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# Development of closed-loop supply chain mathematical model (cost-benefit-environmental effects) under uncertainty conditions by approach of genetic algorithm

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ABSTRACT
In the current world, the debate on the reinstatement and reuse of consumer products has become particularly important. Since the supply chain of the closed loop is not only a forward flow but also a reverse one; therefore, companies creating integrity between direct and reverse supply chain are successful. The purpose of this study is to develop a new mathematical model for closed loop supply chain network. In the real world the demand and the maximum capacity offered by the supplier are uncertain which in this model; the fuzzy theory discussion was used to cover the uncertainty of the mentioned variables. The objective functions of the model include minimizing costs, increasing revenues of recycling products, increasing cost saving from recycling and environmental impacts. According to the NP-hard, an efficient algorithm was suggested based on the genetic Meta heuristic algorithm to solve it. Twelve numerical problems were defined and solved using the NSGA-II algorithm to validate the model

## 1 Introduction

Over the past few years, the emergence of new technologies and the creation of massive changes in global markets have made supply chain management more urgent, so that different organizations have to use supply chain management to create and maintain their competitive position [17, 22]. The supply chain network includes all activities related to flow and product conversion from the supply chain to the delivery of the raw material to the customer as well as the flows associated with them. If the reverse supply chain discussion defined for the problem, consumer products also sent from customers to manufacturers. If in a model, the reverse flow is assumed to be alongside the direct current, the model is called the closed loop supply chain network [9, 10, 15, 16].

Global competition requirements, regulatory requirements, and environmental sensitivities have led organizations to collect their return products to restore, recycle, or destroy these products to protect the environment. Considering the importance of protecting the environment and reducing the use of raw materials, the government tends to recycle its products to give them to manufacturers after a change. The government provides the ground to reduce costs and increase productivity through the delivery of new products and products from recycled products. Considering the necessity of the research the theoretical vacuum available in the design of the closed loop supply chain network can be noted, taking into account the objectives defined in the model presented in this study.

The problem in this research is to develop an integrated supply chain network model, in which the network includes supplier levels, production centers, distribution centers, customers, gathering centers, and inspection and cleaner centers. In this problem, production centers purchase raw materials, convert them into finished products, send them to distribution systems, and then send them out for customers through product distribution centers. For various reasons (e.g. defectiveness, etc.), a percentage of products are sent back from customers to gathering centers as the first loop in the reverse network. Such products are first sent to inspection and destruction centers and, if they are repairable, they will be sent to production centers. After being repaired, the products re-enter the network and will then be used to fulfill customers' needs. If the products in the inspection and destruction centers are not repairable, they will be destroyed therein and are excluded from the network to be properly expelled from the environment. Because the goods are introduced in the reverse supply chain cycle and in the direct supply chain cycle, the network will thus be a closed loop network. Accordingly, the model is multi-objective, multi-level, and single-product with product return under indeterminate conditions. The target functions of the model include cost minimization, profit augmentation from recycling, and increasing the saving costs of recycling and environmental impacts. Moreover, given that data on indicators affecting problems are not definitively available in the real world, it would be more appropriate to use an indeterminate approach. Hence, the demand and capacity of the supplier are considered to be indeterminate in this study.

## 2 Literature review

In the past few years, the issue of close-loop supply chain has been considered due to its scientific significance and computational challenges encountered in the models. Of course, despite previous efforts, which have been provided in line with the baseline modification, today, most of studies are conducted to develop a better solution with more diverse goals. As the summary of studies shows, most conducted studies in recent years have created innovation in methods of solving problem.

Farrokh et al. [6] investigated on the design of Closed-Loop supply chain networks under uncertainty using comprehensive fuzzy random planning. Fathollahi-Fard and Hajiaghaei-Keshteli [7] designed a random multi-objective model for the CLSC with environmental considerations and used ε-limitation for model validation in small sizes, and a combination of meta-heuristic algorithms for large sizes. Zeballos et al. [29] focused on integration of Closed-Loop supply chain design under indeterminate return flow and proposed a linear two-dimensional linear model with uncertainty on the quality and quantity of return flow. Paydar et al. [18] considered the design of the closed-loop supply chain of the oil engineering, taking into account the risk of collecting. Amin and Baki [2] considered a location model for the design of a global Closed-Loop supply chain network, which is an integrated multi-objective linear programming model with unlimited demand. Chen et al. [4] addressed optimization of product freshness in the Closed-Loop supply chain using a multi-cycle model combined with a fuzzy controller under uncertainty conditions. Al-Salem et al. [1] discussed on a CLSC problem and stated that a nonlinear integer program was a combination to solve transport, order, and location problems. Kaya and Urek [14] studied a single-objective nonlinear integer programming model and initial solutions for location decision, inventory, and price in the CLSC. Zohal and Soleimani [30] have developed an ant colony approach in the green Closed-Loop supply chain network aiming at reductions of costs and carbon emissions. Xie and Ma [28] in their study on the complexities and control of supply chain of Chinese color TV market recycling based on government subsidy, attempted to solve the supply chain of closed-loop recycling model. The results can be used in improving the environmental conditions and increasing social welfare. Tiwari et al. [27] aimed at analyzing the evolutionary algorithm approach for designing a network of closed-loop green supply chain and solving it. Ruimin et al. [21] have designed a robust environmental Closed-Loop supply chain model under uncertainty; the proposed model aims to reduce economic costs and environmental impacts. Kadambala et al. [12] studied the closed-loop supply chain network and designs for the efficiency of time and energy. Moreover, the used approach was one of multi objective mass optimization for solving the model and using genetic algorithm. Dai and Zheng [5] worked on designing the network of closed-loop supply chain. In this sense, they used hybrid genetic algorithm which can be regarded as a fuzzy scheduling and a limited chance model. Talaei et al. [25] studied an allocation/facility location model for a network of closed-loop green supply chain of several products consisting of production/reproduction and collection centers/inspection and also the markets and available centers. The mentioned model, considering the environmental considerations and decreasing the amount of carbon dioxide emissions in environment, have been developed all through the network. Tao et al. [26] aimed at balancing multi-cycle closed-loop supply chain network with the help of compressing carbon emission. In this sense reconstruction was the goal in order to reduce waste and increase environmental safety. Subulan et al. [23] attempted the following in their study; designing a network of closed-loop supply chain with multiple recovery choices. Applying fuzzy ideal planning, they analyzed and solved model. Kafa et al. [13] studied simulation, modeling and network design analysis of nutrition closed-loop chain. It was a case study on battery industry analyzing and solving closed-loop supply chain model. Jayant et al. [11] worked on simulation, modeling and analyzing the network design of nutrition closed-loop chain. It is worth mentioning that it was a case study on the battery industry proposing to analyze and solve the closed-loop supply chain model. Ramezani et al. [20] studied the designing of closed-loop supply chain network under fuzzy environment and attempted to solve closed-loop supply chain model. Ozceylan et al. [15] aimed at modeling the integration problems of closed-loop supply chain network design and also assembling the production line balance. Amin and Zhang [3] presented a model on Two-objective closed-loop supply chain network. The closed-loop logistics network of this study can be thought of as a network consisting of Manufacturing factories, demand market, collection and burial centers.

