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Sustainable closed-loop supply chain design for the car battery industry with taking into consideration the correlated criteria for supplier selection and uncertainty conditions

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Abstract

Based on the concept of Sustainability and sustainable development, focusing only on economic and profitable issues is not sufficient, and companies need to pay attention to environmental and social impacts of car industry. In this regard, in this research, a mathematical model for designing a sustainable closed-loop supply chain multi-Surface and multi-product for car battery industry under uncertainty conditions, considering the correlation between supplier selection criteria presented. The study of supply chain network is including suppliers, manufacturers, distributors, customers, recycling centers and destruction centers. The proposed model is able to locate the levels of producers, distributors, Recycling and disposal centers As well as the flow of materials between the different levels of the supply chain to minimize the total costs, minimize overall environmental impact, And maximize social utility and maximize utility of supplier selection In view of the set criteria correlated. Then Lexicography method was introduced to solve the mode and finally, in order to assess the proficiency and validity of the proposed model, a problem as a numerically issue for different priorities in goals is solved, and the results have been analyzed. The solution outcomes represent that the proposed model and method of solution have the required efficiency and validity

Key words: Closed- loop supply chain; Sustainable supply chain; Lexicography method; Principal Component Analysis (PCA); Battery industry

Projeto sustentável da cadeia de suprimentos de circuito fechado para a indústria de baterias de automóveis, levando em consideração os critérios correlatos para seleção de fornecedores e condições de incerteza

Resumo

Com base no conceito de Sustentabilidade e Desenvolvimento Sustentável, o foco apenas em questões econômicas e lucrativas não é suficiente, e as empresas precisam prestar atenção aos impactos ambientais e sociais da indústria automobilística. Nesse sentido, nesta pesquisa, é apresentado um modelo matemático para o projeto de uma cadeia de suprimentos sustentável em circuito fechado Multi-Superfície e Multi-Produto para a indústria de baterias de automóveis sob condições de incerteza, considerando a correlação entre os critérios de seleção de fornecedores apresentados. O estudo da rede da cadeia de suprimentos inclui fornecedores, fabricantes, distribuidores, clientes, centros de reciclagem e centros de destruição. O modelo proposto é capaz de localizar os níveis de produtores, distribuidores, centros de reciclagem e descarte, bem como o fluxo de materiais entre os diferentes níveis da cadeia de suprimentos para minimizar os custos totais, minimizar o impacto ambiental geral e maximizar a utilidade social e maximizar utilidade da seleção de fornecedores,Tendo em vista os critérios estabelecidos correlacionados. Em seguida, o método Lexicography foi introduzido para resolver o modo e, finalmente, a fim de avaliar a proficiência e a validade do modelo proposto, um problema como uma questão numericamente para diferentes prioridades em objetivos é resolvido e os resultados foram analisados. Os resultados da solução representam que o modelo e o método de solução propostos têm a eficiência e validade necessárias

Palavras-chave: Cadeia de suprimentos em circuito fechado; Cadeia de suprimentos sustentável; Método de Lexicografia; Análise de componentes principais (PCA); Indústria de baterias

1. Introduction

Nowadays economies and industries are rapidly changing. Also, countries are more likely to compete because of the globalization process. Customers are looking for products and services that can respond to their needs; on the other hand, companies seek to maintain profits and create competitive advantage with the goal of more durability in the market. All of these factors have led to greater attention to the supply chain and logistics. Sustainability and sustainable development today have become one of the most important issues in the development of environmental degradation (global warming, ozone depletion, etc.) and human rights violations. It is worth mentioning that the World Commission on Environment and Development (WHDC), also known as the Brandt land, has provided two distinct definitions of sustainable development, namely:

1- An extension that meets the needs of the present without threaten the ability of future generations to meet their needs.

2- Accurate use of resources in a framework of environmental, socioeconomic and preventive factors, as well as improving the quality of life, while preserving the quality of life of future generations.

Nowadays, due to the increasing importance of environmental criteria and the effort of organizations for the impressive and efficient use of products and consumer protection, researchers pay particular attention to two categories of supply chain and closed-loop supply. The primary purpose of the topic of use defective goods with using recycling process, preventing more waste of resources, reducing environmental pollution and reducing costs and profitability, and of course some social and commercial benefits. On the other hand, attention to the flow of defective products and the management of waste and recycling can also affect the success of organizations in accordance with the laws and expectations of customers. A wast overview of the research background in this area represents that a specific type of supply chain design problem, called the design of sustainable supply chains, is highly sought after by researchers. Based on sustainable concepts and sustainable development, focusing on economic and profitable issues is not sufficient, and companies must also consider the environmental and social impacts of their industry. In fact, sustainability is a kind of balance between economic, environmental and social goals for sustainable and balanced development.

In Section 2, previous research has been investigated. Then, in section 3, the main problem of the research is described and the mathematical model of the research is proposed.

In section 4, the methodology for analyzing the key issues is described to eliminate the correlation between the criteria. Also, in section 5, the lexicography method is described for solving the model. In order to evaluate the efficiency and validity of the mathematical model and the solution method presented in clause 6, a numerical example is presented and solved and its results are carefully analyzed. Finally, in Section 7, conclusions and suggestions for future research are presented.

2. Theoretical basis and Review of Past Studies:

In this section, we investigate previous studies related to our research. The design of the supply chain, including the identification of appropriate infrastructure for the supply chain as one of the most important activities in the supply chain management, has always been a concern for industry executives. For this reason, in recent years, extensive research has been done on supply chain design. Milo et al. (2009) and Klebi et al. (2010) have a comprehensive overview of modeling issues related to the design of supply chain networks. According to Chloe Vekminsky (2004), the design of the supply chain network is the most important decision in management, which affects all other decisions related to the chain and has the broadest effect on the return on chain capital and its overall performance. Lin and Wang (2011) define the design of the supply chain network as an integrated configuration of supply, production and demand systems. Atefeh Beghaliyan (2013) Design of supply chain network with strategic chain decisions. Mello et al., Presented a literature review paper on the development of supply chain design models that featured a variety of supply chain design models. Pearcey et al. (2011) proposed a mixed integer linear programming model with the objective functions of minimizing costs and maximizing accountability in its proposed model. They have used an efficient memetic multi-objective algorithm to achieve a set of responses. Their proposed algorithm uses a dynamic search strategy with three different local searches.

