Optimization of Supply Chain Network Perspective Environmental Impact based on Fuzzy Mathematical Programming

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Abstract

Supply chain management (SCM) is concerned with a complex business relations network that contains interrelationships between various entities, such as suppliers, manufacturers, distribution centers and customers. SCM integrates these entities and manages their interrelationships through the use of information technology to meet customer expectation effectively along the entire value chain. Thus, one of the vital issues in supply chain management is the design of the value chain network.In this paper, a multi objective fuzzy mathematical programming model is developed to optimize the supply chain networking under inherent uncertainty of input data. The proposed model is able to optimize the environmental impacts beside the traditional cost minimization objective to make a fair balance between them. The model determines the fuzzy capacities of the facilities and the design of the network con?guration with a minimum total cost. A real case is used to demonstrate the significance and applicability of the developed fuzzy optimization model as well as the usefulness of the proposed solution approach. The developed model is solved by a professional software package (LINDO), and the computational results are discussed.

Index terms— optimization, fuzzy, supply chain network design, environmental impact and model formulation.

supply chain. In general, supply chain network design includes determining the locations, numbers and capacities of network facilities and the aggregate material flow between them. Since the end-of-life (EOL) products have significant impact on environment, a considerable part of literature is dedicated to EOL product management. This has created a need to develop models for reverse supply chain (logistics) network design. Reverse supply chain network design problem addresses the number of collection, recovery, recycling and disposal centers needed, their location and capacities and material flows between them.

In the last several years, many studies have been proposed and much research has been performed on the design and optimization of supply chain networks. In one study, Pirkul and Jayaram an [1] studied a multi-commodity, multi-plant, capacitated facility location problem and proposed an efficient heuristic solution to the problem. In the capacitated plant and warehouse location model, customers typically demand multiple units of different products that are distributed to customer outlets from open warehouses that receive these products from several manufacturing plants. The objective function of the model minimizes the sum of the fixed cost of establishing and operating the plants and the warehouses plus the variable cost of transporting units of products from the plants to the warehouses and distributing the products from the warehouses to the customer, to satisfy the multiple demands of the customers. Recently Ilgin and Gupta et al. [2] present a comprehensive review on environmentally conscious manufacturing and product recovery; below we have surveyed some relevant papers on environmental supply chain network design. Timpe and Kallrath [3] considered a multi-site, multi-product production network and presented a general mixed integer linear programming model that combines aspects related to production, distribution and marketing and involves production sites (plants) and sales points. Cakra vastia et al. [4] developed an analytical model of the supplier selection process in designing a supply chain network. The constraints on the capacity of each potential supplier are considered in the process. The objective of the supply chain is to minimize the level of customer Optimization of Supply Chain Network Perspective Environmental Impact based on Fuzzy Mathematical Programming Subrata Talapatra ? & Md. Shakil ? dissatisfaction, which is evaluated by two performance

1 I. Introduction

well-structured supply chain is an important strategic competency that enables firms to be competitive in today's marketplace. Along this important issue, the concern about environmental impact of business activities results in governmental legislations and environmentally conscious consumers. Environmental or green supply chain management can be defined as integrating environmental aspects into supply chain management covering both forward and reverse supply chains from product design to end-of-life management of used products. The ultimate goal is to consider environment in every decision making process across supply chain, especially the strategic level decisions. Supply chain optimization can help define, recommend, and set flexible supply chain strategies based on organization's operations, resources, and other capabilities. Optimization of supply chain network design, as the most important strategic decision in supply chain management, plays an important role in overall environmental and economic performance of the A criteria: (i) price and (ii) delivery lead time. The overall model operates at two levels of decision making: the operational level and the chain level. The operational level concerns decisions related to optimizing the manufacturing and logistical activities of each potential supplier, to meet the customer's requirements. At the chain level, all of the bids from potential suppliers are evaluated, and the final configuration of the supply chain is determined. The structure of the chain de pends on the product speci fic ations and on the customer's order size. An optimal solution in terms of the models for the two levels can be obtained using a mixed -integer programming technique [4,5] presented a multi-phase mathematical programming approach for effective supply chain design. Syarif et al. [6] considered the logistic chain network problem formulate d by the 0-1 mixed integer linear programming problem. The design of the problem involves the choice of the facilities (plants and distribution center s) to be opened and the distribution network de sign, with the goal of satisfying the demand with minimum cost. For the solution method, the spanning tree-based genetic algorithm using Pr?fer number representation is proposed. Sanayeia et al. [7] proposed an integrated approach of multi-attribute utility theory (MAUT) and linear programming (LP) for rating and choosing the best suppliers and defining the optimum order quantities among selected ones in order to maximize total additive utility. Javadi et al. [8] developed a fuzzy multi-objective linear programming (FMOLP) model for solving the multi-objective no-wait flow shop scheduling problem in a fuzzy environment. The proposed model attempted to simultaneously minimize the weighted mean completion time and the weigh ted mean earliness. A numerical example demonstrated the feasibility of applying the proposed model to no-wait flow shop scheduling problem. The proposed model yielded a compromised solution and the decision maker's overall levels of satisfaction.

