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The impact of petrochemical industry economic activities on environmental factors using a fuzzy mathematical programming model

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Abstract

Due to the nature of activities and processes, the petrochemical industry causes the production of industrial effluents, emissions and wastes that have adverse effects on the environment. The purpose of this study is to investigate the effect of petrochemical economic activities on environmental factors. In this paper, in order to minimize the costs and the amount of pollution caused by the emission of harmful gases, the closed-loop green supply chain model has been used, in which direct and reverse logistics networks have been considered. As a result, a fuzzy mathematical programming model has been developed for when the data are not definitively known. After the demand parameters and the amount of pollution are considered fuzzy, the maximum and bisector mean methods of the area are considered as methods (diffusion) of comparison and ranking of fuzzy definite numbers, and by adding Limitations of these two methods, the model was developed. To solve the model with real data, a plant from the petrochemical industry was selected and the data were prepared for solution with very good estimates. Finally, the colonial competition algorithm was used to solve it. According to the model, its applicability was shown to reduce the amount of environmental pollutants along with the reduction of transportation and waste, and the model for the closed-loop supply chain, which simultaneously considers two direct and inverse logistics networks, it is appropriate.

Keywords: Fuzzy programming, Environmental pollutants, Petrochemical, Colonial competition algorithm

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1. Introduction

The petrochemical industry is defined as industries that convert hydrocarbons in petroleum or natural to chemical products. Petrochemical is composed of the two words, petro and chemical, which means chemicals derived from petroleum.

The most potent instrument to realize the sustainable development strategic goals is Environmental assessment. Because of accelerating the planning, These studies best protect resources and prevent irreversible effects on the environment and natural resources as much as possible [3]. Since 1990, producers have been faced with the concept of green supply chain management in the production process [24]. by considering various environmental factors and minimizing the effects of pollutants on the environment, the new concept has tried to create a healthy and sustainable environment [4]. In the last two decades, factories have focused on recycling their waste. Investment reasons for this sector are two-fold: environmental factors and commercial factors[23].

The adverse effects of waste on the environment and humans and the valuable materials available have led to significant efforts to develop new methods for recycling [19]. Therefore, factories can economically benefit from recycling valuable materials, reducing pollution from their products, achieving a high competitive advantage, and attracting more consumers [12].

The need for green logistics is felt to protect the environment since the producers have minor responsibility for their goods after being used by consumers and do not take responsibility for the products consumed and products have led to considerable damage on the environment, and everyone, including consumers and officials, is concerned about the state of their environment [6]. By minimizing waste and recycling the waste and turning into usable products, Industries increase income and reduce environmental pollution [21]. An industry maximizing the profit from waste provides the necessary incentive to reduce environmental pollutants in the supply chain [2]. To provide a more realistic model, Fuzzy-natured Parameters should be taken into account fuzzy [8]. according to the results, A multi-objective model motivates investors to reduce environmental pollutants [26]. We are faced with parameters including fixed and variable costs for transport, facility capacity, production rates of various pollutants by transport facilities, and methods [9].

Fuzzy-natured variables are used when data are not available in a precise manner, the fact that is not been explored in previous models. Also, the Imperialist competition algorithm has been used to solve the designed model. This algorithm solves similar models efficiently in previous studies [14]. The fact that tourism is seasonal has a negative environmental and economic impact. At peak times, A reduction in the seasonality of tourism improves economic sustainability and reduces environmental pressure [17].

2. Literature Review

The executive history of petrochemical industry projects shows that many petrochemical companies have been designed and operated in the absence of environmental considerations, thereby leading to various pollutions and damaging natural resources [13]. Also, petrochemical industry discharges may degrade a significant part of the biological elements because of their relationship with the receiving water resources so that it paves the way for the gradual elimination of aquatic animals and plant species directly and indirectly and facilitates the food chain by reducing the number and variety of species whereby water resources, especially on Beaches, become a dead resource [18].

