STATISTICS, OPTIMIZATION AND INFORMATION COMPUTING
Stat., Optim. Inf. Comput., Vol. **8**, June 2020, pp 0–9.
Published online in International Academic Press (www.IAPress.org)

Optimal Multi-echelon Integrated Supply Chain Selecting Best Supplier and Distributor using Multi-objective Genetic Algorithm

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Abstract Supply chain managers across the globe are struggling to integrate and utilize core competencies of supply chain players, so that goods are manufactured and delivered at right time while minimizing cost and satisfied customers demand. In this model we have discussed the problem of supplier and distributor selection for an optimal supply chain. Where both selection is done on the basis of multi-criteria like offer price, limited supply and storage capacity, delivery time, geographic location, quality etc. On the basis of these multi-criteria we have formulated multi-objective mathematical model. We have optimized this model using *multi-objective Genetic algorithm and visualized by parallel coordinates plot*. In the end, numerical example is carried out to justify the feasibility of the model. The present model deals with an integrated multi-echelon supply chain that reduce the total cost of supply chain by allocating optimal supplier and distributor to the manufacturer and retailer respectively.

Keywords Supplier selection, Multi-echelon integrated inventory model, Multi-objective optimization, Visualization, Parallel coordinates plot

AMS 2010 subject classifications 90B85, 90C26.

DOI: 10.19139/soic-2310-5070-446

1. Introduction

Due to globalization of world, today organizations are outsourcing the different activities. In outsourcing activities, the selections of the supply partner place an important role. For selecting supplier's on several criteria Timmerman [7] formulated linear weighting models. Weber and Current [3] firstly use *Multi-objective programming* (MOP) for selecting vendors under multiple criteria. In that different constraint affect the number of vendors to employ. That problem was solved by Weber *a*t el. [4] with data envelopment analysis (DEA) tool. Amin and Zhang [19] A formulated model for integrated close loop supply chain configuration. Shaw *a*t el. [11] generated multi-objective model and optimize it by Fuzzy AHP and Fuzzy Multi Objective Linear Programming. Seifbarghy and Esfandiari [14] proposed supplier selection model with transportation cost. Model formulation of supplier pre-selection platform-based products was done by Cao *a*t el. [22] formulated model in the Presence of Dual-Role Factor. Moreover, not only in supply chain but whenever conflict nature objective occurs then Multi-objective programming gives better result so Verma [17] formulated second order generalized hybrid invexity frameworks for MOP. Further that used by Roman *at el.* [6] for optimizing dengue transmission model.

MPO gives set of pareto optimal front solutions. From that we select appropriate optimum solution. To visulize all in terms of quality, shape and distribution of solution set different methods are given by different

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ISSN 2310-5070 (online) ISSN 2311-004X (print)

researchers.Obayashi and Sasaki [18],Pryke *a*t el.[1], Tusar and Filiplic [21], He and Yen[23], Li *a*t el. [13],Ibrahim *a*t el.[2] gave self-organizing map, heatmap, presection method, performance metric, parallel co-ordinate, Radvis methods respectively.

Genetic algorithm is inspired by Darwin's theory "Survival of fittest". It is an evolutionary algorithm based on natural selection process. Algorithm begins with a initial population and then chromosomes with fitness score has been to reproduce next population. After appying genetic algorithm for machine learning by Schaffer[10] different researcher worked on GA to solve their problem. Srinivas and Deb [15] used non-dominated GA to solve their multi-objective optimization problem. Murata *a*t el. [20] using multi-objective GA for flowshop scheduling problem.Parks *a*t el. [8] done selection of breeding using multi-objective GA. Basnet and Weintraub [5] formulated supplier selection under bi-cretia and solved using multi-objective GA. In some complex problem it is observe that when global optimized stuck with local optimized value then ga gives better results like Talati and Mishra [9] and Mishra and Talati [16]. This paper is formated as follows.In section 2 Problem description is discussed. Section 3 contain notations and assumption those used to formulate mathematical model. Using assumption multi-echelon inventory model is formulated in section 4. Section 5 gives overview of multi-objective genetic algorithm. Numerical example is carried out in section 6. The results and observations are carried out in section 7.

2. Problem description

The problem of selecting the supply partners for an organization is given in present model. The question is to select the best supplier and best distributor to find the optimal total cost of the entire supply chain. The pictorial representation of present model is given below in Figure 1. This model is for p items.