To overcome the literature gap, this paper proposes a practical, but tractable, multi-objective fuzzy mathematical programming model for optimization of supply chain networking perspective environmental impact problem that is able to (1) consider both economic and environmental objectives in the design of the supply chain network, (2) integrate the design of reverse and forward supply chain networks to avoid the sub-optimality's results from separated design of forward and reverse supply chains, (3) The model allows decision-makers to design the network configuration with the minimum total cost. (4) Handle the epistemic uncertainty in parameters in real cases results from unavailability or incompleteness and imprecise nature of input data. Also, this paper proposes an efficient solution approach that is able to generate both balanced and unbalanced solutions through making a reasonable tradeoff between environmental and economic objectives.

This paper is organized into eight sections. After the introduction, in which some supply chain models are described, the remainder of the paper is structured as follows. In Section 2, problem statement of the proposed supply chain network is introduced. This model is formulated in section 3 and developed an equivalent auxiliary crisp model in section 5. Implementation and evaluation of this proposed model is described in section 6, and section 7 represents the results and discussion. Conclusions are presented in Section 8. As well as finally appendix and references are attached.

2 II. Problem Statement

The concerned integrated supply chain network in this paper is motivated by a real industrial case. The case is a supply chain network of Coca-Cola drinks in Bangladesh that supplies about 80% of domestic demand. The manufacturer has one production plant with about 600 thousand production capacity per one year. In transportation system of supply chain networking consists of environmental impact like, carbon di oxide (co 2) that is responsible for the environmental disasters. To overcome this problem proposed a multi-echelon supply chain network that includes both forward and reverse networks is illustrated in Fig. 1. Through forward network the new products manufactured by plants (production centers) are distributed among customer zones. In the reverse network, the used products are shipped to recycling centers through collection/disassembly centers. All demands of customers must be satisfied and all of the returned products from customers must be collected.

Also, a predefined percent of demand from each customer is assumed as returned products from corresponding customer. Unavailability or incompleteness of data in real world network optimization problems is an important challenge that imposes a high degree of uncertainty in such problem. The problem is concerned with the uncertain parameters are presented by fuzzy numbers described by their possibility distribution. The possibility distributions are estimated based on current insufficient data and the decision makers' knowledge. The main objective of this integrated supply chain under uncertain conditionincludes the material flow quantities between different facilities with respect to two conflicting objective functions: (1) minimization of total cost and (2) minimization of total environmental impact. ?? =index of candidate location for production centers, i=1, 2, 3, 4??.i j=index of fixed location of customer zones, j=1, 2, 3, 4??.j k=index of candidate location for collection centers, k=1, 2, 3, 4??.k l=index of existing glass recycling centers, l=1, 2, 3, 4??.l m=index of existing plastic recycling centers, m=1, 2, 3, 4??.m b) Parameters ?? ?? = demand of customer zone, j ?? ?? = rate of return percentage from customer zones, j ð ??"ð ??" ?? = fixed cost of opening production centers, i ð ??"ð ??" ?? = fixed cost of opening collection centers, k ?? ???? = transportation cost per product unit from plant, i to customer zones, j ?? ???? = transportation cost of per used product unit from customer zone, j to collection center, k ?? ???? = transportation cost of per glass part of used product unit from collection center, k to glass recycling center, l ? ???? = transportation cost of per plastic part of used product unit from collection center, k to plastic recycling center, m ?? ?? = manufacturing cost per unit of product at production center, i ?? ?? = processing cost for per unit of used product at collection center, k ?? ?? = processing cost for per glass part of used product unit at glass recycling center, l ?? ?? = processing cost for per plastic part of used product unit at plastic recycling center, m ?? ?? = maximum capacity of production center, i ?? ?? = maximum capacity of collection center, k ?? ?? = maximum capacity of glass recycling center, l ?? ?? = maximum capacity of plastic recycling center, m ???? ?????? = Environmental impact per production of one unit of product ?? ???? ?????? = environmental impact of shipping one unit of product from plant, i to customer zone, j ?? ???? ?????? = environmental impact of shipping one unit of used product from customer zone, j to collection center, k ?? ???? ?????? = environmental impact of shipping glass part of used product unit from collection center, k to glass recycling center, l ?? ???? ?????? = environmental impact of shipping plastic part of used product unit from collection center, k to plastic recycling center, m ???? ?????? = environmental impact per handling one unit of collected used product at collection centers ???? ?????? = environmental impact of recycling the glass part of one unit of used product ???? ?????? = environmental impact of recycling the plastic part of one unit of used product c) Variables ?? ???? = quantity of product shipped from plant, i to customer zone, j ?? ???? = quantity of used product shipped customer zone, j to collection center, k ?? ???? =+ ? ? (?? ?? + ?? ????)?? ???? ?? ?? + ? ? (?? ?? + ?? ????)?? ???? ?? ?? + ? ? (?? ?? + ?? ????)?? ???? ?? ?? + ? ? (?? ?? + ? ?? ??)?? ???? ?? ??

