}$$

$$DR_{jrgt} \le CM_{jrt} * CH_{jrt} \quad \text{for all } j,r,g,t. \tag{14}$$

$$C_{jmt} \le CU_{jmt} * A_{jmt} \quad \text{for all } j,m,t. \tag{15}$$

$$Y_{ilt} \le (CR)_{ilt} * V_{ilt} \quad \text{for all } i,l,t. \tag{16}$$

$$W_{iht} \le (CG)_{iht} * RH_{iht} \quad \text{for all } i,h,t. \tag{17}$$

$$Q_{ij} * P_{jot} \le \sum_{k} X_{ikot} + \sum_{l} F_{ilot} \quad \text{for all } i,j,o,t. \tag{18}$$

Constraints (12) to *(15)* indicate the amount of product in each center in relation to its capacity. *Constraints (16)* and *(17)* show the number of parts in the recycling and destruction centers in relation to its capacity and *Constraint (18)* shows the amount of parts in the manufactured product in relation to the amount of parts shipped from the supplier and recycling centers.

$$\sum_{n} TR_{jont} \le P_{jot} \quad \text{for all } j,o,t. \tag{19}$$

$$\sum_{m} TD_{jmrt} \le DR_{jrt} \quad \text{for all } j,r,t. \tag{20}$$

$$C_{jmt} \geq \sum_{l} TL_{jmlt} \qquad \text{for all } j,m,t. \tag{21}$$

Constraint (19) shows the relationship between the amount of product produced in the production center and the amount of product transported from the production center to distribution. *Constraints (20)* and *(21)* indicate the amount of product transported with the amount of product in each of the retail, collection and recycling centers.

$$\sum_{h} E_{ilht} \leq (1-\lambda_i * Y_{ilt}) \qquad \text{for all } i,l,t. \tag{22}$$

$$\sum_{n} TU_{jnrt} \geq \sum_{l} TC_{jmrt} \qquad \text{for all } j,r,t. \tag{23}$$

Constraint (22) shows the relationship between the number of parts transported from the recycling center to destruction with the product of the inventory level of parts in the recycling center with the maximum parts that are recycled. *Constraint (23)* shows the relationship between the amount of product transported from the distribution center to the retail center and the product transported from the retail center to the collection center.

$$TXI_{ikot} * (X_{ikot} / MXI_{ikt}) \leq TA\max_{ikot} \qquad \text{for all } i,k,o,t. \tag{24}$$

$$TXP_{jont} * (TR_{jont} / MXP_{jot}) \leq TB\max_{jont} \qquad \text{for all } j,o,n,t. \tag{25}$$

$$TXN_{jnrt} * (TU_{jnrt} / MXN_{jnt}) \leq TO\max_{jnrt} \qquad \text{for all } j,n,r,t. \tag{26}$$

Constraint (24) shows the relationship between the delivery time of the raw material and the maximum time allowed to receive the raw material from the suppliers by the production centers, and *Constraint (25)* shows the relationship between the product delivery time and the maximum time allowed to receive the product from the production centers to the distribution centers. *Constraint (26)* shows the relationship between the product delivery time and the maximum time allowed to receive the product from distribution centers to retail centers.

$$P_{jot}, C_{jmt}, S_{ikt}, B_{jnt}, Y_{ilt}, DR_{jrt}, W_{iht}, TU_{jnrt}, TC_{jmrt}, X_{ikot}, TR_{jont}, TL_{jmlt}, F_{ilot}, E_{ilht} \geq 0$$
$$\text{for all } j,o,t,m,i,k,l,h,r,n,g. \tag{27}$$

$$A_{jmt}, V_{ilt}, U_{jnt}, RH_{iht}, GH_{jot}, CH_{jrt}, BH_{jrgt} \in \{0,1\} \qquad \text{for all } j,o,t,m,i,l,h,r,n,g. \tag{28}$$

Constraint (27) shows the non-negativity constraint on the decision variables and *Constraint (28)* shows the binary variables related to facility construction and demand fulfillment.