Ramezani et al. (2013) present a multi-objective probabilistic model for the problem of integrated logistic network design under uncertainty conditions. In this research, the decision-making levels in the forward network include suppliers, manufacturers, distribution centers and customers, and in the reverse network, including collection centers and disposal centers. The objective functions used in the model are considered to maximize profits, customer responsiveness and quality.

Ozkaru et al. (2012) examined the main features of the creation of a closed-loop supply chain, including product retrieval processes. They define the closed-loop supply chain network, including customers, collection centers, production centers, retrieval centers and distribution centers, a multi-objective optimization model with the goal of maximizing the level of satisfaction with the business, maximizing the degree of customer satisfaction, and ultimately Maximize the total profit. Fleischen et al. (2001) defined the reverse logistics as follows: the reverse logistics of the planning, implementation, and control of second-hand goods and their information is counterproductive to the traditional supply chain with the goal of retrieving value or disposal. In this definition, returning products are not forced to return to their origin, they can return to the same supply chain or other supply chain. Moreover, products may be returned to customers for multiple reasons. Also, Ramezani et al. (2013) noted in their study factors such as environmental concerns, government regulation, social responsibility and customer awareness, which led not only to the factories being forced to supply products in an environmentally sustainable manner but also be responsible for returning products. Hence, a random multi-objective model for forward / reverse logistic network design was proposed under uncertainty conditions, which included three levels of forward movement (supplier, factory, distributor) and two levels of reverse (total collection) and the center of disposal), and on the other hand, their model maximized three goals (profit, customer satisfaction, quality).

Saberamanyan and colleagues (2013) offer a two-objective, multi-rotation, and multi-product closed loop supply chain in order to minimize the costs of the entire supply chain and maximize the efficiency of warehouse services and combined facility. Pidero et al. (2010) modeled the potential supply chain using phase sets and developed a phase linear programming model for supply chain planning in multilevel, multi-product, multi-course conditions. In multi-objective linear programming model presented by Paksoy et al. (2010), minimizing the cost and amount of carbon dioxide emissions in forward logistic and minimizing only chain reverse logistics costs has been evaluated. Kanan et al (2012) in their proposed model consider carbon emission as a decision variable. Amin and Zhang (2013) developed a closed-loop supply chain network, which includes manufacturing centers, collecting centers, and multi-product demand markets under uncertainty. One of the ways to select a supplier based on the criteria is to use methods based on multivariate statistical analysis techniques. Lam et al. (2010) introduced one of these techniques into supply chain management issues, they selected the best supplier by using the analysis of the main fuzzy components, after separating the selection criteria of suppliers. Lickens et al (2007) proposed a mixed integer nonlinear deterministic programming model for the design of a single-level reverse logistics network, a single-product with randomnumbered wait times. If the forward and reverse supply chain is considered together, the network that is being brought together will be the closed loop supply chain. Govindan et al., 2007). Garg and et al (2014) proposed a closed structure in the green supply chain logistics and optimized site selection in order to integrate environmental issues into a traditional logistics system. Zou et al. (2008) introduced a randomized fuzzy multicast planning model to minimize factory costs and supply chain distribution centers and maximize customer service. Using the mathematical simulator operator and model luck constraints, the model is transformed into a multi-objective programming problem and then solved using the genetic algorithm. Jafari et al.(2016) proposed a Sustainable supply chain design with water environmental impacts and justice-oriented employment considerations also jafari and seifbarghy (2016) proposed a Bi-Objective Multi-Echelon Multi-Product Supply Chain Network Design and They optimized their proposed model Using New Pareto-Based Approaches.

3. **Proposed mathematical model of research**

3.1. An outline of the general mathematical model

In this part of the paper, a mathematical model of research will be presented. The proposed mathematical model is presented to design a stable closed loop supply chain network, taking into account the correlated criteria for choosing the supplier and the conditions of uncertainty for use in the battery industry. It should be noted that the supply chain studied in the forward sector including suppliers of raw materials for distribution centers and demand and supply chain markets, including recycling centers and destruction centers. In the next step, a proposed fuzzy mathematical model is presented to investigate the possibility of solving in de-phased mode.

3.2. Graphic structure of closed-loop supply chain

Figure 1 shows the structure of proposed supply chain.

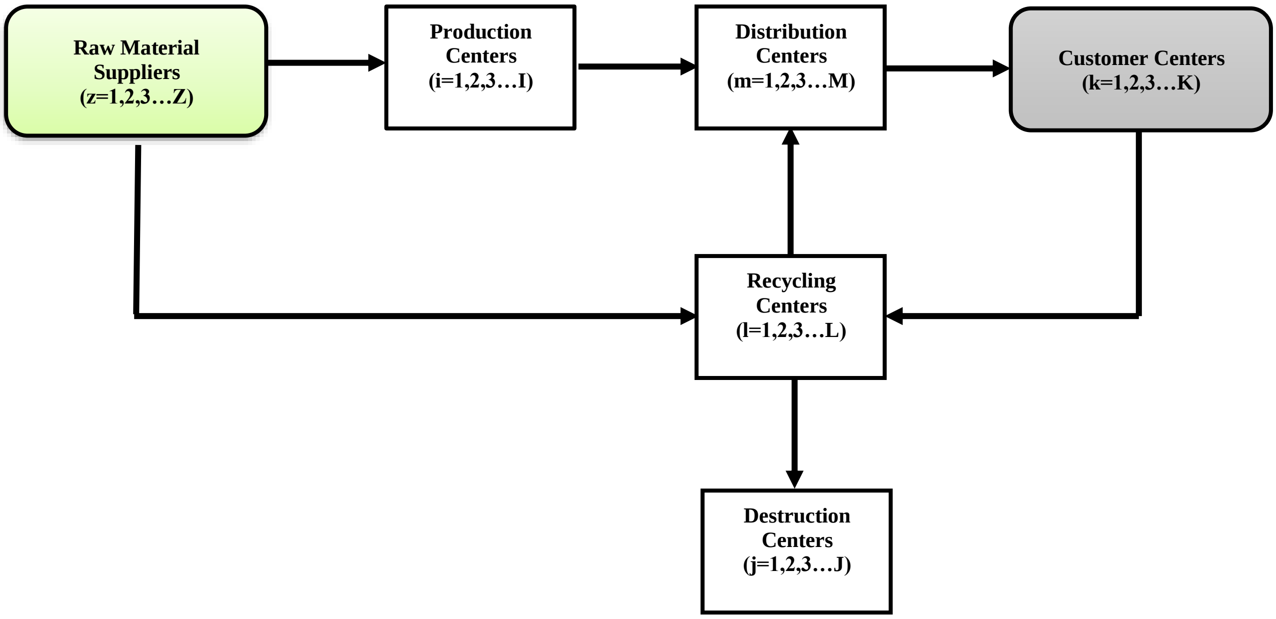

Figure 1. Studied closed-loop supply chain

3.3. Assumptions of mathematical model

Assumptions that are considered for proposed model are following:

The location of raw material suppliers and customers is fixed.