Here transportation costs between facilities are calculated by multiplying the transportation cost of one unit shipping per unit of distance.

For the second objective: minimizing the total environmental impact

The purpose of this supply chain network is to fulfill the customer demand by producing and distributing the product at forward network and the safe management of product by reverse network.

The purpose of using ECO-indicator is to estimate the environmental impact of different supply chain network configurations. Following ECO-indicators are considered for this supply chain network design.

? The production (pro)

? Transportation from production centers to customer zone (tpc)

? Transportation from customer zone to collection centers (tcc)

? Handling the used product at collection centers(col) ? Transportation from collection to glass recycling centers (tcs) ? Glass recycling center (src)

? Transportation from collection centers to plastic recycling centers (tcp)? Plastic recycling centers (src) Min w 2 = ? ? (???? ?????? + ???? ???? ??????)?? ???? ?? ?? + ? ? (???? ?????? + ???? ???? ??????)?? ???? ?? ?? + ? ? (???? ?????? + ???? ???? ??????)?? ???? ?? ?? + ? ? (???? ?????? + ???? ???? ??????)?? ???? ?? ??

3 IV. Constraints

4 Demand and return satisfaction constraints

Here following constraints (3) and (4) ensure the demands of all customers are satisfied and the entire used products are collected from the customer zones.? ?? ???? ?? ? ?? ??**(3)**? ?? ???? ?? ? ?? ?? ?? ??**(4)**

a) Flow Balance Constraints

Here constraints (**??**) and (**??**) ensure the flow balance at collection centers. Two EOL options are considered in the proposed model, the collected used product should be sent to glass and plastic recycling centers. Therefore the total number of plastic and glass parts should be equal to recycling centers because they are disassembled from one used product.? ?? ???? ?? ? ? ?? ???? ?? (5) ? ?? ???? ?? ? ? ?? ???? ?? (6) ? ?? ???? ?? ? ?? ?? ?? ?? (8) ? ?? ???? ?? ? ?? ??**(9)**

? ?? ???? ?? ? ?? ?? (10) Here constraints (8) to (10) are capacity constraints on production, collection and glass recycling and plastic recycling centers respectively. Also constraints (7) and (**??**) prohibit the units of new and used products from being transferred to production and collection centers which are not opened respectively.

5 Decision variables constraints

The following constraints are related to the binary and non-negatively restrictions on the corresponding decision variables. ?? ?? , ?? ?? Ñ?”{0,1}**(11)**

V. Proposed Method This is a multi-objective probabilistic mixed integer programming model. To solve this model a two phase approach is proposed one is the method of Jimenez to convert the proposed model and the second Second objective function: minimization of total environmental impact First objective Function: minimization of total cost VI. Equivalent Auxiliary Crisp Model Jimenez et al. [9] method is selected to develop this equivalent auxiliary crisp model as well as this triangular, trapezoidal and nonlinear ones in both symmetric and asymmetric functions. This method also computational efficient to solve fuzzy linear problems as it can preserve its linearity and do not increase the number of objective functions and inequality constraints. The detail of this method is given in Appendix.

