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Optimization of multi-echelon reverse supply chain network using genetic algorithm

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Abstract

Remanufacturing products has been more popular in recent years among businesses as a result of environmental concerns, and the close loop supply chain (CLSC) network has been used to optimise the reverse logistic system. The objective of the current study is to identify the ideal CLSC network, which consists of several producers, remanufacturers, intermediary centres, and customer centres. The consideration of a multi-product, multi-echelon, closed loop supply chain network (CLSC) model for returns products, in which choices about the procurement of materials and their production, distribution, recycling, and disposal play a significant part, is necessary to meet the work's objectives. In order to resolve the issue more cheaply, a mixed-integer linear programming (MILP) approach is used. Genetic algorithm (GA) is applied as a solution approach in this.

Subject Classification: *90B06 Logistics, 90C11 Mixed integer programming.*

Keywords: *Optimization, SCM, Reverse logistic, Genetic algorithm, Echelon.*

1. Introduction

Managers strive to improve procurement, demand management, and order fulfilment in the forward supply chain. In supply chain management (SCM), the actions of gathering and retrieving product returns are referred to as the reverse supply chain (RSC) [5]. A site location model for a basic reverse supply chain network is provided in this paper. Multiple facilities

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(producing and reproducing) demand marketplaces, collecting centres, and goods are all included in the model. The aim is to figure out how many, where and which plants and collecting centres must be open, as well as what items and in what amounts they should store. The objective function seeks to reduce the total cost as much as possible [2].

1.1 *Supply Chain Networks:*

A supply chain network, which examines the programmes and policies that affect the supply chain, describes the transaction of both information and commodities. Keeping costs as low as feasible was the goal function for many supplies chain networks. They deliver as planned during typical times when demand is predictable [1]. To set themselves apart from the competition, supply chain executives are expected to continually adopt new technologies. Adopting the correct mix of various supply chain innovations moving elements into a single, unified framework capable of guiding effective decision-making is a time-consuming and challenging task [8].

1.2 *Reverse Supply Chain*

The backward supply chain is the process of moving a product from a client back to a vendor/supplier/retailer, which is practically the opposite of a typical supply chain. Disposal or cleaning,

Pickups, repairing, sorting, repackaging, and finally Reshipping is an important aspect of the reverse supply chain management process. [1][9].

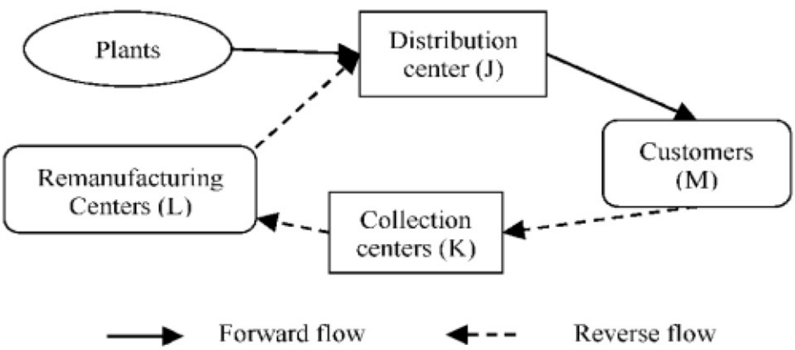

Figure 1

Structure of Reverse Supply Chain

In figure 1 the backward flow of commodities from consumer to supplier is the focus of a backward supply chain, with the purpose of increasing return goods' worth or lowering total reverse logistics costs [12].

2. Literature Review

Amin, S. H. et. al. [1] provided a MILP model to find out how much the closed-loop supply chain (CLSC) network costs. Cui, Y. Y et. al. [3] discussed result compare with genetic algorithm (GA) and artificial bee colony (ABC). Rasi, R. E. et. al. [10] A MILP approach for streamlining the supply chain network for several objectives was created to combine economic and environmental variables. Khan, S. H. et. al. [7] formulated the network has been optimized using a bi-objective MILP model using a Goal Programming technique and Genetic Algorithm.