The cost of destroying waste products is assumed fix in each disposal centers.

Some parameters are non-deterministic (fuzzy).

All the fuzzy parameters of the model are in the form of a fuzzy number of teasers.

The costs of establishment and production is fix and definite in production centers.

The location of the facility will take place at discrete points.

Transport cost between facilities is constant and definite.

The capacity of facilities is a fuzzy number.

3.4. Indexes and Sets

Table 1 shows the indexes and sets for proposed model.

Table 1. Indexes and sets used in the model

Sets	Symbol
Sets of Raw material suppliers	z=1,2,…,Z
Sets of production centers	i=1,2,…,I
Sets of distribution centers	m=1,2,…,M
Set of demand/customer markets	k=1,2,…,K
Set of recycling/collection centers	l=1,2,…,L
Set of destruction centers	j=1,2,…,J
Sets of raw materials	h=1,2,…,H
Sets of products	p=1,2,…,P
Sets of disintegrating/ disposable products	u=1,2,…,U
Sets of toxic substances in products	s=1,2,…,S

3.5. Parameters

A) **The uncertain parameters (fuzzy)**

Fuzzy parameters are defined according to table 2.

Table 2. The uncertain Parameters used in the model

Parameter	Symbol
Fixed cost of construction of center i	$\widetilde{FC_i}$
Fixed cost of construction of distribution center m	$\widetilde{FC_m}$
Fixed cost of the establishment of the recycling/collection center l	$\widetilde{FC_l}$
Fixed cost of the establishment of the disposal center j.	$\widetilde{FC_j}$
Variable production cost of product at the production center i	$\widetilde{V_{ip}}$
The variable cost of producing a p product at the l center	$\widetilde{V_l}$
Disposal cost of a disposable product unit u at the disposal center j	$\widetilde{DS_{uj}}$
purchase cost of a raw material unit h from the supplier z.	$\widetilde{CP_{hz}}$
transportation cost of a product unit p from the production center i to the distribution center m.	$\widetilde{T_{imp}}$
transportation cost of a product unit p from the distribution center i to customer market k.	$\widetilde{T_{mkp}}$
transportation cost of a product unit p from the customer market k to the collection center l.	$\widetilde{T_{klp}}$
transportation cost of a material unit h from supplier z to the collection center l	$\widetilde{T_{hzl}}$
transportation cost of a material unit h from supplier z to the production center i	$\widetilde{T_{hzi}}$
transportation cost of a recycled product unit p from the recycling center l to the distributor m.	$\widetilde{T_{lmp}}$

transportation cost of a wastage unit u (disposable product) from the distribution center l to the disposal center j.	$\widetilde{T_{lju}}$
The rate of p products that are lost in the recycling center	$\widetilde{\alpha_p}$
Negative environmental rate of substance s from disintegrating product u	$\widetilde{B_{su}}$
Negative Environmental Impact Factor for the release of toxic substances at the j-th destroying Center	$\widetilde{e_j}$
Consumption factor h for a unit of recycled product	$\widetilde{\gamma_h}$
The demand for the product p from the customer k.	$\widetilde{D_{pk}}$
The amount of raw material h in the product p	$\widetilde{B_{hp}}$
Importance (coefficient) of creating a job by the manufacturer i.	$\widetilde{W_i}$
The importance (coefficient) of creating a unit of work by the distributor m	$\widetilde{W_m}$
The importance (coefficient) of the creation of an employment opportunity unit by the recycling center l.	$\widetilde{W_l}$
The maximum supply capacity of the material h by the supplier z	$\widetilde{MZ_{zh}}$
The maximum distribution/ delivery from the distribution center m.	$\widetilde{MM_m}$
The pure time available for the production center i.	$\widetilde{MP_i}$
The pure time available for the recycling center l.	$\widetilde{ML_l}$
The pure time available for the disposal center j.	$\widetilde{MU_j}$
The return rate of the product p.	$\tilde{\epsilon}$
The number of employment opportunities created by the recycling of a product unit p at the recycling center l.	$\widetilde{G}_{lp}$
The number of employment opportunities created by the production of a product unit p at the production center i.	$\widetilde{E}_{ip}$
The number of employment opportunities created by the distribution of a product unit p at the distribution center m.	$\widetilde{F}_{mp}$
The final score of the principle component for the supplier z.	$\widetilde{PCDSS_z}$

B) The certain parameters

The certain parameters used in the mathematical model are given in Table 3.

Table 3. The certain parameters used in the model

Parameters	Symbol
Cycle of product p	O_p
Recycle time of the product p in the recycle center l.	N_{lp}
possibility degree of constraint	αf_f
Destruction time for destroyed product u	TT_u

3.6. Decision Variables

Decision variables are defined according to table 4.

Table 4. The Decision Variables used in the model

Decision variable	Symbol
If the production center i starts up 1, otherwise 0.	X_i
If the recycling center l starts up 1, otherwise 0.	Y_l
If the disposal center j starts up 1, otherwise 0.	Z_j
If the distribution center m starts up 1, otherwise 0.	H_m
The amount of raw material h sent from the z supplier to the production center i	QZ_{hzi}
The amount of raw material h sent from the lender to the collection / recycling center l	QL_{hzl}
The amount of product p sent from the production center i to the distributor m	QI_{imp}
The amount of product p sent from the m distributor to the market demand for k	QD_{mkp}
Quantity of p products sent from the k market to the l collection / recycling center	QK_{klp}
The amount of product p sent from the recycling center l to the distributor m	QR_{lmp}
The amount of disposable product u sent from the recycling center l to the destruction center j	QU_{lju}
Amount of recycled product at the recycling center l	QR_l
The amount of product produced by the product p in the i-th factory	Q_{ip}
The amount of product distributed from the product p in the m distribution center	Q_{mp}

3.7. Proposed Fuzzy model

In this section, the mathematical model is presented in two parts. The first part is the objective functions and the related explanations and the second part is the constraints and explanations of each one.