In case of green partner selection, Yeh and Chuang (2011)[25] provided an optimal mathematical planning model. This model includes four objectives, i.e., cost, time, quality, and green evaluation score. In order to face these contradictory objectives, they applied two multi-objective genetic algorithms to obtain optimal Pareto. The subject of this research was a Taiwanese electronic components producer. The company should choose a green partner, stockpile, and a specific aggregate demand according to the production constraints. This is a multi-product, multi-stage supply chain problem. A nonlinear mixed multi-objective mathematical programming model with four objectives and no constraints is suggested to solve this problem. The four constraints in this model are: minimizing the total cost, minimizing total time, maximizing average product quality, and maximizing green evaluation score. Abdallah, and *et al* (2012)[1] proposed a mixed-integer programming model for a carbon-sensitive supply chain that minimizes the emission across the supply chain, taking into account green supply and procurement known as environmental resources. For reverse logistics, Ramezani and *at al* (2013)[16] suggested a multi-objective stochastic model for forward and reverse logistics network design under uncertain environmental conditions with three stages for forward path: supplier, plant, and distribution centers and two stages for reverse path: collection centers and disposal centers. They proposed a method to evaluate the supply chain's systematic configuration to maximize profits, customer responsiveness, and quality as the goals of the logistics network. Fazlullah and *at al* (2013)[5] suggested a fuzzy mathematical planning model for a supply chain that takes into account multiple warehouses, multiple vehicles, multiple products, multiple customers, and different times. They consider decision variables and demand and cost as fuzzy variables. Here, two ranking functions are used to solve the model. The purpose of fuzzy mathematical programming is to select suitable warehouses from the nominated warehouses, allocate orders to warehouses and vehicles, and allocate returned vehicles to warehouses to minimize costs. Zhu and Sarkis (2014)[27] studied multiple networks, green knowledge integration, and green supply chain efficiency. They chose Chinese Ecological Park as an example and experimentally evaluated the logic and mechanism of embedding multiple networks on green supply chain performance. The simulation method was also investigated. As a result, they examined three dimensions of the network that significantly enhance green knowledge integration: relationship, structure, and knowledge, and green knowledge integration had a mediating effect between multiple network deployment and green supply chain performance. The sharing economy has been used in many sectors and delivers significant benefits to consumers and asset owners. As an expansive survey of 420 participants, this study suggested that investment recovery practices and corporate social responsibility used by sharing economy platforms have a significant and positive impact on the customer's intention to use services/products based on The sharing Economy [7]. This study takes into account the environmental effects of button cells in supply chain network design. Due to much uncertainty in the real world, demand, cost, and capacity are uncertain variables. Two multi-objective mixed-integer programming models under uncertainty have been developed to examine the effect of these uncertainties in the supply chain network. A life cycle assessment method is suggested for environmental impact assessment in the supply chain network [22]. As a measure of economic performance, This study focuses on labor productivity. We argue that environmental management harms the firm's labor productivity in some increasingly tight environmental law regions in China. The results show that environmental management harms labor productivity with moderating effect of quality management [10].

There is no model for a closed-loop green supply chain in past studies where parameter values are considered fuzzy. In this research, the fuzzy parameters in the real world are considered fuzzy, if possible. Consequently, the closed-loop green supply chain is examined as a multi-objective fuzzy mathematical programming model. Two defuzzification methods, along with the Imperialist competition algorithm, have been applied in this research.

3. Research method

In this research, active production petrochemical plant data has been applied. Applying this plant was more compatible with the model proposed in this study, so its production cycle is closely related to this model. Also, after discussion with the plant and the recycling department officials, the model was reviewed and estimated in a careful manner by the contribution of the plant research and development department so that it was included in the plant agenda for development, if possible. For pollution level calculation, the inspection and quality department opinion was used, and demand, production, and capacities were estimated according to the plant information.

3.1. Research instruments

The research instrument is a multi-objective fuzzy mathematical planning model with Imperialist competition meta-heuristic algorithm. Two sets of constraints are added to the model to defuzzify fuzzy values and solve the model, the first is related to the bisector of area (BOA), and the second is related to the mean of maximum (MOM method) where the mean Values with a membership of one in trapezoidal fuzzy numbers are considered as a definite value for the desired parameter.

In this research, given the characteristics in the literature models, the model is closely related to the real world. The model structure is a multi-stage single product closed-loop supply chain. Environmental factors and fuzzy data are studied.

Figure 1: The supply chain network structure

3.2. the planning model specification

Now the assumptions are provided to solve the model:

- The model is a single-product multi-stage closed-loop supply chain that considers environmental factors.

- Parameters including customer demand, harmful environmental pollutants of each vehicle are considered as trapezoidal fuzzy numbers.
- Alternatives are considered for transporting products and parts between production, distribution, customer, collection, disassemble, recycling, and disposal centers—processing capacity of various products [11].

As previously stated, the objective function has two contradictory objectives, and this model must achieve the optimum state. The first objective is to minimize the total costs, including the fixed cost of building the facility, the variable cost of processing and producing products in different facilities, and transporting materials by different transport alternatives between each center at different supply chain stages. The second objective is to minimize the emission and the environmental effects of goods and materials transport between each stage and by each transport alternative[15].

3.2.1. Subscripts and sets

$M = \{1, ..., m, ..., M\}$: The set of manufacturers' candidate locations.

$D = \{1, ..., d, ..., D\}$: The set of candidate locations for distribution centers.

$C = \{1, ..., c, ..., C\}$: The set of customer centers of the main product.

$K = \{1, ..., k, ..., K\}$: The set of candidate locations of collection centers.

$A = \{1, ..., a, ..., A\}$: The set of candidate locations for disassembling centers.

$P = \{1, 2\}$: The set of disposal methods at the disposal center.

$T = \{1, ..., t, ...T\}$: The set of all candidate alternatives for transporting products between different stages of the chain.

TM: The set of candidate alternatives for transporting products from manufacturers to distribution centers.

TD: The set of candidate alternatives for transporting products from distribution centers to customer centers.

TC: The set of candidate alternatives for transporting returned product and used product from customer centers to collection centers.

TK: The set of Candidate alternatives for transporting returned product and used product from collection centers to disassembling centers.

TAM: The set of candidate alternatives for transporting returned product from disassembly centers to manufacturers.