Equivalent auxiliary crisp model can be formulated as follows:minw 1 = ? (ð ??”ð ??” ?? ?????? +2ð ??”ð ??” ?? ?????? +ð ??”ð ??” ?? ?????? 4)?? ?? ?? + ? (ð ??”ð ??” ?? ?????? +2ð ??”ð ??” ?? ?????? +ð ??”ð ??” ?? ?????? 4)?? ?? ?? + ? ? (?? ?? ?????? +2?? ?? ?????? +?? ?? ?????? +?? ???? ?????? +2?? ???? ?????? +?? ???? ?????? 4) ?? ?? ?? ???? + ? ? (?? ?? ?????? +2?? ?? ?????? +?? ?? ?????? +?? ???? ?????? +2?? ???? ?????? +?? ???? ?????? 4) ?? ?? ?? ???? + ? ? (?? ?? ?????? +2?? ?? ?????? +?? ?? ?????? +?? ???? ?????? +2?? ???? ?????? +?? ???? ?????? 4) ?? ?? ?? ???? + ? ? (?? ?? ?????? +2?? ?? ?????? +?? ?? ?????? +? ???? ?????? +2? ???? ?????? +? ???? ?????? 4) ?? ?? ?? ???? minw 2 = ? ? ????? ?????? + ???? ???? ?????? ??? ???? ?? ?? + ? ? ????? ?????? + ???? ???? ?????? ??? ???? ?? ?? + ? ? (???? ?????? + ???? ???? ??????)?? ???? ?? ?? + ? ? ????? ?????? + ???? ???? ?????? ??? ???? ?? ?? Subject to, ? ?? ???? ?? ? ? (?? ?? ?????? +?? ?? ?????? 2) + (1-?)(?? ?? ?????? +?? ?? ?????? 2) ? ?? ???? ?? ? ??? ? ?? ?? ?????? +?? ?? ?????? 2 ? + (1 ? ??)(?? ?? ?????? +?? ?? ?????? 2)? ??? ? ?? ?? ?????? +?? ?? ?????? 2 ? + (1 ? ??)(?? ?? ?????? +?? ?? ?????? 2)? ? ?? ???? ?? = ? ?? ???? ?? ? ?? ???? ?? = ? ?? ???? ?? ? ?? ???? ?? ??? ?? ??? ? ?? ?? ?????? +?? ?? ?????? 2 ? + (1 ? ??)(?? ?? ?????? +?? ?? ?????? 2)? ? ?? ???? ?? ??? ?? ??? ? ?? ?? ?????? +?? ?? ?????? 2 ? + (1 ? ??)(?? ?? ?????? +?? ?? ?????? 2)? ? ?? ???? ?? ???? ? ?? ?? ?????? +?? ?? ?????? 2 ? + (1 ? ??)(?? ?? ?????? +?? ?? ?????? 2)? ? ?? ???? ?? ???? ? ?? ?? ?????? +?? ?? ?????? 2 ? + (1 ? ??)(?? ?? ?????? +?? ?? ?????? 2)? ?? ?? , ?? ?? Ñ?”{0,1}

?? ???? , ?? ???? , ?? ???? , ?? ???? ? 0

6 VII. Implementation and Evaluation

The validity of the developed model as well as the usefulness of the proposed solution method is investigated via the data withdrawn from the case study. The manufacturer firm has nine customer zones. The firm is responsible to collect the used product from domestic customers therefore the return rate from the foreign customer is considered equal to zero. To estimate the possibility of distribution parameters first objective data is gathered and the firm managers determined three prominent values (most likely, most pessimistic and most optimistic) of triangular fuzzy numbers according to available data. The fuzzy data for demand and rate of return each customer is represented in table: 1 for the over three years.

7 VIII. Results and Discussion

Firm supplies products from different production centers to customer's zone as well as shipped using transportation by trucks. Products manufactured in production centers are directly dispatched to customer zone, and the manufacturer has to pay transportation costs. The firm assigns trucks with respect to the capacities of truck options and transports the products from the production center to the customer zone.

Table 4. presents the transportation cost form production center to customer zone; here trucks are used to transport the products. Table 10. Represents the transportation cost of product from collection center to plastic recycling center by using trucks in reverse supply chain networking. Table 12. Represents the environmental impact of shipping product from production center to customer zone, here environmental impact means the amount of carbon di oxide (CO_2) obtained from the trucks during transportation. Environmental impact per production of one unit of product, ???? ?????? =42 ? ?(???? ?????? + ?? ???? ??????) = 6155 ?? ?? Table 13. Represents the environmental impact of shipping one unit of product from customer zone to collection center, here environmental impact means the amount of carbon di oxide (CO_2) obtained from the trucks during transportation. Environmental impact of handling one unit of collected used product at collection center, ???? ?????? =32 ? ?(???? ?????? + ?? ???? ??????) = 5416 ?? ?? Table 14. Represents the environmental impact of shipping glass part from collection center to glass recycling center, here environmental impact means the amount of carbon di oxide (CO_2) obtained from the trucks during transportation. Environmental impact of recycling one unit of glass part, ???? ?????? =40 ? ?(???? ?????? + ?? ???? ??????) = 3197 ?? ?? Table 15. Represents the environmental impact of shipping plastic part from collection center to plastic recycling center, here environmental impact means the amount of carbon di oxide (CO_2) obtained from the trucks during

transportation. The above solution represent the minimization of total cost is 0.1394333E+11; here no iteration is required to get the optimal solution. The optimal solution is obtained for the proposed supply chain networking contains of variables of production centers (X) is 10175.00 that shows that if a new production center is opened than cost will increase otherwise reduced amount is 10175.00. The variables (Y) represent the collection center that is obtained 15925.00, that presents if a collection center is opened than cost will increase amount of 15925.00 otherwise reduced.