3.7.1. Objective Functions

$$Min\ Z_1 = \left[\sum_{i=1}^{I} FC_i . X_i + \sum_{m=1}^{M} FC_m . H_m + \sum_{l=1}^{L} FC_l Y_l + \sum_{j=1}^{J} FC_j . Z_j \right]$$

$$+ \left[\begin{array}{l} \sum_h \sum_z \sum_i QZ_{hzi} . T_{hzi} + \sum_i \sum_m \sum_p QI_{imp} . T_{imp} + \sum_m \sum_k \sum_p QD_{mkp} . T_{mkp} \\ \sum_k \sum_l \sum_p QK_{klp} . T_{klp} + \sum_l \sum_m \sum_p QR_{lmp} . T_{lmp} + \sum_l \sum_j \sum_u QU_{lju} . T_{lju} + \sum_h \sum_z \sum_l QL_{hzl} . T_{hzl} \end{array} \right]$$

$$+ \left[\sum_i \sum_m \sum_p QI_{imp} . V_{ip} + \sum_l OR_l . v_l \right]$$

$$+ \left[\sum_l \sum_j \sum_u QU_{lju} . DS_{ju} + \sum_h \sum_z \sum_l QL_{hzl} . CP_{hz} + \sum_h \sum_z \sum_i QZ_{hzi} . CP_{hz} \right]$$

(1)

$$Min\ Z_2 = \sum_j \sum_s \sum_u \sum_l \tilde{e}_j \left[B_{su} + QU_{lju} \right] \quad (2)$$

$$Max\ Z_3 = \left[\sum_i \sum_p W_i . Q_{ip} . E_{ip} + \sum_m \sum_p W_m . Q_{mp} . F_{mp} + \sum_l \sum_p W_l . QR_l . G_{lp} \right] \quad (3)$$

$$Max\ Z_4 = \sum_z PCDSS_z \left[\sum_h \sum_i \sum_l \left(QZ_{hzi} + QL_{hzl} \right) \right] \quad (4)$$

3.7.2. The Constraints of the Fuzzy Model

$$\sum_m QD_{mkp} \geq D_{pk} \qquad \forall k, p \quad (5)$$

$$\sum_k QD_{mkp} = \sum_i QI_{imp} + \sum_l QR_{lmp} \qquad \forall m, p$$

(6)

$$\sum_z QZ_{hzi} = \sum_p Q_{ip} . B_{hp} \qquad \forall i, p$$

(7)

$$\sum_l \sum_p QK_{klp} = \left(1 - \in \right) \sum_m \sum_p QD_{mkp} \qquad \forall k \quad (8)$$

$$\sum_j \sum_l QU_{lju} = \alpha_p \sum_k \sum_l QK_{klp} \qquad \forall p, u$$

(9)

$$\sum_m QR_{imp} = \left(1-\alpha_p\right)\sum_k QK_{klp} \qquad \forall l.p$$

(10)

$$\sum_m QI_{imp} = Q_{ip} \qquad \forall i,p$$

(11)

$$\sum_p Q_{ip}.Q_p \le MP_i.X_i \qquad \forall i$$

(12)

$$\sum_p \sum_k QD_{mkp} \le MM_m.H_m \qquad \forall m$$

(13)

$$\sum_i QZ_{hzi} \le MZ_{zh} \qquad \forall z,h$$

(14)

$$\sum_k \sum_p QK_{klp}.N_{lp} \le ML_l Y_l \qquad \forall l$$

(15)

$$\sum_l \sum_u QU_{lju}.TT_u \le MU_j.Z_j \qquad \forall j$$

(16)

$$\sum_k QK_{klp}.\gamma_h = \sum_z QL_{hzl} \qquad \forall l.p.h$$

(17)

$$\sum_k QD_{mkp} = Q_{mp} \qquad \forall m,p$$

(18)

$$\sum_m \sum_p QR_{lmp} = QR_l \qquad \forall l$$

(19)

$$X_i, Y_l, Z_j, H_m = 0 \text{ يا } 1$$

(20)

$$QD_{mkp}, QK_{klp}, Q_{ip}, QL_{hzi}, QZ_{hzi}, QI_{imp}, QU_{lju}, QR_l, QR_{lmp} \ge 0$$

(21)

Describe the purpose functions and constraints of them:

- Objective function (1): it is to minimize the fixed cost of establishment of production centers, distribution centers, recycling and destruction centers. In addition, it minimizes transportation costs of goods between centers, variable costs of productions, and the cost of destroying waste products in the closed- loop supply chain.
- Objective function (2): it minimizes the negative environmental effect from destroying waste products.
- Objective function (3): This objective function maximizes the employment generated in production, distribution, and recycling units. In this function, the objective of the first sentence is the first set of employment created by the production of all products in all production centers with the importance of creating jobs by each production center, as well as the second sentence of the employment series created by distributing all products in all distribution centers with the importance of creating jobs It is represented by each distribution center, as well as the third sentence of the employment series created by recycling all products in all recycling centers with the importance of creating jobs by each recycling center.
- Objective function (4): This objective function seeks to minimize the amount of deviation from the ideal value of the main component of the supply chain components. In this way, components are selected that have the maximum desirability for the entire supply chain.
- Constraint (5): This constraint guarantees that customer demands will be met. That is, in each period the amount of sending each product from the distribution centers to each market, is equal to the amount of customer demand of the product in question.
- Constraint (6): This constraint indicates that in each period the total amount of dispatch from the production centers to the distribution centers and the amount of product sent to the recycling center is equivalent to the amount of product sent from the distribution centers to the demand markets.
- Constraint (7): This constraint indicates that the total amount of raw materials sent to each producer from the side of all suppliers is equal to the product of each product produced by the consumption of the product from that particular raw material.
- Constraint (8): This constraint refers to the equilibrium relationship between the total amount of products sent from distribution centers to each demanded market and the sum of products sent from the same demand centers to recycling centers.