Diabat, A. et. al. [5] developed an example MINLP was used to predict the quantity and location of the first centralized return and collection centres, as well as the maximum holding period, for an effective return and collection system. Safaei, S. et. al. [11] The goal of this study was to reduce total expenses by matching a specified service level to demand while also taking into account the cost of not meeting the complete amount of demand. Goli, A. et. al. [6] According to the research assumptions, a bi-objective mathematical model is offered, as well as a function showing the link between the amount of demand and the price. The model was solved using LP-metric and goal programming techniques.

3. Problem description and mathematical model:

The considered problem is an illustration of a network issue with the reverse supply chain. The cost of moving goods that are new or have been returned from one plant to another is detailed in Table 1 and the cost unit in the Chinese yuan (CNY). (Chinese Yuan). The number of returned goods, product demand, and facility fixed costs are among the variables Reverse flows are utilized at each facility site.

3.1 *Mathematical Model*

A Model for MILP can be used to describe the network of figure 2. The following is a list of sets, constraints, and deciding factors:

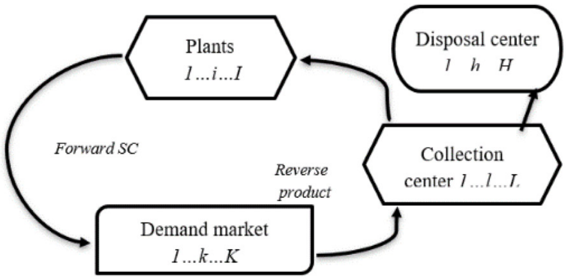

Figure 2

Reverse Supply Chain Networks with Closed Loop

Sets

I = set of producing and reproducing plant's locations (*1 ... i ... I*); *J* = set of locations demand markets (*1 ... j ... J*); L = set of collection center's locations (*1 ... l ... L*);

H = set of disposal centers (*1 ... h ... H*)

Parameters

U_i = fixed cost for startup plant i ; V_l = fixed cost for startup collection centre l;

P_i = production cost of product ; T_{ij} = Product transportation costs between facilities and demand markets ; R_{jl} = product transportation cost between demand markets and collection centres ; S_{li} = product transportation cost between collection centres and plants ; D_{lh} = product transportation cost between collection centers and disposal centers ; Q_h = disposal cost of product ; M_i = product production capacity of plant i

N_l = product production capacity collection centre l; d_j = quantity of demand of customer j; r_{kj} = quantity of return of customer j ; α =minimum product disposal fraction j

Variables

A_{ij} = product quantity produced by plant i for demand market j

B_{jl} = number of returned products from the demand market j to the collecting centre l C_{li} = number of returned products from collection centre l to plant i

G_{lh} = number of returned products from collection centre l to disposal centre

Z_i = 1, if a plant is situated there and set up at potential site i, 0, otherwise

W_l = 1, if a collection centre is situated there and set up at potential site l, 0, Otherwise

$$MinZ_1 = \sum_i U_i Z_i + \sum_l V_l W_l + \sum_i \sum_j (P_i + T_{ij}) A_{ij} + \sum_j \sum_l R_{jl} B_{jl} + \sum_l \sum_i S_{li} C_{li} + \sum_l \sum_h (Q_h + D_{lh}) G_{lh}$$

$s.t.$

$$\sum_i A_{ij} \ge d_j, \forall j \quad ...(1) \qquad \sum_l B_{jl} \le \sum_i A_{ij}; \forall j \quad ...(2)$$

$$\sum_l C_{li} + \sum_j A_{ij} \le Z_i M_i, \forall i; \quad ...(3) \qquad \sum_j B_{jl} \le W_l \sum_j N_j, \forall l \quad ...(4)$$

$$\alpha \sum_j B_{jl} \le \sum_h G_{lh}, \forall l; \quad ...(5) \qquad \sum_j B_{jl} = \sum_i C_{li} + \sum_h G_{lh}, \forall l \quad ...(6)$$