TAR: The set of candidate alternatives for transporting recyclable materials from disassembling centers to recycling centers.

TAP: Candidate alternatives for waste transport from disassembling centers to the disposal center.

3.2.2. parameters

c_t^T: The cost of transporting each unit of product per unit of distance using the transporting option t.

$dis_{ij}^{ff'}$: The distance between the potential facility i of the set f and the potential facility j of the set f'.

FC_j^f: Fixed cost of facility f located at location j such that $f \in \{M, D, K, A, R\}$.

VC_j^f: The variable cost of processing each unit of product in facility f located at location j.

VC_j^p: Cost of disposal of each waste unit in the disposal center under the method j ($j = 1$ and $j = 2$).

CAP_j^f: facility f capacity located at location j such that $f \in \{M, D, K, A, R\}$.

CAP_j^p: Capacity of disposal method j in the center of disposal ($j = 1$ equivalent to burning and $j = 2$ equivalent to burial).

CAP_t^T: The capacity of the transport option t to transfer products between the two stages.

GN_j^f: The NO_2 released from the processing of each unit of product in facility f located at location j.

GN_j^p: The NO_2 released from the disposal of each unit of waste using the method j ($j = 1$ and $j = 2$).

GC_j^f: The CO released from the processing of each unit of product in the facility f located at location j.

GC_j^p: The CO released from the disposal of each waste unit using the method j ($j = 1$ and $j = 2$).

GO_j^f: The volatiles released from the processing of each product unit in facility f located at location j.

GO_j^p: The volatiles released from the disposal of each waste unit using the method j.

$\widetilde{GN}_t^T$: The fuzzified NO_2 released from the transport of a product unit.

$\widetilde{GC}_t^T$: The fuzzified CO released from the transport of a product unit.

$\widetilde{GO}_t^T$: The fuzzified volatiles released from the transport of a unit of product.

α: A portion of the product returned by the customer to the customer centers before the end of the product life cycle for reasons such as sales policies, return obligations, warranty, and guarantee, after-sales service, etc.

β: A portion of the product returned to customer centers after the end of its life cycle as a used product.

ρ_1: A portion of the used product recycled and used in the consumer market of the recycled product.

ρ_2: A portion of the used product that must be disposed.

$\widetilde{dem}_c$: customer center c Fuzzy demand for the main product.

3.3. Mathematical model

Here, a multi-objective fuzzy mathematical model is suggested to solve the problem.

The mathematical model of this problem is formulated as follows:

$$\min f_1 = FC + VC + TC \tag{3.1}$$

$$FC = \sum_{m-1}^{M} FC_m^M Y_m^M + \sum_{d-1}^{D} FC_d^D Y_d^D + \sum_{k=1}^{K} FC_k^K Y_k^K + \sum_{a-1}^{A} FC_a^A Y_a^A + \sum_{r-1}^{R} FC_r^R Y_r^R \tag{3.2}$$

$$\begin{aligned} VC = &\sum_{m-1}^{M} VC_m^M (\sum_{d-1}^{D} \sum_{tm\in TM} \left(X_{md,tm}^{TM} + W_{md,tm}^{TM}\right)\Bigg) + \sum_{d=1}^{D} VC_d^D \left(\sum_{c=1}^{c} \sum_{td\in TD} \left(X_{dc,td}^{TD} + W_{dc,td}^{TD}\right)\right) \\ &+ \sum_{k=1}^{T} VC_k^K \left(\sum_{a=1}^{A} \sum_{tk\in TK} \left(W_{ka,tk}^{TK} + Z_{ka,tk}^{TK}\right)\right) \\ &+ \sum_{a=1}^{A} VC_a^A \left(\sum_{m=1}^{M} \sum_{tam\in TAM} W_{am,tam}^{TAM} + \sum_{r=1}^{R} \sum_{tar\in TAR} Z_{ar,tar}^{TAR} + \sum_{tap\in TAR}^{T} Z_{ap,tap}^{TAP}\right) \\ &+ \sum_{r=1}^{R} VC_r^R \left(\sum_{a=1}^{A} \sum_{tar\in TAR} Z_{ar,tar}^{TAR}\right) + \sum_{j=1}^{2} VC_j^P Q_j^P \end{aligned} \tag{3.3}$$

$$\begin{aligned} TC = &\sum_{m=1}^{M} \sum_{d=1}^{D} \sum_{tm\in TM} dis_{md}^{MD} C_{tm}^{T} \left(X_{md,tm}^{TM} + W_{md,tm}^{TM}\right) + \sum_{d=1}^{D} \sum_{c=1}^{C} \sum_{td\in TD} dis_{dc}^{DC} C_{td}^{T} \left(X_{dc,td}^{TD} + W_{dc,td}^{TD}\right) \\ &+ \sum_{c=1}^{c} \sum_{k=1}^{K} \sum_{tc\in TC} dis_{ck}^{CK} C_{tc}^{T} \left(Z_{ck,tc}^{TC} + W_{ck,tc}^{TC}\right) + \sum_{k=1}^{K} \sum_{a=1}^{A} \sum_{tk\in TK} dis_{ka}^{KA} C_{tk}^{T} \left(Z_{ka,tk}^{TK} + W_{ka,tk}^{TK}\right) \\ &+ \sum_{a=1}^{A} \sum_{m=1}^{M} \sum_{tam\in TAM} dis_{am}^{AM} C_{tam}^{T} W_{am,tam}^{TAM} + \sum_{a=1}^{A} \sum_{r=1}^{R} \sum_{tar\in TAR} dis_{ar}^{AM} C_{tar}^{T} Z_{ar,tar}^{TAR} \\ &+ \sum_{a=1}^{A} \sum_{tap\in TAP} dis_{ap}^{AP} C_{tap}^{T} Z_{\mathrm{ap,tap}}^{TAP} \, \% \end{aligned} \tag{3.4}$$