Variables (Z) show the quantity of product shipped from production centers (i) to customer zone (j) that is obtained 15012.00 units for the minimization of cost.

Variables (W) shows the quantity of product shipped from customer zone (j) to collection center (k) that is obtained 10730.61 for the minimization of total cost. For the reverse flow variables (m) & (n) presents the quantity of used product shipped from collection center (k) to glass recycling center (l) & quantity of plastic part of used product shipped from collection center (k) to plastic recycling center (m) those are 43925.00 and 41375.00 reduced cost. Inequality constraint to transform it to equality slack and surplus values for the row 1,2,4,5 are 0.1394333E+11, 7281.000, 6736.500 and row 2 & 3 presents the transportation cost of production center(i) to customer zone(j)& customer zone (j) to collection center (k). The above solution represent the minimization of total environmental impact here environmental impact minimization means the reduction of carbon di oxide (CO 2) during the transportation of product from production center (i) to customer zone (j) and customer zone (j) to location centers (k) finally location centers (l) to glass or plastic recycle center(l or m) through trucks.

Here for the proposed supply chain networking problem only carbon di oxide (CO 2) is considered as an environmental impact others are neglected. The 2 nd objective function shows the minimization of environmental impact that is 0.9239886E+08 as well as no iteration is required to get the optimal solution. Variables (Z) show the quantity of product shipped from production centers (i) to customer zone (j) that is obtained 15012.00 units for the minimization of environmental impact. The variables (Y) represent the collection center that is obtained reduced 5416.000. A variable (M) is the quantity of glass part shipped from collection center (k) to glass recycling center (l) than the reduced amount of 3197.000. A variable (N) is the quantity of plastic part shipped from collection center (k) to plastic recycling center (m) than the reduced amount of 1510.000. A variable (W) is the quantity of used product shipped from customer zone (j) to collection center (k) amount of 10730.61.Inequality constraint to transform it to equality slack and surplus values for the row 1,4,5 are 0.9239886E+08, 7281.000, 6736.500 and dual prices are showing in row 1 & 2.

8 IX. Conclusion

Effective supply chain network design and optimization of the network are tasks that provide a competitive advantage to firms and organizations in today's highly intractable global business environment. In this study, design and optimization supply chain networking based on multi-objective fuzzy mathematical programming model, this consists of minimizing the total cost and environmental impact and determining the optimal physical shipment of product from production center to customer zone in forward flow and collection center to recycling center in reverse flow. The proposed fuzzy model includes the design of the network configuration with a minimum total cost and environmental impact under the fuzzy capacity constraints with triangular and trapezoidal member ship functions. The total cost involves the following: the transportation costs between production center and customer zone; customer zone to collection center and collection center to recycling center. To solve the proposed optimization model, an interactive fuzzy solution approach is developed based on the econstraint method and the possibility programming approach proposed by Jimenezet al. [9].The proposed hybrid solution approach is able to generate both balanced and unbalanced solutions and making a reasonable tradeoff between environmental and economic objectives. The effectiveness of the developed fuzzy optimization model as well as the usefulness of the proposed solution approach is investigated through a real industrial case. Finally, a sensitivity analysis developed to show the correlation between the objective function value and the constraints using LINDO 12 optimization software.

According to the ranking method of Jimenez [10], for any pair of fuzzy numbers 'a and b', the degree in which a is bigger than b can be de fined as follows.

When ? m (a,b)?? it will be said that a is bigger than, or equal to, b at least in degree of ? and it will be represented as a? ? b. Now, consider the following fuzzy mathematical programming model in which all parameters are defined as triangular or trapezoidal fuzzy numbers.

Min z= ? t x ST, ?? ?? ?? ? ?? ?? , i= 0,1,2???l;

Eq. (17) can be rewritten as follows.

?(1 ? ??)??