$$\sum_j B_{jl} = r_j, \forall j; \quad ...(7) \qquad Z_i, W_l \in \{0,1\}, \forall i, l \quad ...(8)$$

$$A_{ij}, B_{jl}, C_{li}, G_{lh} \ge 0 \ , \forall i, j, l, h \quad ...(9)$$

The goal of this challenge is to reduce total expenditures. The fixed costs of establishing plants and collection centers are shown in the first and second portions, respectively. The third section depicts the costs of new product development and transportation. The fourth section is on product recovery and the expenses of returning things. In addition, the fifth section covers the overall expenses of product recovery and transportation from collecting centers to factories. In addition, the sixth section evaluates the expenses of disposal and transportation. The restriction (1) guarantees that for any demand market, the total number of manufactured products is same or higher than to the complete order. according to eq. (2), The forward flow is larger than backward flow. Plant capacity is restricted in eq. (3). The eq. (4) indicates the capacity constraints. The eq. (5) requires each product to have a lowest disposal percentage. For each collecting center and product, eq. (6) states that the number of reversed goods from the demand market equals the number of reversed goods to plants and total goods in the disposal center. The reversed goods are shown in eq. (7). The eq. (8) assures that choice variables are binary, while eq. (9) ensures that decision variables are non-negativity restricted.

4. Methodology

4.1 *Genetic Algorithms*

One of the most sophisticated feature selection methods is the genetic algorithm. The first step of the genetic algorithm is to create a

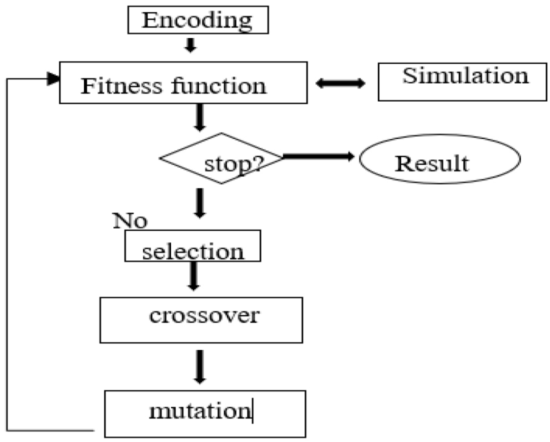

Figure 3

A flowchart showing how a genetic algorithm operates

population of potential solutions. The starting population of the genetic algorithm was generated randomly. There are members of the population in this population known as chromosomes. A population of individuals is used by genetic algorithms to gradually improve approximations. Every generation, the algorithm generates a new population by selecting individuals based on their problem domain fitness in figure 3.

The proposed algorithm has some steps as follow:

- Initial Population
- Fitness-related activities
- Processes of selection
- Crossover
- Mutation

Numerical Illustration:

We have taken three numerical problems of daily real life. It is based on reverse supply chain networks. first problem is a small, second is middle and third problem large problem. Problem-1, problem-2 and problem-3 have nodes 5,8, and 12 respectively. table 1, 2, 3 are here describe the cost of transporting new and rejected goods from plant to another, with the unit of cost being Chinese Yuan. The total rejected items, product demand, and facility fixed costs are among the variables used at each facility site for reverse flows. The costs of each pair of all destinations are given in the following: The distances of each pair of the problem are given. This supply chain problem contains different transportation costs between two nodes. In this problem, we have considered the node 'A' as distribution center.

Table 1

Product and returned product transportation costs between various destination [3]

Destination Places	A	B	C	D	E
A	0	10	20	25	20
B	10	0	15	17	13
C	20	15	0	10	10
D	25	17	10	0	12
E	20	13	10	12	0
F	35	25	15	13	12
G	10	12	22	30	15
H	14	10	20	28	12

In this problem, one point is a distribution center and 4 customer points. The genetic algorithm (GA) provides an optimal solution of problem-1 with minimum cost 47 (including return cost) solved in python.