$$\min f_2 = PN + PC + PO \tag{3.5}$$

$$\begin{aligned}
PN = &\sum_{m=1}^{M} GN_m^M \left(\sum_{d=1}^{D} \sum_{tm \in TM} \left(X_{md,tm}^{TM} + W_{md,tm}^{TM} \right) \right) \\
&+ \sum_{d=1}^{D} GN_d^D \left(\sum_{c=1}^{c} \sum_{td \in TD} \left(X_{dc,TD}^{TD} + W_{dc,td}^{TD} \right) \right) \\
&+ \sum_{k=1}^{K} GN_k^K \left(\sum_{a=1}^{A} \sum_{tk \in TK} \left(Z_{ka,tk}^{TK} + W_{ka,tk}^{TK} \right) \right) \\
&+ \sum_{a=1}^{A} GN_a^A \left(\sum_{m=1}^{M} \sum_{ta \in TAM} W_{am,tam}^{TAM} + \sum_{r=1}^{R} \sum_{ta \in TAR} Z_{ar,tar}^{TAR} + \sum_{ta \in TAP} W_{ap,tap}^{TAP} \right) \\
&+ \sum_{r=1}^{R} GN_r^R \left(\sum_{a=1}^{A} \sum_{ta \in TAR} Z_{ar,tar}^{TAR} \right) + \sum_{p=1}^{P} GN_p^P Q_p^P \\
&+ \sum_{m=1}^{M} \sum_{d=1}^{D} \sum_{tm \in TM} dis_{md}^{MD} GN_{tm}^{T} \left(X_{md,tm}^{TM} + W_{md,tm}^{TM} \right) \\
&+ \sum_{d=1}^{D} \sum_{c=1}^{c} \sum_{td \in TD} dis_{dc}^{DC} GN_{td}^{T} \left(X_{dc,td}^{TD} + W_{dc,td}^{TD} \right) + \sum_{c=1}^{c} \sum_{k=1}^{T} \sum_{tc \in TC} dis_{ck}^{TK} GN_{tc}^{T} \left(Z_{ck,tc}^{TC} + W_{ck,tc}^{Tc} \right) \\
&+ \sum_{k=1}^{K} \sum_{a=1}^{A} \sum_{tk \in TK} dis_{ka}^{KA} GN_{tk}^{T} \left(Z_{ka,tk}^{TK} + W_{ka,tk}^{TK} \right) + \sum_{a=1}^{A} \sum_{m=1}^{M} \sum_{tam \in TAM} dis_{am}^{TM} GN_{tam}^{T} W_{am,tam}^{TAM} \\
&+ \sum_{a=1}^{A} \sum_{r=1}^{R} \sum_{tar \in TAR} dis_{ar}^{AR} GN_{tar}^{T} Z_{ar,tar}^{TAR} + \sum_{a=1}^{T} \sum_{tap \in TAP} dis_{ap}^{AP} GN_{tap}^{T} Z_{ap,tap}^{TAP}
\end{aligned} \tag{3.6}$$

$$\begin{aligned}
PC = &\sum_{m=1}^{M} GC_m^M (\sum_{d=1}^{D} \sum_{tm \in TM} \left(X_{md,tm}^{TM} + W_{m,tm}^{TM} \right) \Bigg) + \\
&\sum_{d=1}^{D} GC_d^D \left(\sum_{c=1}^{c} \sum_{td \in TD} \left(X_{dc,td}^{TD} + W_{dc,td}^{TD} \right) \right) \\
&+ \sum_{k=1}^{K} GC_k^K \left(\sum_{a=1}^{A} \sum_{tk \in TK} \left(Z_{ka,tk}^{TK} + W_{ka,tk}^{TK} \right) \right) \\
&+ \sum_{a=1}^{A} GC_a^A \left(\sum_{m=1}^{M} \sum_{ta \in TAM} W_{am,tam}^{TAM} + \sum_{r=1}^{R} \sum_{ta \in TAR} Z_{ar,tar}^{TAR} + \sum_{ta \in TAP} Z_{ap,tap}^{TAP} \right) \\
&+ \sum_{r=1}^{R} GC_r^R \left(\sum_{a=1}^{A} \sum_{ta \in TAR} Z_{ar,tar}^{TAR} \right) + \sum_{p=1}^{2} GC_p^P Q_p^P \\
&+ \sum_{m=1}^{M} \sum_{d=1}^{D} \sum_{tm \in TM} dis_{md}^{MD} GC_{tm}^{T} \left(X_{md,tm}^{TM} + W_{md,tm}^{TM} \right)
\end{aligned} \tag{3.7}$$