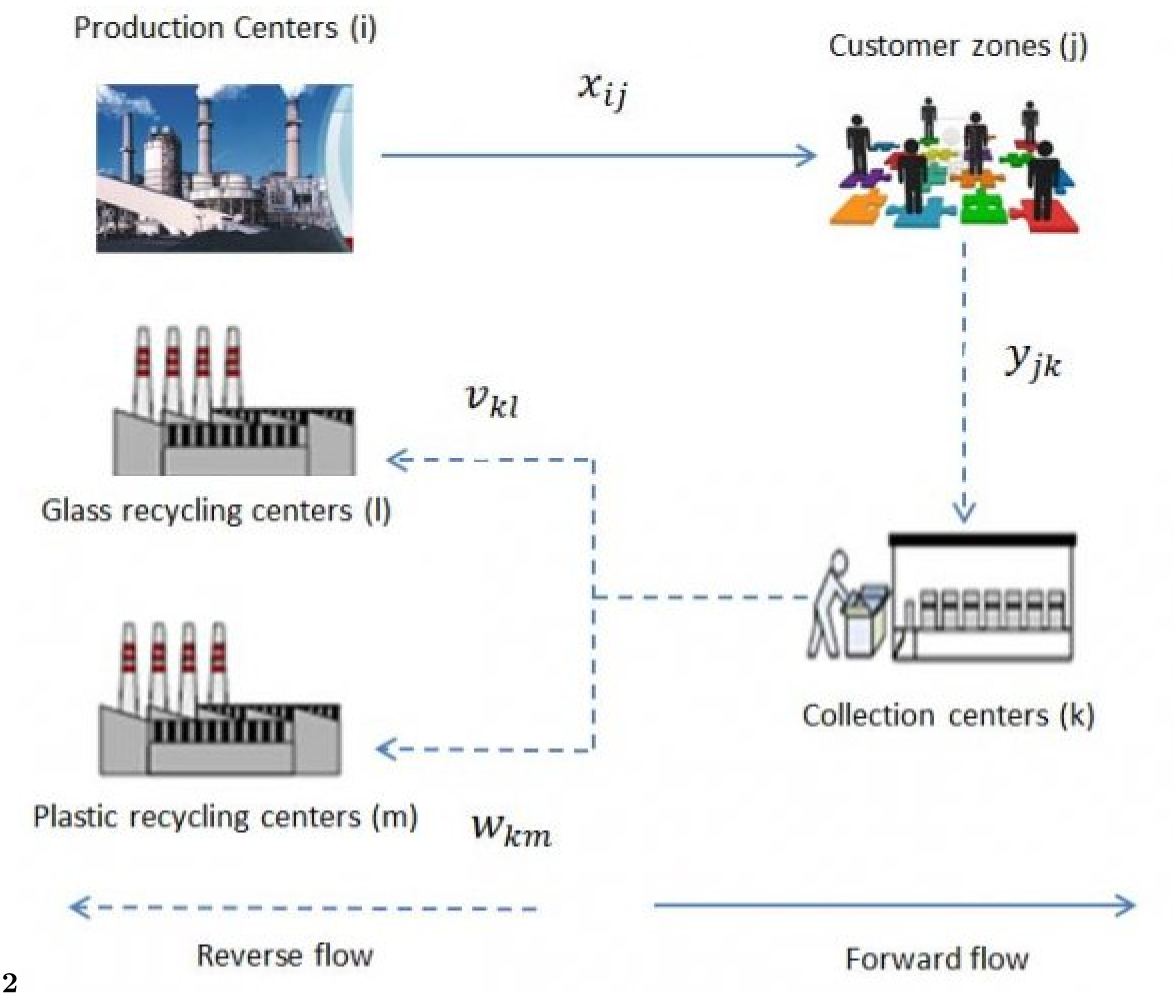
Also, Jimenez et al. [9] showed that a feasible solution like x 0 is an acceptable optimal solution of the model (18) [1 2 3]

[2]Optimization of Supply Chain Network Perspective Environmental Impact based on FuzzyMathematical Programming

8 IX. CONCLUSION

1

Figure 1: Fig. 1 :



2

Figure 2: 2 =

?? ???? = quantity of plastic part of used product shipped from collection center, k to plastic recycling cent

Minw 1 =? ð ??"ð ??" ?? ??
?? ??
\+ ?
ð ??"ð ??"
??

[Note: ?? ?? ?? + ? ? (?? ?? + ?? ????)?? ???? ?? ??]

Figure 3:

Optimization of Supply Chain Network Perspective Environmental Impact based on Fuzzy
Mathematical Programming
b) Capacity Constraint
? ?? ????

[Note: ??? ?? ?? ?? ??]

Figure 4:

1

different kind of membership functions such as
model is based on mathematical concepts that is
expected interval and expected value of fuzzy numbers
and also explain a ranking method which can support

Figure 5: Table 1 :

2

Location(i)	Fixed Cost, ?? ?? (Thousand) pes mos opt			Capacity, ?? ?? (Thousand) pes mos opt		
Khulna	13300	14500	15300	190	200	210
Rajshahi	13500	14700	15400	190	200	210
Narayongonj	13600	14800	15500	200	210	220
Chitagong	13500	14700	15400	165	180	195
Dhaka	13000	14000	15000	190	200	210
Rangpur	13600	14700	15400	190	200	210
Barisal	13400	14200	15200	165	180	195
Joshor	0	0	0	170	190	210

Figure 6: Table 2 :