4 | Solution Methodology

In this paper the methodology proposed by Jiménez et al. [33] is used to find out the optimal solution. This method is based on the definition of expected value and expected interval. The steps in solving the proposed model are shown below:

I. Convert the fuzzy objective function to crisp using the expected value of the corresponding parameter.
II. Determine the triangular fuzzy number for the demand parameter.
III. Determine the minimum acceptable degree decision vector (Δ) and converting fuzzy constraints to crisp.
IV. Getting a linear membership function for the demand parameter in the constraints.

$$
\begin{aligned}
&\text{Max imaize} \\
&\sum_t\sum_g\sum_r\sum_j \left(DP_{jrt} * \left(\frac{D_{1jrgt}+2\times D_{jrgt}+D_{2jrgt}}{4}\right) * BH_{jrgt}\right) + \sum_t\sum_o\sum_l\sum_i (RP)_{it} * F_{ilot} \\
&-\sum_t\sum_k\sum_i (PC)_{ik} * S_{ikt} - \sum_t\sum_o\sum_j (MP)_{jo} * P_{jot} - \sum_t\sum_n\sum_j (MD)_{jn} * B_{jnt} \\
&-\sum_t\sum_m\sum_j (MC)_{jm} * C_{jmt} - \sum_i\sum_l\sum_t (RC)_{il} * Y_{ilt} - \sum_t\sum_h\sum_i (WDC)_{ih} * W_{iht} \\
&-\sum_t\sum_o\sum_j (SO)_{jo} * GH_{jot} - \sum_t\sum_n\sum_j (SU)_{jn} * U_{jnt} - \sum_t\sum_r\sum_j (ST)_{jr} * CH_{jrt} \\
&-\sum_t\sum_m\sum_j (SC)_{jm} * A_{jmt} - \sum_t\sum_l\sum_i (SR)_{il} * V_{ilt} - \sum_t\sum_h\sum_i (SX)_{ih} * RH_{iht} \\
&-\sum_t\sum_o\sum_k\sum_i (TCU)_{iko} * X_{ikot} - \sum_t\sum_n\sum_o\sum_j (TCO)_{jon} * TR_{jont} \\
&-\sum_j\sum_n\sum_r\sum_t (TCM)_{jnrt} * TU_{jnrt} - \sum_j\sum_m\sum_r\sum_t (TCN)_{jmrt} * TC_{jmrt} \\
&-\sum_t\sum_j\sum_m\sum_l (TCD)_{jml} * TL_{jmlt} - \sum_t\sum_o\sum_l\sum_i (TCR)_{ilo} * F_{ilot} \\
&-\sum_t\sum_h\sum_l\sum_i (TCK)_{ilh} * E_{ilht}.
\end{aligned}
\tag{29}
$$

Assuming *d*=(d1, d2, d3) a triangular fuzzy number, d1 represents the smallest and d2 is the largest number of sets is the desired number that can be changed between them and its membership function will be *Eq. (30)*.

$$
\mu_{\tilde{d}}(x) = \begin{cases} 0, & x \le d_1, \\ \dfrac{(x-d_1)}{(d_2-d_1)}, & d_1 \le x \le d_2, \\ \dfrac{(d_3-x)}{(d_3-d_2)}, & d_2 \le x \le d_3, \\ 0, & x > d_3. \end{cases} \tag{30}
$$

The triangular membership function is as shown in *Fig. 1*.

Given the presented membership function, the expected interval and its expected value are according to *Eqs. (31)* and *(32)* stated [34].

$$
El(\tilde{d}) = \left(E_1^{\,d} + E_2^{\,d}\right) = \left(\frac{d_1+d_2}{2}, \frac{d_2+d_3}{2}\right). \tag{31}
$$

$$
Ev(\tilde{d}) = \left(\frac{E_1^{\,d}+E_2^{\,d}}{2}\right) = \left(\frac{d_1+2d_2+d_3}{4}\right). \tag{32}
$$

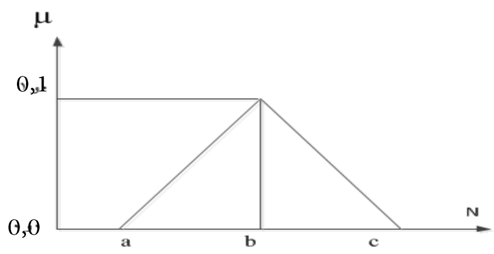

Fig. 1. Triangular membership function.

According to the Jiménez et al. [33] ranking method for each pair of fuzzy numbers *a* and *b* the magnitude of the number *a* relative to the number *b* represented by the μM (*a*, *b*) the *Eq. (33)* is calculated [35].

$$\mu_{\tilde{M}}(\tilde{a},\tilde{b})=\begin{cases}0, & \text{if} \quad E_2^a-E_1^b\le 0,\\ \dfrac{E_2^a-E_1^b}{E_2^a-E_1^b-(E_1^a-E_2^b)}, & \text{if} \quad 0\in\left[E_1^a-E_2^b,\ E_2^a-E_1^b\right]\le 0,\\ 1, & \text{if} \quad E_1^a-E_2^b.\end{cases} \tag{33}$$