$$+\sum_{d=1}^{D}\sum_{c=1}^{c}\sum_{td\in TD} dis_{dc}^{DC} GC_{td}^{T}\left(X_{dc,td}^{TD}+W_{dc,td}^{TD}\right)+\sum_{c=1}^{c}\sum_{k=1}^{K}\sum_{tc\in TC} dis_{ck}^{CK} GC_{tc}^{T}\left(X_{ck,tc}^{TC}+W_{ck,tc}^{Tc}\right)$$
$$+\sum_{k=1}^{K}\sum_{a=1}^{A}\sum_{tk\in TK} dis_{ka}^{KA} GC_{tk}^{T}\left(Z_{ka,tk}^{TK}+W_{ka,tk}^{TK}\right)+\sum_{a=1}^{A}\sum_{m=1}^{M}\sum_{tam\in TAM} dis_{am}^{AM} GC_{tam}^{T} W_{am,tam}^{TAM}$$
$$+\sum_{a=1}^{A}\sum_{r=1}^{R}\sum_{tar\in TAR} dis_{ar}^{AM} GC_{tar}^{T} Z_{ar,tar}^{TAR}+\sum_{a=1}^{A}\sum_{tap\in TAP} dis_{ap}^{AP} GC_{tap}^{T} Z_{ap,tap}^{TAP}\%$$

$$\begin{aligned}
PO=&\sum_{m=1}^{M} GO_{m}^{M}\left(\sum_{d=1}^{D}\sum_{tm\in TM}\left(X_{md,tm}^{TM}+W_{md,tm}^{TM}\right)\right)\\
&+\sum_{d=1}^{D} GO_{d}^{D}\left(\sum_{c=1}^{c}\sum_{td\in TD}\left(X_{dc,td}^{TD}+W_{dc,td}^{TD}\right)\right)\\
&+\sum_{k=1}^{K} GO_{k}^{K}\left(\sum_{a=1}^{A}\sum_{tk\in TK}\left(Z_{ka,tk}^{TK}+W_{ka,tk}^{TK}\right)\right)\\
&+\sum_{a=1}^{A} GO_{a}^{A}\left(\sum_{m=1}^{M}\sum_{ta\in TAM} W_{am,tam}^{TAM}+\sum_{r=1}^{R}\sum_{ta\in TAR} Z_{ar,tar}^{TAR}+\sum_{ta\in TAP} Z_{ap,tap}^{TAP}\right)\\
&+\sum_{r=1}^{R} GO_{r}^{R}\left(\sum_{a=1}^{A}\sum_{ta\in TAR} Z_{ar,tar}^{TAR}\right)+\sum_{p=1}^{2} GO_{p}^{P} Q_{p}^{P}\\
&+\sum_{m=1}^{M}\sum_{d=1}^{D}\sum_{tm\in TM} dis_{md}^{MD} GO_{tm}^{T}\left(X_{md,tm}^{TM}+W_{md,tm}^{TM}\right)\\
&+\sum_{d=1}^{D}\sum_{c=1}^{c}\sum_{td\in TD} dis_{dc}^{DC} GO_{td}^{T}\left(X_{dc,td}^{TD}+W_{dc,td}^{TD}\right)+\sum_{c=1}^{c}\sum_{k=1}^{T}\sum_{tc\in Tc} dis_{ck}^{cK} GO_{tc}^{T}\left(X_{ck,tc}^{TC}+W_{ck,tc}^{Tc}\right)\\
&+\sum_{k=1}^{T}\sum_{a=1}^{A}\sum_{tk\in TK} dis_{ka}^{KA} GO_{tk}^{T}\left(Z_{ka,tk}^{TK}+W_{ka,tk}^{TK}\right)+\sum_{a=1}^{A}\sum_{m=1}^{M}\sum_{tam\in TAM} dis_{am}^{AM} GO_{tam}^{T} W_{am,tam}^{TAM}\\
&+\sum_{a=1}^{A}\sum_{r=1}^{R}\sum_{tar\in TAR} dis_{ar}^{AM} GO_{tar}^{T} Z_{ar,tar}^{TAR}+\sum_{a=1}^{T}\sum_{tap\in TAP} dis_{ap}^{AP} GO_{\mathrm{ap}}^{T} Z_{ap,tap}^{TAP}
\end{aligned}\tag{3.8}$$