3

Location, i	Fixed cost, ?? ?? (Thousand) pes mos opt			Capacity, ?? ?? (Thousand) pes mos opt		
Khulna	1700	1740	1780	240	245	250
Rajshahi	1750	1790	1830	240	245	250
Chitagong	1700	1740	1780	250	255	260
Dhaka	1680	1720	1740	220	225	230
Narayongonj	1780	1830	1880	230	235	240
Rangpur	1760	1810	1860	220	205	210
Savar	1740	1780	1820	200	205	210
Barisal	1720	1750	1780	210	215	220
Joshor	1730	1770	1810	225	230	235

Figure 7: Table 3 :

4

Production Zone, j	Customer Center, i	1	2	3	4	5	6	7
	pes	900	1000	900	1000	1100	1100	1000
1	mos	1000	1200	1200	1200	1300	1250	1400
	opt	800	1100	800	1100	1200	1000	1200
	pes	1100	1100	1000	1100	1000	1200	1000
2	mos	1200	1350	1100	1250	1400	1250	1300
	opt	1150	1200	1200	1300	1200	1300	1200
	pes	1200	1200	1100	1100	1200	1400	1000
3	mos	1400	1400	1150	1300	1450	1100	1350
	opt	1100	1100	1200	1200	1000	1200	1200
	pes	1400	1200	1000	1100	1200	1200	1300
4	mos	1500	1500	1200	1350	1500	1150	1400
	opt	1300	1300	900	1200	1400	1000	1200
	pes	1200	1200	1000	1200	1300	1000	1000
5	mos	1350	1550	1300	1400	1500	1200	1500
	opt	1100	1100	1200	1100	1400	1100	1300
	pes	1200	1400	1300	1200	1400	1200	1200
6	mos	1500	1600	1350	1450	1600	1250	1550
	opt	1100	1350	1200	1100	1300	1300	1200
	pes	1400	1200	1500	1200	1400	1200	1100
7	mos	1600	1700	1400	1500	1250	1300	1600
	opt	1300	1300	1300	1100	1500	1000	1200
	pes	1500	1400	1400	1300	1000	1000	1000
8	mos	1700	1750	1450	1600	1300	1350	1650
	opt	1600	1500	1200	1400	1200	1200	1100
	pes	1500	1300	1000	1000	1200	1000	1200
9	mos	1650	1400	1500	1250	1350	1400	1400
	opt	1400	1200	900	1200	1100	1200	1000

Figure 8: Table 4 :

5

Figure 9: Table 5 .

5

Production centers, i	pes	mos	opt
1	10000	10500	11000
2	10500	12000	12500
3	11000	11500	10000
4	10000	12000	11000
5	11500	12500	13000
6	12000	11000	14000
7	11000	10000	15000
8	10500	11500	12000

Figure 10: Table 5 :

6

Figure 11: Table 6 .

6

Collection Center, k Customer Zone, j		1	2	3	4	5	6	7	8	9
	pes	650	800	900	650	700	650	600	700	800
1	mos	800	900	1000	700	600	700	800	900	1000
	opt	700	700	800	600	800	600	700	600	900
	pes	500	700	700	600	600	700	700	800	650
2	mos	750	800	600	650	750	800	850	900	700
	opt	600	750	800	700	700	750	800	700	600
	pes	700	700	600	700	600	700	600	750	750
3	mos	800	600	700	900	1000	800	700	800	900
	opt	850	750	500	750	900	900	650	700	800
	pes	900	1000	400	800	800	800	800	700	700
4	mos	1000	1200	800	900	700	600	1000	800	900
	opt	800	900	500	850	850	900	900	600	800
	pes	700	800	600	900	900	800	700	850	1000
5	mos	800	900	700	650	600	700	800	900	950
	opt	600	750	750	950	800	900	900	950	800
	pes	800	800	850	700	900	700	800	700	550
6	mos	850	950	750	900	700	600	550	500	600
	opt	700	900	800	800	800	950	900	600	700
	pes	750	800	900	700	900	700	800	700	550
7	mos	800	900	950	900	700	600	550	500	600
	opt	700	700	800	800	800	950	900	600	700
	pes	800	900	700	1000	750	1000	500	600	600
8	mos	900	950	800	850	800	700	600	650	550
	opt	700	800	750	900	700	900	700	700	700
	pes	600	700	1100	700	750	700	500	850	650
9	mos	900	800	1000	800	800	800	600	900	700
	opt	500	600	900	600	650	600	550	800	600

Figure 12: Table 6 :

7

Figure 13: Table 7 .

7

Collection center, k	pes	mos	opt
1	1000	1200	1100
2	800	700	1000
3	900	800	1200
4	1100	1000	900
5	800	700	1000
6	1100	800	1000
7	1000	900	1200
8	1100	800	1000
9	1000	900	1200

Figure 14: Table 7 :

8

Figure 15: Table 8 .