- Constraint (9): This constraint indicates that p α percent of products sent from demand markets to recycling centers are defective and should be destroyed, which is equal to the amount of disposable products sent from the collection centers to destruction centers.
- Constraint (10): This constraint indicates that (p α-1) percent of products sent from demand markets to recovery / collection centers can be recycled, and this amount is equal to the amount of products from recycling centers to distribution centers it is sent.
- Constraint (11): This constraint guarantees that the production of each production center from each specific product is equivalent to the total dispatch of that product from the same production center to all distribution centers.
- Constraint (12): This constraint ensures that, if a production center is activated, the production unit of that unit should not exceed the capacity of that production unit.
- Constraint (13): This constraint ensures that, if a distribution center is activated, the distribution of that distribution unit of that center should not be larger than its distribution capacity.
- Constraint (14): This constraint shows the supplier's capacity, in fact, this constraint ensures that the supply capacity of suppliers is not less than the total amount of raw materials sent to production centers.
- Constraint (15): This constraint ensures that if a recycling center is activated, the recycling rate of that recycling center should not be greater than the recycling capacity of that recycling center.
- Constraint (16): This constraint ensures that if the destruction center is activated, the destruction rate of that destruction center should not be the destruction capacity of that destruction facility.
- Constraint (17): This constraint refers to the relationship between the amount of primary material that should be purchased directly from suppliers and used in return products.
- Constraint (18): This constraint represents the amount sent from each product and each distribution center.
- Constraint (19): This limit represents the total amount of recycled products sent from each recycling center to all distribution centers.
- Constraint (20-21): These constraint define the type of decision variables.

Given the fact that some of the parameters and variables of the fuzzy model are of uncertainty, defuzzyfication is necessary to decompose this model in order to solve the model. The defuzzyficated model is presented in the next section.

3.8. The Defuzzified Mathematical Model

In this section, to approximate the certainty conditions in the uncertain fuzzy model, the proposed model was developed in the defuzzified format; the trapezoid fuzzy number X is defined as follows:

$$X = \left(X^a, X^b, X^c, X^d\right) \tag{22}$$

Also, the X (defuzzification) is defined as follows:

$$\overline{X} = \frac{X^a + X^b + X^c + X^d}{4} \tag{23}$$

3.8.1. Objective Functions Defined in Defuzzy Format

$$Min\ Z_1 = \left[\sum_{i=1}^{I}\overline{FC}_i.X_i + \sum_{m=1}^{M}\overline{FC}_m.H_m + \sum_{l=1}^{L}\overline{FC}_l Y_l + \sum_{j=1}^{J}\overline{FC}_j.Z_j\right]$$
$$+\left[\begin{array}{l}\sum_h\sum_z\sum_i QZ_{hzi}.\overline{T}_{hzi} + \sum_i\sum_m\sum_p QI_{imp}.\overline{T}_{imp} + \sum_m\sum_k\sum_p QD_{mkp}.\overline{T}_{mkp} \\ \sum_k\sum_l\sum_p QK_{klp}.\overline{T}_{klp} + \sum_l\sum_m\sum_p QR_{lmp}.\overline{T}_{lmp} + \sum_l\sum_j\sum_u QU_{lju}.\overline{T}_{lju} + \sum_h\sum_z\sum_l QL_{hzl}.\overline{T}_{hzl}\end{array}\right]$$
$$+\left[\sum_i\sum_m\sum_p QI_{imp}.\overline{V}_{ip} + \sum_l OR_l.\overline{V}_l\right]$$
$$+\left[\sum_l\sum_j\sum_u QU_{lju}.\overline{DS}_{ju} + \sum_h\sum_z\sum_l QL_{hzl}.\overline{CP}_{hz} + \sum_h\sum_z\sum_i QZ_{hzi}.\overline{CP}_{hz}\right]$$

(24)

$$Min\ Z_2 = \sum_j\sum_s\sum_u\sum_l \overline{e}_j\left[\overline{B}_{su} + \overline{QU}_{lju}\right] \tag{25}$$

$$Max\ Z_3 = \left[\sum_i\sum_p \overline{W}_i.Q_{ip}.E_{ip} + \sum_m\sum_p \overline{W}_m.Q_{mp}.F_{mp} + \sum_l\sum_p \overline{W}_l.QR_l.G_{lp}\right] \tag{26}$$

$$Max\ Z_4 = \sum_z \overline{PCDSS}_z\left[\sum_h\sum_i\sum_l\left(QZ_{hzi} + QL_{hzl}\right)\right] \tag{27}$$

3.8.2. Defuzzified Constraints

$$\sum_m QD_{mkp} \geq \left[(1-\alpha f_f).\left(\frac{D^a_{pk}+D^b_{pk}}{2}\right)+\alpha f_f \left(\frac{D^c_{pk}+D^d_{pk}}{2}\right)\right] \qquad \forall k,p$$

(28)

$$\sum_k QD_{mkp} = \sum_i QI_{imp} + \sum_l QR_{lmp} \qquad \forall m,p$$

(29)

$$\sum_z QZ_{zi} = \sum_p Q_{ip}.\left[(1-\alpha f_f).\left(\frac{B^a_{hp}+B^b_{hp}}{2}\right)+\alpha f_f.\left(\frac{B^c_{hp}+B^d_{hp}}{2}\right)\right] \qquad \forall i,h$$

(30)

$$\sum_l\sum_p QK_{klp} = \left[(1-\alpha f_f).\left(\frac{(1-\in^a)+(1-\in^b)}{2}\right)+\alpha f_f.\left(\frac{(1-\in^c)+(1-\in^d)}{2}\right)\right].\sum_m\sum_p QD_{mkp} \qquad \forall k$$

(31)

$$\sum_l\sum_j QU_{lju} = \left[(1-\alpha f_f).\left(\frac{\alpha^a_p+\alpha^b_p}{2}\right)+\alpha f_f.\left(\frac{\alpha^c_p+\alpha^d_p}{2}\right)\right]\sum_k\sum_l QK_{klp} \qquad \forall p,u$$

(32)

$$\sum_m QR_{lmp} = \left[(1-\alpha f_f).\left(\frac{(1-\alpha^a_p)+(1-\alpha^b_p)}{2}\right)+\alpha f_f.\left(\frac{(1-\alpha^c_p)+(1-\alpha^d_p)}{2}\right)\right].\sum_k QK_{klp} \qquad \forall l,p$$