The decision vector x is displayed as follows:

$$\tilde{a}_i x\le\tilde{b}_i. \tag{34}$$

This vector is justified based on the definition of rating given with the degree Δ if:

$$\left[(1-\Delta)E_2^a+\Delta E_1^a\right]x\le\Delta E_2^b+(1-\Delta)E_1^b. \tag{35}$$

The general form of the model can be defined as *Eq. (36)*.

$$\begin{aligned}&\text{Max } Z=EV(\tilde{C}^t)X\\&\text{s.t.}\\&\left[(1-\Delta)E_2^a+\Delta E_1^a\right]x\le\Delta E_2^b+(1-\Delta)E_1^b,\\&X\ge 0.\end{aligned} \tag{36}$$

The corresponding deterministic limit with the proposed model, the *Eq. (37)*.

$$\mu_{\tilde{D}_{jrgt}}=\begin{cases}1-\dfrac{(\sum_g D_{jrgt}*BH_{jrgt})-\sum_n TU_{jnrt}}{\alpha_{jrgt}}, & \sum_g D_{jrgt}*BH_{jrgt}-\alpha_{jrgt}\le\sum_n TU_{jnrt}\le\sum_g D_{jrgt}*BH_{jrgt},\\ 1-\dfrac{\sum_n TU_{jnrt}-(\sum_g D_{jrgt}*BH_{jrgt})}{\beta_{jrgt}}, & \sum_g D_{jrgt}*BH_{jrgt}\le\sum_n TU_{jnrt}\le\sum_g D_{jrgt}*BH_{jrgt}+\beta_{jrgt},\\ 0, & \text{otherwise.}\end{cases} \tag{37}$$

$$\sum_g D_{jrgt}*BH_{jrgt}-\alpha_{jrgt}\le\sum_n TU_{jnrt}\le\sum_g D_{jrgt}*BH_{jrgt}. \tag{38}$$

$$\sum_g D_{jrgt}*BH_{jrgt}\le\sum_n TU_{jnrt}\le\sum_g D_{jrgt}*BH_{jrgt}+\beta_{jrgt}. \tag{39}$$

The *Eqs. (38)* and *(39)* are the final determined form of the demand fuzzy parameter, which are placed in the constraints in the proposed model.

5 | Numerical Example

In this section, to show the applicability of the proposed model, an example in five different sizes has been designed and analyzed by GAMS software, first in a deterministic way and then in the state of uncertainty, and finally the numerical results have been analyzed. In this example, there are different suppliers and the supply centers are considered specific and definite. For the demand parameter, which is considered as triangular fuzzy number, three pessimistic, probable and optimistic points are $\tilde{d}_{jrgt}=(d_{1\,jrgt},\ d_{2\,jrgt},\ d_{3\,jrgt})$ created and then, by determining the acceptable degree of decision-making vector (Δ), the fuzzy limitation of demand becomes crisp. The value of the objective function for (Δ) is shown in *Table 2*.

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Table 2. Random information related to parameters numerical example.

Parameter	Random Distribution	Parameter	Random Distribution
$\widetilde{D}_{jrgt}$	(300)	Q_{ij}	(5)
PR_{it}	(20)	$M1_{ij}$	(0.45)
λ_i	(0.7)	PC_{ik}	uniform (5,7)
WDC_{ih}	uniform (3,4)	MP_{jo}	uniform (4,7)
MD_{jn}	uniform (3,3)	RC_{il}	uniform (3,6)
DP_{jrt}	uniform (800,950)	MC_{jm}	uniform (1.5,3)
CM_{jrt}	uniform (800,730)	CD_{jnt}	uniform (500,750)
CG_{iht}	uniform (400,550)	CR_{ilt}	uniform (700,650)
CP_{jot}	uniform (2000,45)	CU_{jmt}	uniform (450,600)
SC_{jm}	uniform (18000,23000)	SX_{ih}	uniform (32000,5000)
SR_{il}	uniform (16000,24000)	ST_{jrt}	uniform (14000,1700
SU_{jn}	uniform (15500,25500)	SO_{jo}	uniform (25000,37000)
TCM_{jnrt}, TCN_{jmrt}, TCU_{iko}, TCK_{ilh}, TCR_{ilo}, TCO_{jon}, TCD_{jml}			uniform (6,15)

Table 3. Objective function for different problems in the deterministic state.

Problem	Problem Size |j|*|i|*|k|*|m|*|n|*|l|*|t|*|h|*|o|*|r|*|g|	Objective Function Values
1	2, 2, 2, 2, 3, 2, 2, 2, 2, 3, 1	1024545
2	3, 3, 2, 3, 3, 3, 2, 3, 3, 3, 2	1651435
3	4, 3, 3, 4, 4, 3, 3, 3, 3, 4, 3	6543064
4	5, 4, 3, 5, 5, 3, 3, 3, 4, 5, 3	11530697
5	6, 4, 4, 5, 5, 4, 3, 4, 4, 5, 3	14352385

Table 4. Objective function for different problems in the deterministic state.