The present study is based on the previous studies and, in response to the proposed research axes, Tahmasebi et al. [24] and Zahuri et al. [31], to develop a closed loop supply chain model to determine optimal stakeholder policies. One of the suggested axes of these studies is the use of uncertainty about demand, and the other axis is considering the stage of product recycling as part of the production process, which is included in the current model and the model has been developed with respect to these axes.

Most research in this area has focused its functions on minimizing environmental costs and benefits or maximizing profits and minimizing environmental impacts. In all studies, all three objective functions (minimizing costs, minimizing environmental impacts and Maximization of profits) is not included at the same time, which is covered in this proposed model. From the uncertainty point of view, some studies considered all the parameters to be definitive, while some uncertainties did not focus on the demand parameters and the capacity of the suppliers simultaneously, which is also addressed in the proposed model. It can be said that the innovation of this research is to provide a more comprehensive model than the previous models, which, while considering all supply chain loops, has considered the reverse flow, while during the several periods the stock flow is also considered, and in Together, the cost target focuses on environmental issues and the cost savings from recycling, in order to design a more comprehensive model for different issues and closer to the real world.

## 3 Mathematical modelling

### Hypotheses

In designing the problem mathematical model, the following hypotheses were presented, by considering applicable features and conditions:

- The cost of transfer (transport) is not dependent upon the type of material, piece, and product but is affected by the origin and destination (distance).
- The cost of distribution is accounted for the cost of product transport from the distributor to the customer.
- Centers of providers, manufacturers/assemblers, distributors, and customers are fixed and predefined.
- The cost of gathering is considered within the cost of the product transported from customer centers to collection centers.
- The cost of rebuttal of materials and parts is considered at the cost of transportation to disposal centers.
- The parts used in assembly centers are purchased from the supplier.
- Green products are made of recyclable materials.
- A fixed percentage of commodities sent to each customer is regarded to be equal to the amount of returned commodities from the same customer.
- Demands for products should be satisfied.
- Products are disassembled after collecting from customer centers.
- Parts obtained from disassembly are transported to assembly centers; recycle centers, and disposal centers in three categories of new similar pieces, recycled pieces and waste pieces, respectively.
- A product is taken into consideration.

### Model indices

| | | |
|---|---|---|
| I | Index of suppliers | i=1,2,….I |
| J | Index of manufacturers | j=1,2,….J |
| Ma | Index of material market | ma=1,2,….Ma |
| P | Index of various parts | p=1,2,….P |
| M | Index of raw material | m=1,2,….M |
| T | Index of period | t=1,2,….T |
| K | Index of distribution centers | k=1,2,….K |
| G | Index of gathering centers | g=1,2,….G |
| R | Index of recycle centers | r=1,2,….R |
| Re | Index of rebuttal centers | re=1,2,….Re |
| L | Index of potential disassembly centers | l=1,2,….L |
| C | Index of customer areas | c=1,2,….C |

## Parameters

| | |
|---|---|
| $ship^{1}_{maimt}$ | Unit cost of shipping raw material m from market ma during period t |
| $ship^{2}_{ijpt}$ | Unit cost of shipping piece p from supplier i to manufacturer j during period t |
| $ship^{3}_{jkt}$ | Unit cost of shipping product from manufacturer j to distributor k during period t |
| $ship^{4}_{kct}$ | Unit cost of shipping product from distributor k to customer c during period t |
| $ship^{5}_{cgt}$ | Unit cost of transferring product from customer c to gathering center g during period t |
| $ship^{6}_{glt}$ | Unit cost of transferring product from gathering center to disassembly center l during period t |
| $ship^{7}_{ljpt}$ | Unit cost of transferring similar parts type p from disassembly center l to manufacturer j during period t |
| $ship^{8}_{lrpt}$ | Cost of shipping recyclable parts type p from disassembly center to recycling center r during period t |
| $ship^{9}_{lrept}$ | Cost of transferring waste parts type p from disassembly center l to the re disposal facility during period t |
| $ship^{10}_{rimt}$ | Cost of transferring recycled material type m from recycle center r to supplier i during period t |
| $ship^{11}_{rremt}$ | Cost of transferring waste materials type m from recycle center r to rebuttal center during period t |
| $income_{pt}$ | Average purchase price of parts type p from suppliers during period t |
| $price_{ipt}$ | Price of a part type p from the supplier i during period t |
| $inv_{jpt}$ | Inventory holding cost of part type p by manufacturer j during period t |
| $Fcost_{it}$ | Fixed cost of product supply from supplier i during period t |
| $setg_{gt}$ | Unit cost of setting up gathering center g during period t |
| $setdis_{lt}$ | Unit cost of setting up disassembly center l during period t |
| $setrev_{rt}$ | Unit cost of setting up recycle center r during period t |
| $setrebuttal_{ret}$ | Unit cost of setting up rebuttal center re during period t |
| $costdis_{lt}$ | Unit cost of product disassembly at disassembly center l during period t |
| $costrev_{rpt}$ | Cost of recycling part type pat recycle center r during period t |
| $cost^{2}_{jt}$ | Unit cost of manufacturer j in period t |
| $b\ cost^{1}_{maimt}$ | Cost of purchasing raw materials type m from market ma during period t |
| $h_{kt}$ | Inventory holding cost in the repository of distributor k during period t |
| $CC_{ipt}$ | Chemical contamination generated per part type p by supplier i during period t |
| $WW_{ipt}$ | Wastewater contamination generated per part type p by supplier i during period t |
| $SW_{ipt}$ | Solid waste contamination per production of part type p by supplier i during period t |
| $AEX_{ijpt}$ | Air emission unit during the transfer of part type p by supplier i to manufacturer j during period t |
| $AEY_{jkt}$ | Air emission unit during product transfer from manufacturer j to distributor k during period t |