(33)

$$\sum_m QI_{imp} = Q_{ip} \qquad \forall i,p$$

(34)

$$\sum_i QZ_{hzi} = \left[(\alpha f_f).\left(\frac{MZ^a_{zh}+MZ^b_{zh}}{2}\right)+(1-\alpha f_f).\left(\frac{MZ^c_{zh}+MZ^d_{zh}}{2}\right)\right] \qquad \forall z,i$$

(35)

$$\sum_p Q_{ip}.O_p = \left[(\alpha f_f).\left(\frac{MP^a_i+MP^d_i}{2}\right)+(1-\alpha f_f).\left(\frac{MP^c_i+MP^d_i}{2}\right)\right].X_i \qquad \forall i$$

(36)

$$\sum_p\sum_k QD_{mkp} = \left[(\alpha f_f).\left(\frac{MM^a_m+MM^b_m}{2}\right)+(1-\alpha f_f).\left(\frac{MM^c_m+MM^d_m}{2}\right)\right].H_m \qquad \forall i,h$$

(37)

$$\sum_k \sum_p QK_{klp}.N_{lp} = \left[(\alpha f_f).\left(\frac{ML_l^a + ML_l^b}{2}\right) + (1-\alpha f_f).\left(\frac{ML_l^c + ML_l^d}{2}\right) \right] Y_l \qquad \forall l$$

(38)

$$\sum_l \sum_u QU_{lju}.TT_u = \left[(\alpha f_f).\left(\frac{MJ_j^a + MJ_j^b}{2}\right) + (1-\alpha f_f).\left(\frac{MJ_j^c + MJ_j^d}{2}\right) \right].Z_j \qquad \forall j$$

(39)

$$\sum_k QL_{hzl} = \left[(1-\alpha f_f).\left(\frac{\gamma_{hp}^a + \gamma_{hp}^b}{2}\right) + (\alpha f_f).\left(\frac{\gamma_{hp}^c + \gamma_{hp}^d}{2}\right) \right].\sum_k QK_{klp} \qquad \forall l, p, h$$

(40)

$$\sum_k QD_{mkp} = Q_{mp} \qquad \forall m, p$$

(41)

$$\sum_m \sum_p QR_{lmp} = QR_l \qquad \forall l$$

(42)

$$X_i, Y_l, Z_J, H_m = 01 \qquad (43)$$

$$QD_{mkp}, QK_{klp}, Q_{ip}, QZ_{hzi}, QI_{imp}, QU_{lju}, QR_l, QR_{lmp}, QL_{hzl} \geq 0$$

(44)

4. Introduction of principal component analysis method and Fuzzy PCA

As previously mentioned, in this study, the main goal is design of a supply chain network which components is desirable for all of the criteria considered. One of the ways of selecting a supplier based on the criteria is the use of methods based on statistical analysis techniques. Lam et al Introduced one of these techniques into the supply chain management issues, they selected the best supplier by using the analysis of the main fuzzy components, after separating the selection criteria for the suppliers. In the analysis of principal components, Pearson was first used to reduce the dimensions of the problem. He stated that in analyzing the main components of the goal, the goal is to obtain a new index based on existing indicators. The advantage of this method is, in addition to uncompromising data, reducing the dimensions of the problem without losing a lot of information. Generally, in this method, we seek to maximize the linear combination of variables from the initial variables [21]. In this way, the initial data is converted into a new set called the principal component (which is relatively independent). The primary component of the PCA is a linear combination of primary variables, with the most variance of the total variance of all the initial variables. The second component is a linear combination of primary variables that, after the first component, contains the most variance of the total variance of all the initial variables. Similarly, if we have p initial variables, we can obtain the main component that contains the variance of the initial variables (Equation (45)). The variance of new variables has a bearish trend.

$$\begin{aligned} \xi_1 &= w_{11}x_1 + w_{12}x_2 + \dots + w_{1p}x_p \\ \xi_2 &= w_{21}x_1 + w_{22}x_2 + \dots + w_{2p}x_p \\ &\vdots \\ \xi_p &= w_{p1}x_1 + w_{p2}x_2 + \dots + w_{pp}x_p \end{aligned} \quad (45)$$

In (45), ξ1, ξ2… ξp denotes p the main component and wij is the weight of the jth primary variable in i newest component. If the initial data is fuzzy, FPGA can be used to achieve these goals. Sarbo and Pope [22] proved that they generally have better PCA results in FPCA fuzzy environments.

In order to collectively determine the components of the supply chain, an owner initially introduced as the main component of the main component of the intuition, which in turn takes into account all the important criteria simultaneously. In other words, the facilities that have the best score of the main component, are also the best in terms of all selected criteria. Since the values of different and criteria are considered as fuzzy, the principal component analysis is also performed in fuzzy mode. The method of analyzing the main fuzzy components used in this paper is based on the method of Alem et al, Yaboch and Watada (23). Bashiri and Hejazi [24] have also been used to determine the direction of the extracted component. Suppose that for choosing suppliers, criteria such as total cost, quality, service, past performance, credibility, ability, and relationships with other chain facilities and ... are for decision-making, of course, these criteria are correlated with each other. By analyzing the main components, while reducing the dimensions of the criteria, new criteria are independently identified. This is done for the supplier only, and ultimately it is decided in the form of the fourth objective function. Given the fuzzy assumption of the environment, there will be a matrix of different criteria and supply chain components that will be the score of each chain component in each criterion with the degree of a given membership. On the other hand, the initial input data is used to compute the principal components of the variance-covariance matrix, so in this case, the matrix must be extracted from the fuzzy data. To this end, the proposed relations in the paper Iaboch and Vatada (relations 48-46) have been used to calculate the fuzzy variance-covariance matrix.

$$N = \sum_{m=1}^{n} \mu_A(m) \tag{46}$$

$$X_i = \frac{1}{N} \sum_{m=1}^{n} X_{im} . \mu_A(m) \tag{47}$$

$$S_{ij} = \sum_{m=1} \left(X_{im} - X_i \right) . \left(X_{jm} - X_i \right) . \mu_A(m) \tag{48}$$

In relation (46-48) *m* represents the producer, *i* and *j*, are the criteria. Also, $X_{im}, \mu_A(m), X_i$, S_{ij} represent the membership degree of each producer, its score in accordance with the criterion *m*, the fuzzy average and variance.