8

Glass recycling center, l / collection center, k		1	2	3	4
	pes	500	300	900	400
1	mos	600	400	500	300
	opt	400	200	600	500
	pes	600	400	600	400
2	mos	700	750	650	600
	opt	650	500	700	300
	pes	450	600	700	500
3	mos	500	550	600	700
	opt	550	700	750	600
	pes	700	800	600	500
4	mos	650	700	800	700
	opt	600	900	700	600
	pes	500	800	700	700
5	mos	600	500	450	300
	opt	400	700	600	800
	pes	400	400	500	700
6	mos	450	550	650	750
	opt	300	500	550	600
	pes	500	600	900	500
7	mos	800	750	700	850
	opt	600	700	800	300
	pes	700	650	500	200
8	mos	900	600	300	400
	opt	800	700	600	300
	pes	400	700	500	400
9	mos	300	450	400	500
	opt	500	800	600	600

Figure 16: Table 8 :

9

Figure 17: Table 9 .

9

Glass recycling center, l	pes	mos	opt
1	500	600	900
2	800	900	700
3	700	450	400
4	600	650	500

Figure 18: Table 9 :

10

Plastic recycling center, m					
Collection Center, k		1	2	3	4
	pes	300	400	400	400
1	mos	400	300	450	500
	opt	500	500	500	300

Figure 19: Table 10 :

11

Figure 20: Table 11 .

11

m	pes	mos	opt
1	500	600	700
2	600	650	550
3	500	400	450
4	500	650	700

Figure 21: Table 11 :

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??????) of shipping product from production center, i to customer zone, j

i / j	1	2	3	4	5	6	7	8
1	30	32	34	30	32	36	38	40
2	42	35	36	38	39	40	42	45
3	46	47	48	39	40	46	47	48
4	50	52	42	46	47	48	49	50
5	52	53	54	55	46	48	50	52
6	54	32	34	36	38	40	42	45
7	46	48	50	52	54	46	48	50
8	42	46	40	38	35	45	46	48
9	44	48	38	36	32	40	48	46

Figure 22: Table 12 :

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j to collection center, k

J / k	1	2	3	4	5	6	7	8	9
1	24	26	28	30	39	32	36	38	40
2	26	28	30	32	34	36	38	40	38
3	32	36	38	44	32	24	28	30	32
4	34	34	40	42	34	32	30	28	34
5	30	28	32	36	34	35	28	30	32
6	36	32	38	40	36	26	32	48	38
7	38	34	36	38	38	32	36	46	36
8	36	36	34	36	36	44	38	44	32
9	40	38	32	36	40	42	40	42	34

Figure 23: Table 13 :

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l	1	2	3	4
k				
1	50	48	50	52
2	52	46	54	54
3	48	44	56	55
4	46	42	58	42
5	44	44	42	44
6	50	46	44	46
7	52	48	46	48
8	54	50	48	50
9	50	52	50	52

Figure 24: Table 14 :

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m	1	2	3	4
k				
1	16	18	20	22
2	24	18	22	24
3	26	20	18	16
4	28	18	22	18
5	30	28	18	18
6	32	26	20	20
7	34	24	16	22
8	32	22	20	24
9	18	20	18	18
Environmental impact of recycling one unit of plastic product, ???? ?????? =20				
? ?(???? ?????? + ?? ???? ??????) = 1510				
??	??			

Figure 25: Table 15 :

16

Figure 26: Table 16 .

16

l, m	pes	?? ?? mos	opt	pes	?? ?? mos	opt
1	100	150	200	180	150	200
2	200	150	180	180	200	250
3	190	200	250	220	180	250
4	230	250	180	240	250	180

Simplifications of the constraints are obtained by developing a program using Code blocks programming software:

minw 1 = Constraints,

?? ???? ? 15012

?? ???? ? 10730.61

?? ???? ? 13860 or ?? ???? ? 0

?? ???? ? 18639 or ?? ???? ? 0

?? ???? ? 7281

?? ???? ? 6736.5

Figure 27: Table 16 :

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Symbol	Modified Symbol
?? ??	X
?? ??	Y
?? ????	Z
?? ????	W
?? ????	M
?? ????	N

Figure 28: Table 17 :

Figure 29:

.1 Appendix

The Jimenez et al. [9] method is based on the definition of the "expected interval" and the "expected value" of a fuzzy number. Assume that ? is a triangular fuzzy number. The following equation can be defined as the membership function of ?.

Here ?? ?????? , ?? ?????? ?????? ?? ?????? are the three prominent points (the most likely, the most pessimistic and the most optimistic values), respectively. Eqs. (**??**3) And (**??**4) define the expected interval (EI) and the expected value (EV) of triangular fuzzy number ?.

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