| | |
|---|---|
| $AEY'_{kct}$ | Air emission unit during product transfer from distributor k to customer area c during period t |
| $AEY''_{cgt}$ | Air emission unit during transfer of product from the customer location c to gathering center g during period t |
| $AEYY'_{glt}$ | Air emission unit during transfer of product from gathering center g to disassembly center l during period t |
| $AEXX'_{lrept}$ | Air emission unit during transfer of part type p from disassembly center l to manufacturer j during period t |
| $AEYY_{lrpt}$ | Air emission unit during transfer of recycled part type p from disassembly center l to recycle center r during period t |
| $AEY'''_{ljpt}$ | Air emission unit during transfer of rebuttable part type p from disassembly center l to rebuttal center during period t |
| $AEXX''_{rremt}$ | Air emission unit during transfer of rebuttable material type m from recycle center r to rebuttal center during period t |
| $AEZ'_{rimt}$ | Air emission unit during transport of recycled materials type m from recycle center r to supplier i during period t |
| $ec_{maimt}$ | Energy consumption unit during transfer of material type m from market ma to supplier i during period t |
| $NC_{ipt}$ | Non-renewable resource usage during production of a part type p by the supplier i during period t |
| $\widetilde{dem}_t$ | Fuzzy product demand during period t |
| $req_p$ | Required number of units from part type p during period t |
| $req'_p$ | Required number of unit part type p (similar to new) in the product |
| $Q_t$ | Percentage of (gathering/customer return) product during period t |
| $Q'_{ptr}$ | Percentage of recycled part type p in recycle center r during period t |
| $\widetilde{supmax}_{ipt}$ | Maximum available fuzzy capacity for part type p supplied by the supplier i during period t |
| $supmin_{ipt}$ | Minimum purchase of part type p from supplier i during period t |
| $reuse_{pt}$ | Maximum percentage of reusable part type p during period t |
| $C^1_{jt}$ | Product capacity of manufacturer j during period t |
| $C^2_{kt}$ | Product capacity of distributor k during period t |
| $C^4_{gt}$ | Product capacity used by gathering center g during period t |
| $ship^1_{maimt}$ | Capacity of like-new part type p in disassembly center l during period t |
| $C^5_{plt}$ | Capacity of recycled material type m in recycle center r during period t |
| $C^6_{rmt}$ | Capacity of rebuttal center during period t |
| $C^7_{ret}$ | Supply budget during period t |



### Variables of decision

| | |
|---|---|
| $S_{it}$ | Binary variable; 1, if supplier i is selected at period t, and 0 otherwise. |
| $ga_{gt}$ | Binary variable; 1, if gathering center g is selected at period t, and 0 otherwise. |
| $dis_{lt}$ | Binary variable; 1, if disassembly center l is selected at period t, and 0 otherwise. |
| $rev_{rt}$ | Binary variable; 1, if recycle center l is selected at period t, and 0 otherwise. |
| $btl_{ret}$ | Binary variable; 1, if rebuttal center is selected at period t, and 0 otherwise. |
| $z_{maimt}$ | Integer variable; material type m purchased from market ma to supplier i during period t |
| $x_{ijpt}$ | Integer variable; number of purchased parts type p from supplier i to manufacturer j during period t |
| $y_{jkt}$ | Integer variable; number of products transferred from manufacturer j to distributor k during period t |
| $y'_{kct}$ | Integer variable; number of products transferred from distributor k to customer area c during period t |
| $y''_{cgt}$ | Integer variable; number of used products transferred from customer area c to gathering center g during period t |
| $yy'_{glt}$ | Integer variable; number of used products transferred from gathering center g to disassembly center l during period t |
| $y'''_{ljpt}$ | Integer variable; number of parts type p transferred from disassembly center l to manufacturer j during period t. |
| $yy_{lrpt}$ | Integer variable; number of recycled parts type p transferred from disassembly center l to recycle center r during period t. |
| $xx'_{lrept}$ | Integer variable; number of rebuttable parts type p transferred from disassembly center l to rebuttal center re during period t. |
| $xx''_{rremt}$ | Integer variable; amount of rebuttable material type m transferred from recycle r center l to rebuttal center re during period t. |
| $z'_{rimt}$ | Integer variable; amount of recycles material type m transferred from recycle r center l to supplier i during period t. |
| $inv'_{kt}$ | Product inventory in the repository of distributor k during period t. |