After the variance-covariance matrix is extracted, the special value and the special vector, and the linear combinations of the principle components are obtained accordingly. using the special vector and the scree plot, the number of needed principle components is determined. Afterwards, the average score of each principle component (*PC*) is calculated via the vector multiplication of the special value by the initial values of each supplier. The way these score are obtained are presented in the numerical example section in more details. As the coefficients obtained for each relation of the principle components can be different, the direction of the extracted components is unknown and thus should be appropriately determined. For this reason, in this study, Bashiry and Hejazi is used to determine the direction of the extracted components. The *T*, PCS^*, *PCDSM* values are specified using the relations (49-51).

$$PCS^* = Engen \text{ value} \times \max\left(criteria \text{ score}\right) \tag{49}$$

$$T_i = \left| PCS_i - PCS^* \right| \tag{50}$$

$$PCDSS_z = \sum_i \text{var}_i \times T_i \tag{51}$$

The criterion is the max (criterion score) for each criterion, multiplied by special values, to the component of the main component of the best condition (PCS *). Subsequently, for each member of the chain, the value of the principal component score deviation is calculated with PSC * and is considered as the deviation for the desired component (Ti). Relationship (51) calculates the ultimate rational deviation of all components for each member of the supply chain. In relation (49-51) we mean i and m are the producer.

5. The Lexicographic Method

This method requires the decision maker to rank the objectives in sequence. The preferable solution used in this method is to maximize the objectives and start with the most important objective and proceed along the pre-specified order of objectives. Let's assume that the objective index not only determines the vector components *f(x)* but also prioritizes the objectives. In other words, $f_1(x)$ is the first component of *f(x)* and is the most important objective. $f_2(x)$ is the second component of *f(x)* and the next important objective. Therefore, the problem to be solved is as follows:

$$\begin{aligned} &Max\ \ \mathrm{f}_1(x) \\ &\mathrm{St:}\ \mathrm{g}_i(x) \le 0 \\ &\mathrm{j=1,...,m} \end{aligned} \tag{52}$$

Let's assume that f_1^* is the solution resulted from (52). If (52) gives a unique x^* for f_1^*, then this solution is preferred for the entire problem. Otherwise, the second problem to be solved takes the following form. (53).

$$\begin{aligned} &Max\ \ \mathrm{f}_2(x) \\ &St:\ \mathrm{g}_i(x) \le 0 \\ &f_1(x) = f_1^* \\ &j = 1,\ldots,m \end{aligned} \tag{53}$$

Let's assume f_2^* is the solution derived from 53. If 53 gives a unique x* for f_2^*, then this solution is preferred for the entire problem. Otherwise, the process is repeated in the same order until the *k* objectives are included. In general, the *i* th problem is in the form of relation (54).

$$\begin{aligned} &Max\ \ \mathrm{f}_i(x) \\ &\mathrm{St:}\ \mathrm{g}_j(x) \le 0 \\ &f_L(x) = f_L^* \\ &j = 1,\ldots,m \qquad \mathrm{L=1,...,i-1} \end{aligned} \tag{54}$$

According to the problem-solving process is terminated at the time of obtaining a solution to the i-th issue, and this solution is considered as the preferred solution for the whole problem, hence the method neglects the goals which have less importance than f1(x). The logic of this method is that people tend to decide in the same way. The method presented by waltz reduces this sensitivity. After the first goal is maximized, the second goal will be maximized, provided that the first goal is maintained at about the net percentage of its optimality. In the following, the third objective with maintenance of the two previous goals at a certain percentage of their optimal values obtained in the previous steps. Therefore, i-th issue is as follow:

$$Max \ f_i(x)$$

$$\text{St: } g_i(x) \leq 0$$

$$f_L(x) = f_L^* - \sigma_L$$

$$j = 1, \ldots, m \qquad L=1,\ldots,i-1 \tag{55}$$

In the above relation, σL is the tolerance determined by the decision maker. Therefore, the sensitivity of the resulting solution to the ranking of objectives is reduced.

6. Numerical example

In this section, a problem with the battery industry has been studied, with three supplier centers, three production centers, four distribution centers, six sales centers (demand market), two recycling centers and two destruction facilities (according to Figure 2.). In this case, suppliers and demand markets were assumed to be stable and open. The goal of this solution is to decide on the openness and closure of each production center, distribution center, recycling centers and destruction centers, as well as the capacity of each production center and the flow of products between the network facilities. The introduction of the collections presented on this issue is as follows:

$i = \{i_1, i_2, i_3\}$ $m = \{m_1, m_2, m_3, m_4\}$ $k = \{k_1, k_2, k_3, k_4, k_5, k_6\}$ $z = \{z_1, z_2, z_3\}$

$l = \{l_1, l_2\}$ $j = \{j_1, j_2\}$ $h = \{h_1, h_2\}$ $u = \{u_1, u_2\}$ $p = \{p_1, p_2\}$ $s = \{s_1, s_2\}$

Figure 2. Possibilities for establishment of facilities

6.1. Solving Issue

In this section, first, using the principal component analysis method, the values of the parameter are the final component of the main component for the z provider that is used in the fourth objective function, then the applied problem introduced in the form of the proposed mathematical model, Using the Lexicon graph method, the results have been analyzed.

Step 1: First, using the proposed method, the values of the parameter of the final score of the main component for the z supplier have been obtained. To select the supplier, 10 criteria are relevant, including price appropriateness, price stability, quality of materials, timely delivery, ability, flexibility, reliability, reliability, collaboration with other parts of the supply chain and warranties. Then, using the MINITAB software, enter the values of the criteria and obtain the correlation coefficients between the criteria. Using the relationships (48) to (46) of the variance-covariance matrix, special values and special vector are obtained using MATLAB software, and the linear combinations of the main components are written. After the above steps, the special values for suppliers are obtained as shown in Table 5.