Table 2

Product and returned product transportation costs between various destination [3]

Destination Places	A	B	C	D	E	F	G	H
A	0	10	20	25	20	35	10	14
B	10	0	15	17	13	25	12	10
C	20	15	0	10	10	15	22	20
D	25	17	10	0	12	13	30	28
E	20	13	10	12	0	12	15	12
F	35	25	15	13	12	0	27	24
G	10	12	22	30	15	27	0	10
H	14	10	20	28	12	24	10	0

In this problem, one point is a distribution center and 7 customer points. GA gives an optimal solution of problem-2 with minimum cost 106 (including return cost) solved in python.

Table 3

Product and returned product transportation costs between various destination [3]

Destination Places	A	B	C	D	E	F	G	H	I	J	K	L
A	0	5	15	20	15	30	15	18	27	30	32	37
B	5	0	5	15	10	25	13	15	16	17	18	20
C	15	5	0	10	5	15	20	15	7	18	15	10
D	20	15	10	0	7	5	22	17	10	17	13	8
E	15	10	5	7	0	8	10	5	10	12	14	16
F	30	25	15	5	8	0	20	15	5	18	16	8
G	15	13	20	22	10	20	0	5	10	8	11	20
H	18	15	15	17	5	15	5	0	6	5	8	13
I	27	16	7	10	10	5	10	6	0	8	6	8
J	30	17	18	17	12	18	8	5	8	0	5	10
K	32	18	15	13	14	16	11	8	6	5	0	6
L	37	20	10	8	16	8	20	13	8	10	6	0

There is a total of 12 cites in this problem which has 7 consumer centers, 2 middle centers, and 3 locations that must be assigned to identify the facilities in question.

We have taken 8 initial populations for this problem follow as:

C1	→	B	F	C	H	I	G	J	K	D	E	L
C2	→	C	D	F	H	I	B	G	K	J	L	E
C3	→	H	C	F	B	J	G	I	K	E	D	L
C4	→	I	F	B	C	G	H	K	J	L	E	D
C5	→	L	B	H	C	I	L	G	J	E	D	K
C6	→	K	J	F	B	E	C	H	I	G	J	D
C7	→	E	B	F	C	H	I	J	G	K	E	D
C8	→	B	L	F	H	C	I	J	G	D	E	K

We have calculated the fitness value of all initial populations as cost between two places.

C_1=125, C_2=122, C_3=143, C_4= 133, C_5= 162, C_6=151, C_7= 134, C_8= 129

Roulette Wheel selection method (RWSM) has been used to pick-up eight fittest solutions from initial populations and applied 3-point crossover to reproduce generation. Selected four minimum costs: C_1=125, C_2=122, C_4= 133, C_8= 129

Crossover:

B	F	C	H	I	G	J	K	D	E	L
C	D	F	H	I	B	G	K	J	L	E

I	F	B	C	G	H	K	J	L	E	D
B	L	F	H	C	I	J	G	D	E	K

After crossover

C	D	F	H	I	G	J	K	J	L	E
B	F	C	H	I	B	G	K	D	E	L

B	L	F	H	G	H	K	J	D	E	K
I	F	B	C	C	I	J	G	L	E	D

After mutation:

C	D	F	H	I	G	J	K	B	L	E	J ⇒ B
J	F	C	H	I	B	G	K	D	E	L	B ⇒ J
B	L	F	H	G	C	K	J	D	E	K	H ⇒ C
I	F	B	H	C	I	J	G	L	E	D	C ⇒ H

Now C_{21}=128, C22= 160, C_{24}= 131, C_{28}= 153

Selected two minimum costs: C_{21}=128, C_{24}= 131

Again, operate crossover on these populations.

C	D	F	H	I	G	J	K	B	L	E
B	L	F	H	G	C	K	J	D	E	K

After crossover.