## Target functions

**Objective I:** Total cost is obtained according to Equation (1).

$$\text{Min } F(1): \quad \begin{aligned} &\sum_k \sum_c \sum_t ship^4_{kct}\ y'_{kct} + \sum_j \sum_k \sum_t (cost^2_{jt} + ship^3_{jkt})\ y_{jkt} + \\ &\sum_{ma} \sum_i \sum_m \sum_t (bcost^1_{maimt} + ship^1_{maimt})\ z_{maimt} + \\ &\sum_i \sum_j \sum_p \sum_t (price_{ipt} + ship^2_{ijpt} + inv_{jpt})\ x_{ijpt} + \sum_i \sum_t F\ cost_{it}\ S_{it} \\ &\sum_t \sum_g setg_{gt}\ ga_{gt} + \sum_c \sum_g \sum_t ship^5_{cgt}\ y''_{cgt} + \sum_t \sum_l setdis_{lt}\ dis_{lt} + \\ &\sum_t \sum_r setrev_{rt}\ rev_{rt} + \sum_t \sum_{re} setrebuttal_{ret}\ btl_{ret} \\ &\sum_g \sum_l \sum_t (costdis_{lt} + ship^6_{glt})\ yy'_{glt} + \sum_l \sum_j \sum_p \sum_t ship^7_{ljpt}\ y'''_{ljpt} + \\ &\sum_l \sum_r \sum_p \sum_t (costrev_{rpt} + ship^8_{lrpt})\ yy_{lrpt} + \\ &\sum_l \sum_{re} \sum_p \sum_t ship^9_{lrept}\ xx'_{lrept} + \\ &\sum_r \sum_i \sum_m \sum_t ship^{10}_{rimt}\ z'_{rimt} + \\ &\sum_r \sum_{re} \sum_m \sum_t ship^{11}_{rremt}\ xx''_{rremt} + \sum_k \sum_t inv'_{kt}\ h_{kt} \end{aligned} \qquad (1)$$

**Objective II:** Profit from recycled products is presented in Equation (2).

$$\text{Max } F(2): \quad \sum_l \sum_j \sum_p \sum_t income_{pt}\ yy'''_{ljpt} + \sum_l \sum_r \sum_p \sum_t income_{pt}\ yy_{lrpt} \qquad (2)$$

**Objective III:** Increasing cost savings of recycling and environmental impacts as obtained by Equation. (3).

$$\text{Max F(3)}: \begin{aligned} &\sum_t \sum_p \sum_i \left(\sum_j x_{ijpt}\right) CC_{ipt} + \sum_t \sum_p \sum_i \left(\sum_j x_{ijpt}\right) WW_{ipt} + \\ &\sum_t \sum_p \sum_i \left(\sum_j x_{ijpt}\right) SW_{ipt} + \\ &\sum_t \sum_p \sum_i \sum_j x_{ijpt}\ AEX_{ijpt} \\ &+ \sum_t \sum_j \sum_k y_{jkt}\ AEY_{jkt} + \sum_t \sum_{ma} \sum_i \sum_m ec_{maimt}\ z_{maimt} + \\ &\sum_t \sum_i \sum_j \left(\sum_p x_{ijpt}\right) NC_{ipt} + \sum_k \sum_c \sum_t y'_{kct}\ AEY'_{kct} + \\ &\sum_t \sum_c \sum_g y''_{cgt}\ AEY''_{cgt} + \\ &\sum_t \sum_g \sum_l yy'_{glt}\ AEYY'_{glt} + \sum_t \sum_l \sum_{re} \sum_p xx'_{lrept} AEXX'_{lrept} + \\ &\sum_t \sum_l \sum_j \sum_p y'''_{ljpt} AEY'''_{ljpt} + \sum_t \sum_r \sum_{re} \sum_m xx''_{rremt} AEXX''_{rremt} + \\ &\sum_t \sum_r \sum_i \sum_m z'_{rimt} AEZ'_{rimt} \end{aligned} \tag{3}$$

Limitations are presented in Equations (4) to (22)

$$\sum_k y'_{kct} \geq \widetilde{dem}_{t,c} \qquad \forall t, c) \tag{4}$$

$$\sum_{ma} \sum_m z_{maimt} + \sum_r \sum_m z'_{rimt} = \sum_p \sum_j x_{ijpt} \qquad \forall t, i \tag{5}$$

$$\sum_k req_p\, y_{jkt} = \sum_i x_{ijpt} + \sum_l y'''_{ljpt} \qquad \forall t, p, j \tag{6}$$

$$\sum_j y_{jkt} = \sum_c y'_{kct} + \sum_j inv'_{jt} \qquad \forall t, k \tag{7}$$

$$\sum_g y''_{cgt} = \sum_k Q_t\, y'_{kct} \qquad \forall t, c \tag{8}$$

$$\sum_n \sum_g req'_p\, yy'_{glt} = \sum_j y'''_{ljpt} + \sum_r y\,y_{lrpt} + \sum_{re} xx'_{lrept} \qquad \forall p, l, t \tag{9}$$

$$\sum_{p,l} Q'_{ptr} y\, y_{lrpt} = \sum_m \left(z'_{rimt} + \sum_{re} xx''_{rremt}\right) \qquad \forall r, t \tag{10}$$

$$\sum_j x_{ijpt} \leq \widetilde{supmax}_{ipt}\, S_{it} \quad \forall p, i, t \tag{11}$$

$$\sum_j x_{ijpt} \geq supmin_{ipt}\, S_{it} \quad \forall p, i, t \tag{12}$$

$$\sum_j yy'''_{ljpt} \leq \sum_g reuse_{pt}\, yy'_{glt} \qquad \forall p, l, t \tag{13}$$