Problem	Problem Size	Uncertaintylevel (Δ)	Objective Function Values under Uncertainty
1	2, 2, 2, 2, 3, 2, 2, 2, 2, 3, 1	0.1, 0.3, 0.6, 0.9	3592832, 3592508, 3592022, 3591536
2	3, 3, 2, 3, 3, 3, 2, 3, 3, 3, 2	0.1, 0.3, 0.6, 0.9	5897274, 5896734, 5895924, 5895114
3	4, 3, 3, 4, 4, 3, 3, 3, 3, 4, 3	0.1, 0.3, 0.6, 0.9	22376908, 22374856, 22371778, 22368700
4	5, 4, 3, 5, 5, 3, 3, 3, 4, 5, 3	0.1, 0.3, 0.6, 0.9	38961104, 38957540, 38952194, 38946848
5	6, 4, 4, 5, 5, 4, 3, 4, 4, 5, 3	0.1, 0.3, 0.6, 0.9	48333948, 48329640, 48323178, 48316716

It has been shown the objective function crisp using the values of *Table 2* in *Fig. 3* and states that the optimal values of the objective function also increase with the increase in the size of the problem. *Fig. 4* shows the objective function for different delta values in different sizes and states that the optimal amount of the objective function also decreases with the incre ase of uncertainty in the demand value.

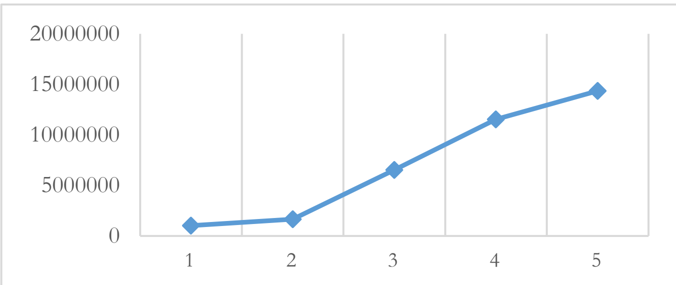

Fig. 2. Optimal values of objective function.

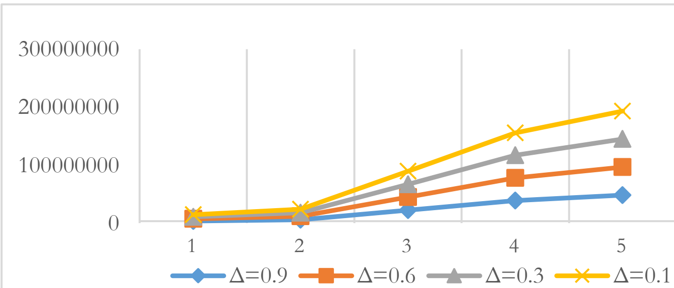

Fig. 3. Optimal values of objective function in uncertainty mode.

6 | Conclusion and Future Research Directions

All logistics activities related to the collection and handling of second-hand consumer goods, parts and materials in order to ensure the desired quality are related to this field also sometimes government restrictions are imposed on supply chains, and in others, there are concerns about the environment and its maintenance. The mentioned conditions lead companies to use forward and reverse integrated logistics network. Increasing attention to environmental issues has multiplied the importance of designing closed-loop supply chain networks that include production, recycling, and waste disposal. When both forward and reverse supply chains are considered with the goal of creating value for the product, the resulting network will be a closed-loop supply chain and designing a proper supply chain network can provide many benefits to improve supply chain performance. In this research presented a multi-product and multi-period forward/reverse integrated supply chain problem with the aim of maximizing profit and meeting customer satisfaction simultaneously and the fuzzy approach has been used to address the lack of certainty in the product. How to collect damaged products, the decision to recycle or destroy the goods, the maximum time to receive parts and products and the lost sales are among the practical dimensions that are in line with this research. In this research to show the applicability of the proposed model, a numerical example has been solved in different size using GAMS optimization software and computational results showed that the total network costs are affected by the amount of demand, return, as well as recycling and disposal for a given capacity of the network, and the optimal value of the objective function decreases by increasing the uncertainty in the amount of demand. As the size of the problem becomes enlarged becomes more computing volume and running time, solve complex issues in the short time is possible by using meta-heuristic methods and this can be the next research work in this field. In addition to the above, other objective can be considered in the model, such as considering warranty for products and maximizing the level of service, consider financial risks in the process, increasing the quality level of output products, and considering environmental factors.

Conflicts of Interest

All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other publication.

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