B	L	F	H	I	G	J	J	D	E	K
C	D	F	H	G	C	K	K	B	L	E

After Mutations process

B	L	F	H	I	G	J	C	D	E	K	J C
C	D	F	H	G	C	K	J	B	L	E	K ⟹ J

Then C_{31}= 5+20+8+15+6+10+8+20+10+7+14 = 123;

C_{34} =15+10+5+15+5+20+15+5+17+20+16 = 143

So minimum cost is C_{31}= 123. In this problem, one point is a distribution Centre and 11 customer points. GA gives an optimal solution of problem-3 with minimum cost 85 (including return cost) solved by python. For the small, medium, and large-scale issues, a graphical approach is utilized to determine the appropriate level of algorithmic parameters. Python calculates the optimal set of conditions for a small problem (problem 1) at every level of the parameter, as shown in Figure 4.

Solution set for problem 1

S. No.	Solutions (1)
1.	81.714218032718578
2.	68.663300320139971
3.	61.623754376871093
4.	73.434535019754049
5.	62.783165631296291
6.	70.588259842236245
7.	71.804867933868650
8.	57.305075352086463
9.	71.018353662253692

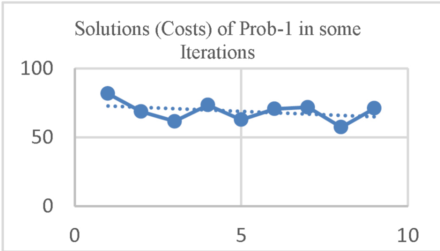

Figure 4

Solution set for problem

S. No.	Solutions (2)
1.	178.74704338998341
2.	108.56838296990194
3.	124.58163484596517
4.	133.29169761080823
5.	108.22757222593881
6.	131.39085223290795
7.	132.82841526877772
8.	136.12696056183347
9.	129.35030378757843

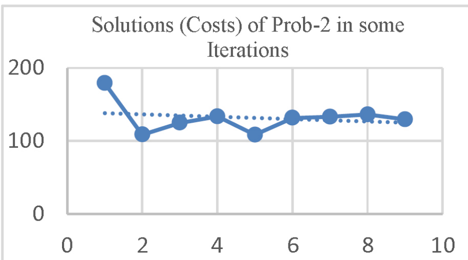

Figure 5

The best parameter setting for medium (problem-2) and large problem (problem-3) is obtained by python for each of the parameter levels, as shown in Figure 5 and Figure 6 respectively.

Solution set for problem 3

S. No.	Solutions (3)
1.	100.49925737617912
2.	93.27915772898106
3.	89.59211563061862
4.	101.75316640410054
5.	87.77229635284303
6.	112.19946752322981
7.	110.47423053980467
8.	95.86246785076406
9.	85.32067181351084

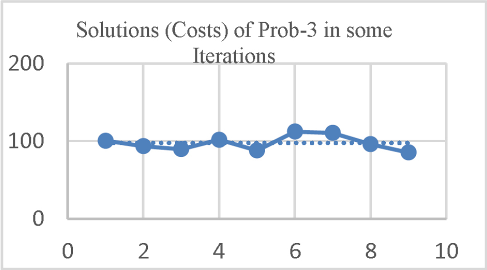

Figure 6

Results: For each distribution centre (DC) in our supply chain network, we have discovered the optimum outcomes for delivering specific items at its lowest cost of problem-1, 2 and 3. There are some optimal solutions for respected DC. In this section, the presented GA is used to analyze small, medium, and large-scale network optimization problems utilizing the best parameter values found in Python. The network solution of these problems obtained from GA algorithm is indicated in Figure 4, Figure 5, and Figure 6 respectively. Finally, we have found the optimal costs 47, 106 and 85 of the problem-1, problem-2 and problem-3 respectively.

5. Conclusion

Recent research has put forward the optimisation of facility placement in a CLSC network. The envisioned CLSC network includes producers, remanufacturers, intermediary centres, and customer centres. To optimise the multi-echelon, multi-product supply chain network using the genetic algorithm (GA), we introduced a mixed integer linear programming model (MILP) in this research. Future study on the work already done, an improvement of closed-loop logistics in a time-constrained supply chain, pricing changes for diverse products, etc.

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