$$\sum_r yy_{lrpt} + \sum_{re} xx'_{lrept} \leq \sum_g (1 - reuse_{pt})\, yy'_{glt} \qquad \forall p, l, t \tag{14}$$

$$\sum_k y_{jkt} \leq C^1_{jt} \quad \forall j, t \tag{15}$$

$$\sum_c y'_{kct} \leq C^2_{kt} \quad \forall k, t \tag{16}$$

$$\sum_g y''_{cgt} \leq C^3_{ct} \quad \forall c, t \tag{17}$$

$$\sum_l yy'_{glt} \leq C^4_{gt}\, ga_{gt} \quad \forall g, t \tag{18}$$

$$\sum_j yy'''_{ljpt} + \sum_r yy_{lrpt} + \sum_{re} xx'_{lrept} \leq C^5_{plt}\, dis_{lt} \quad \forall p, l, t \tag{19}$$

$$\sum_i z_{rimt} + \sum_{re} xx''_{rremt} \leq C^6_{rmt}\, rev_{lt} \quad \forall g, t \tag{20}$$

$$\sum_i \sum_j \sum_p (price_{ipt} + ship^2_{ijt})\; x_{ijpt} + \sum_i Fcost_{it}\, S_{it} \le B_t \tag{21}$$

$$\sum_l \sum_p xx'_{lrept} + \sum_r \sum_m xx''_{rremt} \le btl_{ret} * C^7_{ret} \tag{22}$$

Objective function (1) is used to minimize total cost, including total cost of transferring products sent from distributors to customers at all periods, total cost of manufacturing and transferring products sent from manufacturers to distributors at all periods, total purchase cost of raw materials from markets plus cost of transferring these materials at all periods, total cost of purchasing and transporting parts from suppliers to manufacturers and cost of storing parts in production centers, total fixed costs of suppliers if they are selected, cost of setting up collecting centers (if the centers are set up) plus shipping costs from customers to gathering centers, total cost of setting up disassembly centers and recycle centers, total cost of setting up rebuttal center, total cost of disassembly and transport of products sent from gathering centers to disassembly centers, total cost of like-new parts from disassembly centers to manufacturers, total cost of like-new parts from disassembly centers to manufacturers, total cost of recycling and transferring parts from disassembly center to recycle center, total cost of transporting rebuttable parts from assembly center to rebuttal center, total cost of transporting recycled materials from recycle center to supplier, total cost of transporting rebuttable materials from recycle center to rebuttable centers, and total cost of inventory in the repository of distributor.

Objective function (2): The amount of savings (profits) resulting from the use of like-new and recycled parts from disassembly centers and recycling centers to manufacturers.

Objective function (3) is to increase the cost savings of recycling and environmental impacts, including chemical contamination from waste generated in the production sector, wastewater contamination generated in the supplier sector, total contamination from solid waste including toxic substances produced during the supplier's production, total air pollution from the supplier to the producer, total air pollution from the producer to the distribution center, total energy consumption of purchased materials transferred from market to supplier, total non-renewable resource consumption in supplier's place, total air pollution from distributor to customer, total air pollution from customer to gathering centers, total air pollution from gathering centers to disassembly centers, total air pollution from disassembly centers to rebuttal centers, total air pollution from the disassembly centers to recycling centers, total air pollution from disassembly centers to producer, total air pollution from recycling centers to rebuttal centers, and total air pollution from recycling centers to supplier.

Limitation of fulfilling demands (4): in each period, the number of transferred products from all distributers to the costumer (c) would be higher than the customer's demand for that period (customers' demands are considered as a triangular fuzzy number).

Limitation of flow balance in the supplier (5): the amount of input materials flow to the supplier which consists of raw materials (m) from raw material markets (ma) and recycled materials from recycling centers (r) equals the amount of output parts flaw (p) from the supplier (I) to the producer (j).

Limitation of balance flaw in production/assembly centers in each period and for each part and producer (6): the number of (p) type pieces used for products transferred from producer (j) to distributors equals the number of bought (p) type pieces - by the producer (j) - from suppliers plus disassembly centers.

Limitation of products flaw balance in the distributers' centers in each period (7): the number of transferred products from all producers to the distributer (k) equals the number of transferred products from the distributer (k) to all of the customers plus the product inventory in Manufacturers' stock.

Limitation of products flaw balance in customers' centers (8): the number of transferred products from customer (c) to collecting centers equals product percentage (collect / return from customer) multiplied by the number of transferred products from all distributers to customer (c).

Limitation of production flaw balance in disassembly centers in each period (9): the number of (p) type pieces which are with the transferred products from collecting centers to the disassembly center (l) equals the number of (p) type pieces transferred from disassembly center (l) to all producers, recycling center and disposal center.

Limitation of production flaw balance in recycling centers (10): the number of recycled pieces transferred from disassembly centers to the recycling center (r) equals the number of recycled pieces transferred from recycling center (r) to the recycling centers plus production centers.

Limitation of supplier capacity (bought pieces) (11): the number of (p) type piece which has been bought by producers from the supplier (i) must be less than maximum available capacity of the (p) type piece by the supplier (i). It is so in case of selecting the supplier, but, if we don't select the supplier, we won't be able to buy from that specific supplier (in this limitation, maximum available capacity of the piece is considered as fuzzy).

Limitation of the least purchase from each supplier (12): the number of (p) type piece bought by producers from the supplier (I) must be greater than the minimum amount of the bought (p) type piece from the supplier (I). This limitation will be redundant in case of not selecting the supplier.

Limitation of the reusable percentage in disassembly (13): the number of (p) type piece transferred from disassembly center (l) to producers equals the maximum percentage of the reusable (p) type piece in the number of transferred product from the collecting center to disassembly center (I).

Limitation of recycled pieces percentage and disassembly's waste (14): the total number of the recycled (p) type pieces transferred from disassembly center (l) to the recycling centers and disposal centers should be less than or equal to the number of transferred products from the collecting centers to the disassembly center (l).