St :

$$\sum_{d=1}^{D}\sum_{tm\in TM}\left(X_{md,tm}^{TM}+W_{md,tm}^{TM}\right)\le Y_{m}^{M} CAP_{m}^{M}\qquad m=1,\ldots,M \tag{3.9}$$

$$\sum_{c=1}^{c}\sum_{td\in TD}\left(X_{dc,td}^{TD}+W_{dc,td}^{TD}\right)\le Y_{d}^{D} CAP_{d}^{D}\qquad d=1,\ldots,D \tag{3.10}$$

$$\sum_{a=1}^{A}\sum_{tk\in TK}\left(W_{ka,tk}^{TK}+Z_{ka,tk}^{TK}\right)\le Y_{k}^{K} CAP_{k}^{K}\qquad k=1,\ldots,K \tag{3.11}$$

$$\sum_{m=1}^{M} \sum_{tam \in TAM} W_{am,\,\mathrm{tam}}^{TAM} + \sum_{r=1}^{R} \sum_{\mathrm{tar} \in TAR} Z_{ar,\,\mathrm{tar}}^{TAR} + \sum_{tap \in TAP} Z_{ap,\,\mathrm{tap}}^{TAP} \leq Y_a^A CAP_a^A \quad a = 1, \dots, A \tag{3.12}$$

$$\sum_{a=1}^{A} \sum_{tar \in TAR} Z_{ar,tar}^{TAR} \leq Y_r^R CAP_r^R \qquad r = 1, \dots, R \tag{3.13}$$

$$\sum_{p=1}^{P} Q_p^p \leq CAP_p^p \qquad p = 1, 2 \tag{3.14}$$

$$\sum_{m=1}^{M} \sum_{d=1}^{D} \left(X_{md,tm}^{TM} + W_{md,tm}^{TM} \right) \leq CAP_{tm}^{T} \qquad tm \in TM \tag{3.15}$$

$$\sum_{d=1}^{D} \sum_{c=1}^{c} \left(x_{dc,td}^{TD} + W_{dc,td}^{TD} \right) \leq CAP_{td}^{T} \qquad td \in TD \tag{3.16}$$

$$\sum_{c=1}^{c} \sum_{k=1}^{K} \left(W_{ck,tc}^{TC} + Z_{ck,tc}^{TC} \right) \leq CAP_{tc}^{T} \qquad tc \in TC \tag{3.17}$$

$$\sum_{k=1}^{K} \sum_{a=1}^{A} \left(W_{ka,tk}^{TK} + Z_{ka,tk}^{TK} \right) \leq CAP_{tk}^{T} \qquad tk \in TK \tag{3.18}$$

$$\sum_{a=1}^{A} \sum_{m=1}^{M} W_{am,tam}^{TAM} \leq CAP_{tam}^{T} \qquad \mathrm{tam} \ \in TAM \tag{3.19}$$

$$\sum_{a=1}^{A} \sum_{r=1}^{R} z_{ar,tam}^{TAR} \leq CAP_{tar}^{T} \qquad \mathrm{tar} \in TAR \tag{3.20}$$

$$\sum_{a=1}^{A} Z_{\mathrm{ap,\,tap}}^{TAP} \leq CAP_{\mathrm{tap}}^{T} \qquad \mathrm{tap} \in TAP \tag{3.21}$$

$$\sum_{d=1}^{D} \sum_{td \in TD} X_{dc,td}^{TD} = dem_c \qquad c = 1, \dots, C \tag{3.22}$$

$$\sum_{d=1}^{D} \sum_{td \in TD} X_{dc,td}^{TD} = \alpha \times \widetilde{dem}_c \qquad c = 1, \dots, C \tag{3.23}$$

$$\sum_{k=1}^{K} \sum_{tc \in TC} W_{ck,tc}^{TC} = \alpha \times \widetilde{dem}_c \qquad c = 1, \dots, C \tag{3.24}$$

$$\sum_{k=1}^{K} \sum_{tc \in TC} z_{ck,tc}^{TC} = \beta \times \widetilde{dem}_c \qquad c = 1, \dots, C \tag{3.25}$$

$$\sum_{r=1}^{R} \sum_{tar \in TAR} Z_{ar,\,\mathrm{tar}}^{TAR} = \rho_1 \sum_{k=1}^{K} \sum_{tk \in TK} Z_{ka,ta}^{TK} \qquad a = 1, \dots, A \tag{3.26}$$

$$\sum_{tap\in TAP} Z^{TAP}_{ap,tap} = \rho_2 \sum_{k=1}^{K}\sum_{tk\in TK} z^{TK}_{ka,ta} \qquad a=1,\dots,A \tag{3.27}$$

$$\sum_{m=1}^{M}\sum_{tm\in TM} X^{TM}_{md,tm} = \sum_{c=1}^{c}\sum_{td\in TD} X^{TD}_{dc,td} \qquad d=1,\dots,D \tag{3.28}$$

$$\sum_{m=1}^{M}\sum_{tm\in TM} W^{TM}_{md,tm} = \sum_{c=1}^{c}\sum_{td\in TD} W^{TD}_{dc,td} \qquad d=1,\dots,D \tag{3.29}$$

$$\sum_{c=1}^{c}\sum_{tc\in TC} W^{TC}_{ck,tc} = \sum_{a=1}^{A}\sum_{tk\in TK} W^{TK}_{ka,tk} \qquad k=1,\dots,K \tag{3.30}$$

$$\sum_{c=1}^{c}\sum_{tc\in TC} z^{Tc}_{ck,tc} = \sum_{a=1}^{A}\sum_{tk\in TK} Z^{TK}_{ka,tk} \qquad k=1,\dots,K \tag{3.31}$$