Table 5. The special values for suppliers

Variance	Special Value	PC
0.9177	0.4266	Pc8
0.9211	1.6877	Pc9
0.8354	7.8855	Pc10

The analysis of the principal component analysis reduces the number of variables by eliminating the small amount of special values. In other words, if you do not want to delete a part of the special value, you cannot reduce the number of variables, but the method used will exclude components that have a smaller share of the data values. As it is seen in Table 5, there are two main components, because it contains 96% of the data. In previous studies, such as reference (Lam et al.), The number of components is reduced by ignoring part of the total variance of the data. Now we have to put the initial values of suppliers in formula (49) to get the values of pc1 and pc2. After calculating the value of the score of each of the main components and the matrix of scores of the supplier's criteria, the difference is calculated with the maximum value of the main component based on relation (50). For example, the numeric values are given, pc and t values in table 6 are significant.

Table 6. pc and t values

Provider	Pc9	T9	Pc10	T10	PCDSS
Z_1	8.3905	0	16.6438	24.9657	21.32071
Z_2	6.7124	1.6781	33.2876	8.3219	8.508787
Z_3	5.0343	3.3562	41.6095	0	2.803769

To obtain the final score of the main component of each supplier, (the last column of Table 6), relation (51) can be used. These results indicate the importance of using the main components analysis in supply chain design issues. They are chosen by making data independent, which is also optimal in terms of overall cost-effectiveness, but also qualitatively important for managers and customers. Step 2: At this stage, using the Lexicograph, the proposed model is solved using Gomez software. In lexicograph method first, goals are prioritized, hence the first priority is related to costs, the second priority is suppliers, the third priority is employment and the final priority is environmental effects. After identifying the priorities, the first priority in our model is minimizing costs as a target function in the model and by using the Gomez software. The obtained answer is the best possible answer for our first objective function. The second priority is to minimize the amount of a deviation from the ideal value point of the main component of the supply chain components as the target function and put the first objective function into constraints, which, it will be obtained after solving the optimal answer for the second objective function. It also solves other target functions in the same way. The optimal results obtained for the problems with various coefficients are given in Table 7.

Table 7. Solving a numerical example with priority f2, f3, f4, f1 for different fuzzy coefficients

coefficient	The optimal values of the objective function			
	f 1	f 2	f 3	f 4
0.3	4512637.013	289553.689	107174.762	454.973
0.6	4807667.298	306666.532	108975.262	454.973
0.9	4621310.328	324270.654	108189.762	454.973
0.12	4779133.027	342366.054	110360.262	454.973
0.15	5735543.693	360952.731	111242.806	454.973
0.18	4867507.791	380030.687	108332.435	454.973
0.21	5594584.325	399599.920	111959.937	454.973

0.24	5685792.244	419660.430	105511.045	454.973
0.27	6544476.786	440212.220	103798.058	454.973
0.3	5668768.601	461255.287	101883.549	454.973

Finally, based on the opinions and decisions of the experts, the answer to the problem for the coefficient (12, 0) was chosen as the optimal answer to the final question. Also, the active / inactive status of the supply chain centers is given in Table 2. It should be explained that in this table, the number 1 means that the center is active and 0 indicates the inactivity of the centers. In Figure 3, the position of facilities Active has been displayed.

Table 8. Active status and non-activation of supply chain centers

Production center			distribution center				recycling center		disposal center	
i1	i2	i3	m1	m2	m3	m4	l1	l2	j1	j2
1	0	0	0	1	0	0	1	0	1	0

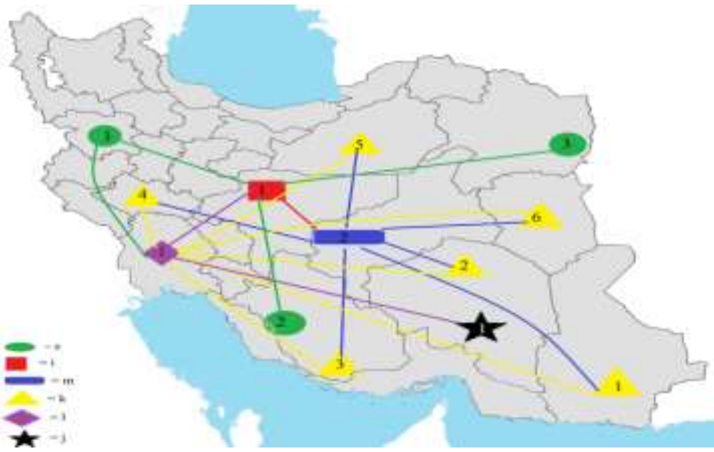

Figure 3. Facility location in optimal conditions

7. Analyze the results of solving the model

In this section, first, using the main components analysis method, we minimized the correlation between the criteria by choosing non-correlated criteria and the final score of the main component, and then using the Lexicon graph for the proposed model of priority We select the form (f1-f4-f3-f2) and solve it in Gom software and obtain the optimal answers. The solution results for different priorities in the objectives show that the objective functions of the model are with each other in Controversy, finally, according to experts, one of the optimal solution of the problem (for the first priority) as the final optimal answer to the problem. We chose. In response, selected from three manufacturing centers, an open center (center 1) and from four distribution centers, an open center (center number 2), as well as from two recycling centers, a recycling center (center number 1) and a facility for destruction, one The destruction facility (center number 1) is open, as well as the optimal amount of material flow between the designated centers. Finally, based on the answers given to the problem, it was clear that all goals were in contact with each other while the objective of the first, second and fourth objectives was decreasing and the third objective function was incremental and the optimal answer for the coefficient of 0.12 was determined by the experts selected.

8. Conclusion and future works

The design of the supply chain network is one of the strategic level decisions of supply chain management issues. Today, researchers focus on sustainable supply chain. Also, based on sustainable concepts and development, it is not sufficient that owner of companies only focus on profitable issues and do not consider the environmental and social effect of their industry. In this regard, in this paper, a mathematical model for multi-level and multi-product closed-loop supply chain are presented for battery industry under uncertainty conditions with considering correlation between criterion of selection of suppliers. Proposed model is able to locate the proper place of facilities. Moreover, flow of materials between different levels of supply chain. Lexicography method is used to solve the proposed model.

In order to develop and improve the proposed model, it is suggested that future models are developed in a multi-cyclic manner, taking into account the time value of money. It is also suggested that the proposed model be modeled with consideration of risk and supply chain impairment. Finally, due to the complexity of the proposed model, it is recommended to use large-scale methods to solve the model in large dimensions.

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