Limitation of producer's capacity (15): the number of transferred products from the producer (j) to all of the distributers must be less than the producer's (j) capacity in the (t) period.

Limitation of distributer's capacity (16): the number of transferred products from the distributer (k) to all customers must be less than the distributer's (k) capacity in the (t) period.

Limitation of customer capacity in each period and for each customer (17): the number of transferred product from the customer (c) to the collecting centers must be less than the maximum capacity of the customer's product (c).

Limitation of collecting center’s capacity in each period and for each collecting center (18): the number of transferred products from the collecting center (g) to disassembly center must be less than the collecting center’s capacity.

Limitation of disassembly capacity (19): the total number of (p) type pieces transferred from disassembly center (l) to producers and recycling centers and disposal centers must be less than (p) type piece capacity of the disassembly center (l).

Limitation of recycling capacity (20): the total amount of the recycled materials from recycling center (r) to the suppliers plus wasted materials (m) transferred from recycling center (r) to the disposal center must be less than recycled materials’ (m) capacity of the recycling center (r).

Limitation of supply budget (21): the total price of the bought pieces from the suppliers plus the pieces’ transfer cost from the suppliers to the producers plus the fixed supply cost from the suppliers must be less than the supply budget of the period.

Limitation of disposal centers’ capacity (22): the total number of the waste pieces from the assembly centers and the total amount of the waste materials from recycling centers (r) must be less than the disposal center capacity (re).

### 3.1 Uncertainty in supplier's supply and capacity parameters

The real conditions, complex nature, and competitive environment of supply chain increase the uncertainty of many parameters of the chain, which in most cases, is associated with a paucity and/or unavailability of information about the parameters. This study considered an uncertainty of triangular fuzzy type. This method is used to deal by the uncertainty of demand parameter and maximum part capacity provided by the supplier. Accordingly, mathematical concepts such as the expected values of a fuzzy number are used and confidence levels of satisfaction with constraints are determined by the decision maker. The triangular fuzzy programming model is shown as in Equation (23):

$$\begin{aligned} & Min\,Z = Cx + Fy, \\ & By \le Ay, \\ & Nec\{Tx \le Sy,\} \ge \beta, \\ & Nec\{Kx \ge \tilde{d}\} \ge \alpha, \\ & y \in \{0,1\},\ x \ge 0. \end{aligned} \tag{23}$$

The definitive model of Equation (23) is shown in Equation (24) [19].

$$\begin{aligned} & Min\,Z = Cx + Fy, \\ & \text{S.T.} \\ & By \le Ay, \\ & Tx \le ((1-\beta)S^{(2)} + \beta S^{(1)})y, \\ & Kx \ge (1-\alpha)d^{(2)} + \alpha d^{(3)} \end{aligned} \quad 24)$$

$$Ex \geq Uy,$$

According to the above, the determinate equivalent of the two fuzzy limitations will be as below: The determinate equivalent of demand limitation: Equation (25).

$$\sum_k y'_{kct} \geq (1-\alpha)dem_{ct}^{(2)} + \alpha dem_{ct}^{(3)} \qquad \forall t, c \tag{25}$$

The determinate equivalent to supplier's capacity limitation: Equation (26).

$$\sum_j x_{ijpt} \leq [(1-\beta)supmax_{ipt}^{(2)} + \beta * supmax_{ipt}^{(1)}]\, S_{it} \quad \forall p, i, t \tag{26}$$

## 4 Genetic algorithms

Researching on the genetic algorithm began right after research on artificial neural networks which in both branches of biological systems is inspired by the motivation and computational model. This algorithm has a repetitive process, and in each repetition, it works with a solution or several solutions. The genetic algorithm begins the search with a population of random initial solutions. If the final criteria not met, three different replication, mutation and integration operators used to update the population. Each repetition of these three operators is known as one generation [8].

Since the representation of solutions in the genetic algorithm is similar to that of natural chromosomes, and also the operators of the genetic algorithm act like genetic operators, they refer to the above process as the genetic algorithm. In fact, the genetic algorithm searches the solving space by repeating three simple steps. The first step evaluates a group of search points that are called populations based on the target function. In the second step, based on the assessed situation, some points selected as problem-solving candidates. In the third step, genetic operators applied to these candidates to make the next generation population. This process repeated until the final criteria obtained. The final criterion is when a result reached in the acceptable range or the maximum number of generations repeated.

The flow diagram for the genetic algorithm is presented in Figure. 1.

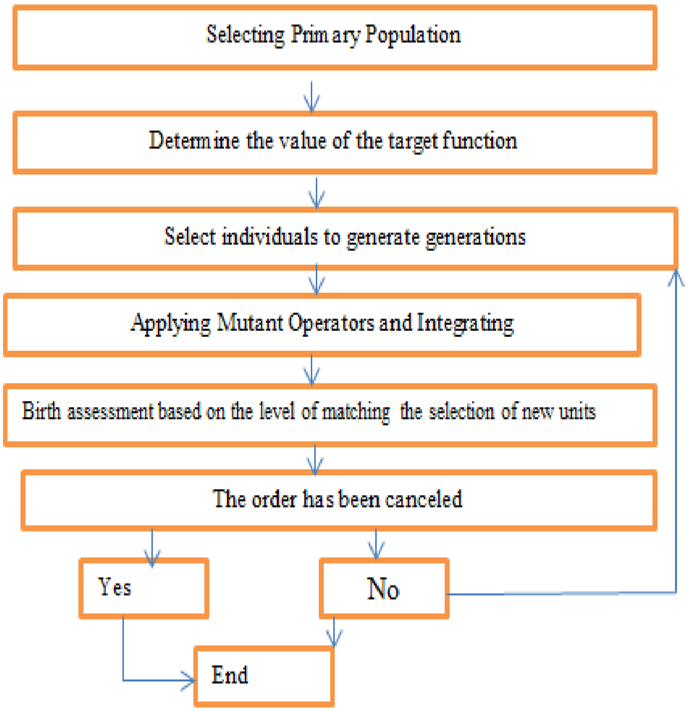


**Figure1.** Genetic algorithm

## 5. Data analysis and research findings

In order to solve the modeled problem, setting parameters was first carried out with Taguchi method. Then the proposed model was solved using NSGA-II algorithm.