$$\sum_{k=1}^{K}\sum_{tk\in TK} W^{TK}_{ka,tk} = \sum_{m=1}^{M}\sum_{tam\in TAM} W^{TAM}_{am,\text{ tam}} \qquad a=1,\dots,A \tag{3.32}$$

$$\sum_{k=1}^{K}\sum_{tk\in TK} Z^{TK}_{ka,tk} = \sum_{r=1}^{R}\sum_{tar\in TAr} Z^{TAR}_{ar,tar} + \sum_{tap\in TAP} Z^{TAP}_{ap,tap}, \qquad a=1,\dots,A \tag{3.33}$$

$$\sum_{a=1}^{A}\sum_{tam\in TAM} W^{TAM}_{am,tam} = \sum_{d=1}^{D}\sum_{tm\in TM} W^{TM}_{md,tm} \qquad m=1,\dots,M \tag{3.34}$$

$$\sum_{j=1}^{2} Q_j = \sum_{a=1}^{A}\sum_{tap\in TAP} Z^{TAP}_{ap,tap} \tag{3.35}$$

$$\left[\frac{\widetilde{dem}_{c^l} + \sqrt{\widetilde{dem}}_{c^u}}{2} + \frac{\widetilde{dem}_{c\beta} - \widetilde{dem}_{ca}}{4}\right] = \text{dem}_c \quad c=1,\dots,C \tag{3.36}$$

$$\left[\frac{\widetilde{GN}^T_t + \widetilde{GN}^T_{t^u}}{2} + \frac{\widetilde{GN}^T_{t\beta} - \widetilde{GN}^T_{ta}}{4}\right] = GN^T_t \quad t=1,\dots,T \tag{3.37}$$

$$\left[\frac{\widetilde{GC}^T_{t^l} + \widetilde{GC}^T_{t^u}}{2} + \frac{\widetilde{GC}^T_{t\beta} - \widetilde{GC}^T_{t\alpha}}{4}\right] = GC^T_t \quad t=1,\dots,T \tag{3.38}$$

$$\left[\frac{\widetilde{GO}^T_{t^l} + \widetilde{GO}^T_{t^u}}{2} + \frac{\widetilde{GO}^T_{t\beta} - \widetilde{GO}^T_{t\alpha}}{4}\right] = GO^T_t \quad t=1,\dots,T \tag{3.39}$$

or

$$\left[\frac{\widetilde{dem}_{c^l} + \widetilde{dem}_{c^u}}{2}\right] = \text{dem}_c \quad c=1,\dots,C \tag{3.40}$$

$$\left[\frac{\widetilde{GN}^T_{t^l} + \widetilde{GN}^T_{t^u}}{2}\right] = GN^T_t \qquad t=1,\dots,T \tag{3.41}$$

$$\left[\frac{\widetilde{GC}_{t^l}^{T}+\widetilde{GC}_{t^u}^{T}}{2}\right]=GC_t^T \qquad t=1,\dots,T \tag{3.42}$$

$$\left[\frac{\widetilde{GO}_{t^l}^{T}+\widetilde{GO}_{t^u}^{T}}{2}\right]=GO_t^T \quad t=1,\dots,T \tag{3.43}$$

$$\begin{aligned}
&Y_m^M, Y_d^D, Y_k^K, Y_a^A, Y_r^R \in \{0,1\} \qquad m \in M, d \in D, k \in K, a \in A, r \in R\\
&X_{md,tm}^{TM}, W_{md,tm}^{TM} X_{dc,td}^{TD}, W_{dc,td}^{TD}, Z_{ck,td}^{TC}\\
&W_{ck,tc}^{TC}, Z_{ka,tc}^{TK}, W_{ka,tk}^{TK}, W_{am,tam}^{TAM}, Z_{ar,tar}^{TAR} \geq 0\\
&tm \in TM, td \in TD, tc \in TC, tk \in TK, tam \in TAM,\ \text{tar} \ \in TAR,\ \text{tap} \ \in TAP\\
&Q_p^P \geq 0 \quad p=1,2
\end{aligned}$$

Eq (3.9)-3.11 is the first objective function that minimizes the total cost, including fixed costs of construction and facilities, the variable cost of production and transport.

Eq (3.10),(3.11) is the second objective function that minimizes the emission of harmful environmental gases such as NO2, CO, and organic volatiles.

Constraints (3.9) to (3.12) determine the production, distribution, collection, disassemble, and recycling centers capacity, and also prevent the transport and processing of products to centers that have not yet been constructed.

Constraint (3.13) Limits the number of wastes disposed by each disposal method according to their capacity. Constraints (3.14) to (3.21) limit transports between the centers of both stages of the supply chain so that the transport does not exceed the capacity of each transport option. Constraints (3.22) and (3.23) ensure that customer center demand is met for new and reproduced products, respectively. Constraints (3.24) and (3.25) calculate the number of used returned products during the life cycle and the number of used products after the life cycle that is transported from customer centers to collection centers according to the product return rate.

Constraints (3.26) and (3.27) estimate the total number of recyclable materials and wastes transported from disassembling centers to recycling centers and disposal centers according to their coefficients. Constraints (3.28) and (3.29) ensure that the number of new products and the number of returned products entered each distribution center is equal to the number of new and returned products departing that center. In a similar manner, constraints (3.30) and (3.31) are for collection centers, (3.32) and (3.33) for disassembling centers, (3.34) for each production unit, and (3.35) is also for disposal centers. Equations (3.36) to (3.37) are suggested by Yager (BOA) to defuzzify fuzzy parameters. Equations (3.38) to (3.43) defuzzify the fuzzy values using the mean of maximum method. Finally, a set of non-negative and binary variables logical constraints are taken into account.

4. Research findings

A closed-loop green supply chain model in this research considers the forward and reverse logistics network and harmful gas emissions. A fuzzy mathematical programming model was developed for uncertain known. The final objective of the model is to minimize the cost and emission of production, recycling, reproduction, and transport of materials and products between different chain facilities.

After studying the model given a real-world sample, We also address the application of the model in the industry and attract the attention of investors and industry owners to invest better in green production. Given the demand and pollution fuzzy parameters, two methods of comparison and ranking of the mean of maximum (MOM) and the bisector of area (BOA) were considered, and the model was developed, taking into account the Constraints. A petrochemical plant was chosen to solve the model with real-world data. After a good estimation, The data were prepared. Finally, the Imperialist competition algorithm was applied.

4.1. Model validation

Table 1: Distance Comparison of Methods for Comparing and Ranking of Mean of Maximum (MOM) and the bisector of area (BOA) with the crisp Value for Transport Alternatives Pollutants

Scenario	The NO_2 released from the processing of each product unit (mg)		The CO released from the processing of each product unit (mg)		The volatiles released from the processing of each product unit (mg)	
	d_{MOM}	d_{BOA}	d_{MOM}	d_{BOA}	d_{MOM}	d_{BOA}
1	0.04	0.01	0.05	0.08	0.05	0.02
2	0.1	0.07	0.25	0.22	0.05	0.08
3	0	0	0.2	0.2	0.03	0
4	0.15	0.02	0.3	0.17	0.05	0.02
5	0.1	0.02	0.25	0.2	0.05	0.07

4.2. a Comparison between models results

In meta-innovative optimization methods, the solutions are different, so 20 iterations were considered for each problem [20]. After solving each problem, the Pareto fronts were stored, and the best solutions was compared. The Pareto front is defined as all the solutions among iterations.

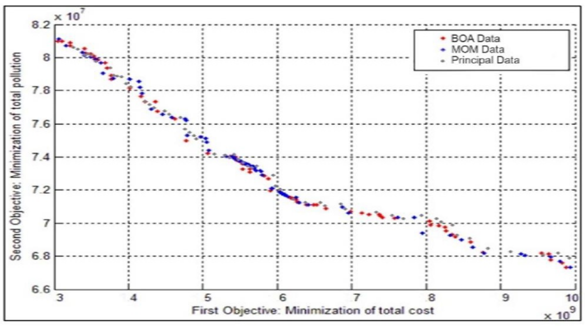

Figure 2: Comparison of Pareto fronts for three problems

It can be seen that these three types of data have approximately similar results. But after a close look at that chart, we can conclude that the results of the data defuzzify by the method of comparison and ranking, the bisector of area (BOA), have not only had better results on the Pareto front but also closer to the crisp data results.

5. Conclusions and suggestions

This research takes into account a closed-loop green supply chain as a multi-objective fuzzy mathematical programming model. Finally, the model was solved using the Imperialist competition algorithm; the most important results are:

1. The model showed that it is possible to recycle raw materials and reproductive products, increase efficiency, reduce costs, increase the company's profitability, and reduce environmental pollutants through industrial waste management.

2. The results show that the transport process adjustment reduces the distances and arrival duration, costs, reduces environmental pollutants and the destructive effects of environmental factors.

3. Given that some parameters are fuzzy in the real world, it is better to consider these parameters fuzzy to gain better and more real-world results.

4. the applicability was established given the model evaluation with approximately real-world data, and it was found that this model is suited to study a closed-loop supply chain that simultaneously considers two forward and inverse logistics networks.

5. the model is solved with new Constraints, the first location was chosen for the production center, and the first and third locations were chosen for the distribution centers. However, the plant was located in the fourth location and its warehouses in the first and second locations in practice. This choice may have been appropriate for the past years given the history of the establishment, but the solution shows that if we want to create a plant with the same conditions, the best locations are the first location for the Production center and the first and third locations for distribution centers.

This research is limited to the petrochemical industry and may yield different results in other industries. Another limitation is that this study considered air pollutants, and the results may change by altering wastes and pollutants such as industrial effluents. Therefore, it is suggested that the methodology of this research be used in other industries.

Given that customer response time is a competitive factor among manufacturers, a response time optimization model is suggested by increasing production and transport times. In some industries, the time interval between storage and delivery to the customer and its consumption is a critical parameter for perishable products, and if the transport conditions are not optimal, the products may Impose colossal cost. Therefore, a model is provided for perishable products given this parameter.

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