### 5.1 Setting parameters

Meta-heuristic algorithms are very sensitive to their parameters, and changing these parameters significant affect their search styles. Taguchi method was used to set the parameters of the algorithms using the Minitab software, as shown in Tables 1.

**Table 1.**Parameters tested by genetic algorithm with designing Taguchi experiments

Parameters tested for the algorithm of NSGA-II

| Level | Npop | Crossover(nc) | Mutation(nm) |
|---|---|---|---|
| 1 | (350,400) | 0.6 | 0.1 |
| 2 | (400,450) | 0.7 | 0.15 |
| 3 | (450,500) | 0.8 | 0.2 |

The design of Taguchi experiments in Minitab software was tested in the form of orthogonal arrays (Figures 2 and 3).

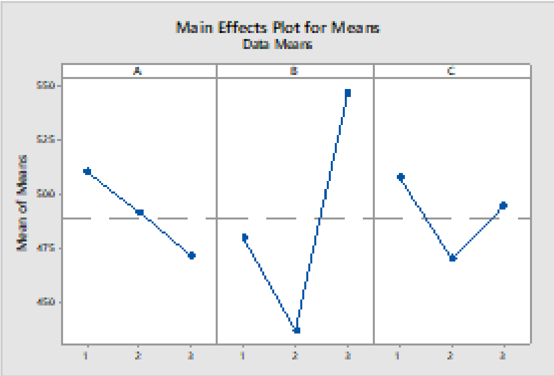


**Figure 3.** M/M diagram of NSGA-II

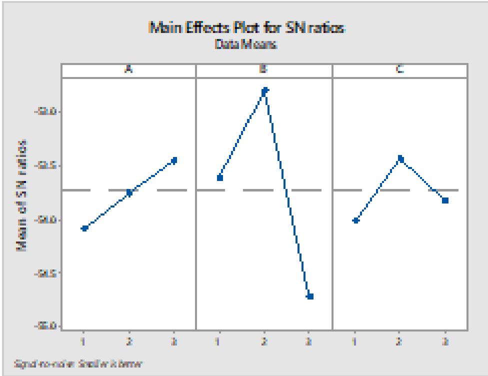


**Figure 2.** S/N diagram of NSGA-II

As can be seen, proper parameters for the two algorithms are as in Table 2.

**Table 2.**Confirmed parameters for the algorithms

Parameters tested for genetic algorithm

| Level | Population size, generation No. npop | Crossover nc | Mutation nm |
|---|---|---|---|
| 1 | (450,500) | 0.7 | 0.15 |

## 5.2 Solving the proposed model

The modeled problem was solved by NSGA-II algorithm using Matlab R2015a software in a 7-core computer with a 2.45 GHz processor and 8 GB of RAM. The algorithm was then run with 500 iterations. Given that the initial population was of 500 points, 350 points (Figure 4- d) for the genetic algorithm, which have the best possible conditions in the available decision space. A series of points are placed outside the range due to the search of solution points in NSGA-II algorithm based on minimum and maximum coordinates of the points in the range that considers a quadrangle space, but the targeted space is circular, hence, excluding all points outside the range. To achieve an optimal solution frontier, the values of objective functions were investigated for each final solution of the algorithm. In Pareto graphs, NSGA-II algorithm (Figure 4) indicates Pareto pairwise comparison of objective functions from the algorithm in Figures 4, a, b and c.

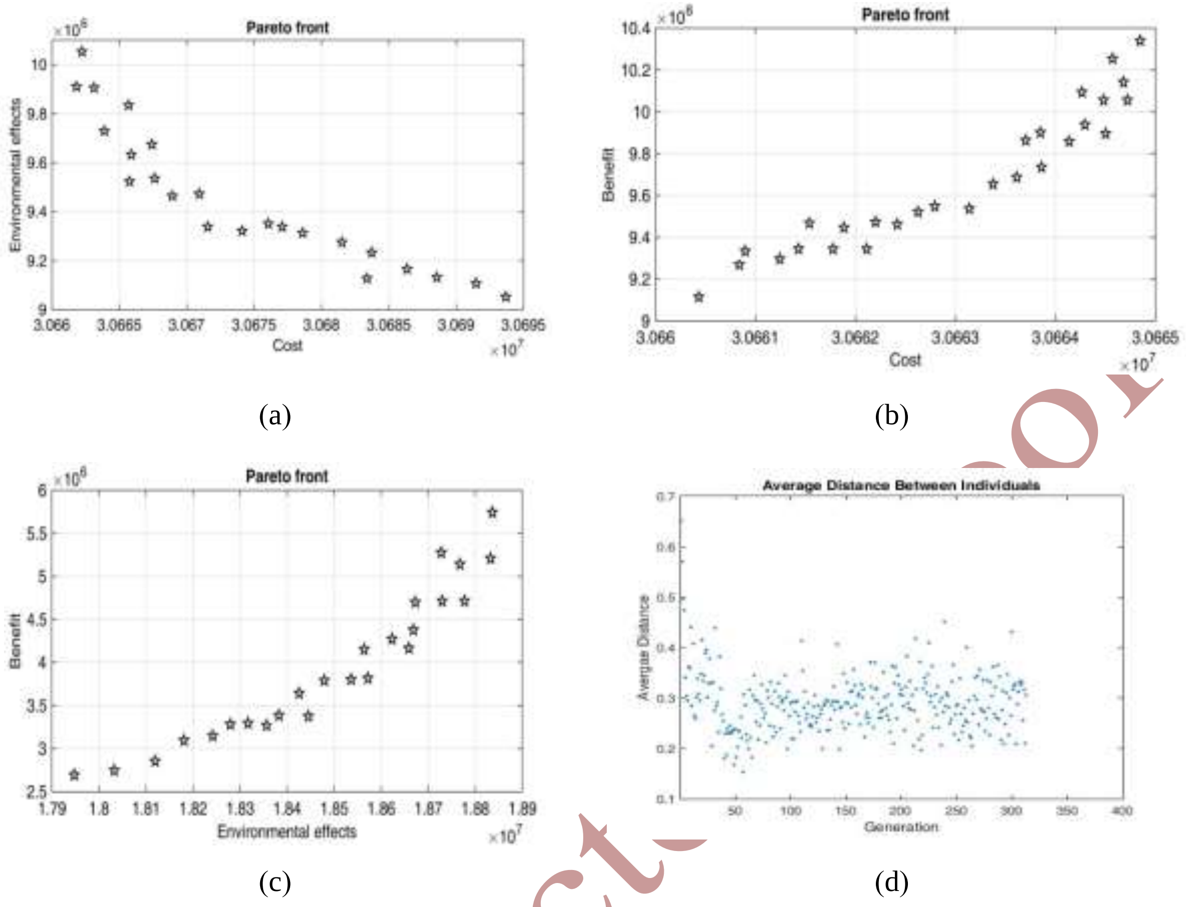


**Figure 4.**Pareto answer set using NSGA-II

## 5.3 Computational results

In this part, 12 problems were generated in different dimensions and an average of five implementations of NSGA-II algorithm was reported for the values of objective functions. Dimensions of the problems are shown with M × I × J × C, where M is the number of material markets, I is the number of suppliers, J is the number of producers, and C denotes customer centers. In the following, values for the target functions have been reported in Table 3.

**Table 3.**The values of the target functions

| Problem | Problems dimension M×I×J×C | NSGA-II | | |
|---|---|---|---|---|
| | | First goal | Second goal | Third goal |
| 1 | 30×25×30×30 | 1579507630 | 1259951971 | 895040625.7 |
| 2 | 33×27×35×35 | 1634444716 | 1290213492 | 1018150970 |
| 3 | 35×29×38×38 | 1798498298 | 1397356699 | 1053238589 |
| 4 | 40×32×42×42 | 2057761614 | 1630473226 | 1310795138 |
| 5 | 43×33×43×43 | 2292357189 | 1843773927 | 1671275405 |
| 6 | 46×36×46×45 | 2594314372 | 2143716886 | 2015556082 |
| 7 | 48×38×49×48 | 3076728067 | 2309491075 | 2057437773 |
| 8 | 50×40×50×50 | 3327409429 | 2407449179 | 2260876116 |
| 9 | 55×42×55×55 | 3952429702 | 2887766869 | 2355638397 |
| 10 | 58×45×58×58 | 4275113794 | 3327924302 | 2367348893 |
| 11 | 60×49×60×60 | 4952011631 | 3739420914 | 2781408570 |
| 12 | 65×50×65×65 | 5229687810 | 4165320425 | 2887793539 |
| | Average | 3064188688 | 2366904914 | 1889546675 |

## 6 Discussion and Conclusion

This research tries to provide a new and comprehensive model for designing a closed loop supply chain network, taking into account the environmental approach. Hence, by optimizing the network, management capabilities improve the organization's supply chain loops and solve real-world problems. The comprehensive model presented with the consideration of various components of the supply chain can help managers to locate and allocate new equipment. Also, attention to the results of this research will lead managers to rethink their organization's supply chain network design and related decisions and make such plans more efficient. In addition, it helps managers increase returns on profits, as well as their interest in addition to increasing profits and reducing costs to reduce negative environmental impacts. Finally, it can be said that attention to the comprehensive supply chain model presented in this study and its effective application brings along results , such as sustainable development, reduction of environmental degrading effects, consideration of optimal use of energy and natural resources, as well as the reuse of depleted products, Reducing the cost of returning products and improving company reputation.

This research, combined with an integrated approach, with regard to forward and reverse flows, not only optimizes the level of customer satisfaction, but also economically reduces re-production costs and even profits from the sale of recycled materials. The results indicate that taking into account the collection centres, in addition to improving the quality of the recycled product and saving the costs, leads to lower costs of construction and commissioning. The main purpose of setting up collection centres and recycling of consumable products is that the customer can always have a better product at a lower cost, and the government will also achieve its goals of reducing environmental damage and less use of raw materials.

The purpose of this study is to develop a new mathematical model for closed loop supply chain network. According to research literature, in most studies, the demand and maximum component capacity provided by the supplier are assumed to be definitive, whereas in the real world the demand and the maximum parameter of the component capacity offered by the supplier are uncertain. Therefore, to solve the problem, the above variables are fuzzy in uncertainty conditions, and by optimizing three functions, the objective of cost, profit, and environmental impacts defined. According to the NP-hard, an efficient algorithm was suggested based on the genetic Meta heuristic algorithm to solve it. Twelve numerical problems were defined and solved using the NSGA-II algorithm to validate the model. The results obtained from the Pareto graphs show the genetic algorithm have an appropriate performance for solving the model.

**For future studies, the following suggested:**

Model development by considering several products instead of single products

Considering the environmental-related objective functions including Green Packaging, Clean Technology, Environmental Certificates

Using a robust planning approach and comparing its results with linear and fuzzy scheduling

Solve the model with other Meta heuristic algorithms and compare their results with each other

Considering the uncertainty conditions for other parameters

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