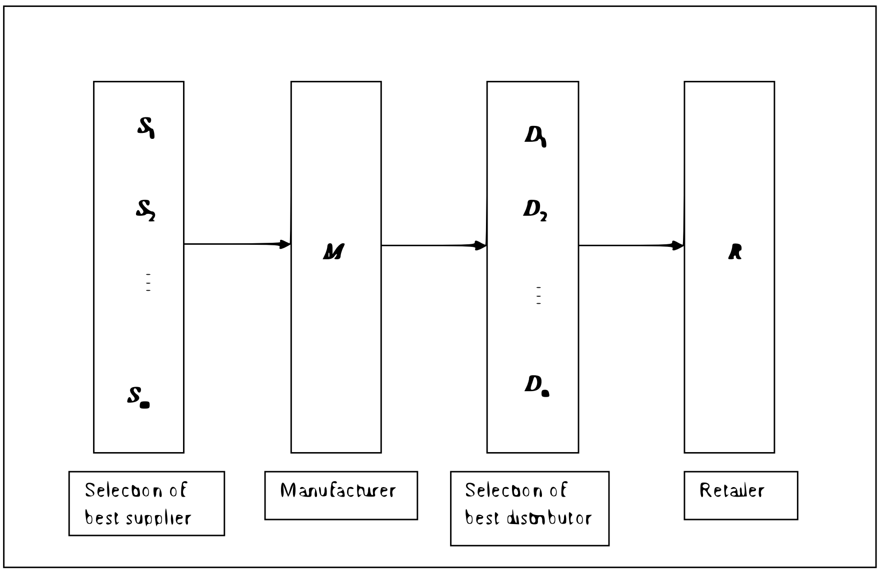

Figure 1. Present model

Price (include transportation cost), quality, delivery time and supplier supply capacity for each items are used to evaluate best supplier. While price, distribution area, delivery time and storage capacity are taken into consideration to select best distributor.

3. Notations and Assumptions

3.1. Notations

$i = 1, 2, ..., p$	Index of items
$j = 1, 2, ..., m$	Index of candidate suppliers
$k = 1, 2, ..., n$	Index of candidate distributors
D_i	Demand of item i
P_i	Processing price of manufacturer for item i
T_k	Transportation cost for distributor k to retailer
P_{ij}	Price from supplier j to manufacturer to supply item i /unit ($)
$P_{ik}^{'}$	Price from manufacturer to distributor k to receive item i /unit ($)
C_{ij}	Supply capacity of supplier j to supply item i
$C_{ik}^{'}$	Storage capacity of distributor k to store item i
q_{ij}	Defective quality of supplier j when supplying item i
Q_i	Acceptable quality for item i
$A_{ik}^{'}$	Outside distribution area of distributor k when distribute item i
$A_i^{'}$	Acceptable outside distribution area for item i
l_{ij}	Late delivery of supplier j when supply item i
L_i	Acceptable delivery for item i
$l_{ik}^{'}$	Late delivery of distributor k when distribute item i
$L_i^{'}$	Acceptable delivery for item i
TC	Total cost for item i
PUC	Total purchasing cost for item i
PRC	Total processing cost for item i
TRC	Total manufacturer to distributor transportation cost
MIC	Total manufacturer inventory carrying cost
DIC	Total distributor inventory carrying cost
RIC	Total retailer inventory carrying cost
INC	Total inventory carrying cost for system

3.2. Assumptions

- Demand of customer is deterministic.
- Supplier's supply capacity of each item is limited.
- Supplier selection is done on the base of quality and delivery performance.
- Distributor selection is done on the base of distributor coverage area and delivery performance.
- Distributor's storage capacity of each item is limited.
- Transportation cost per item from supplier to manufacturer and manufacturer to distributor are included into price.
- Inventory carrying cost at any player of supply chain remains fixed.

4. Multi-echelon inventory model

Here we want to minimize the total cost of supply chain for different items so our objective function of the mathematical model is given below

$$TC = PUC + PRC + TRC + INC \tag{1}$$

The basic costs involved as below.

Purchasing cost:
Purchasing cost is defined as follow

$$PUC = \sum_i \sum_j x_{ij} P_{ij} \tag{2}$$

Where x_{ij} =order quantity of i^{th} item from j^{th} supplier
Processing cost:
Here we take constant processing cost for different items.

$$PRC = \sum_i x_i P_i \tag{3}$$

where $x_i = \sum_j x_{ij}$
Transportation cost:
Transportation from distributor k to retailer is given below

$$TRC = \sum_i \sum_k y_{ik} T_k \tag{4}$$

Wherey_{ik} = order quantity of i^{th} item from manufacturer to distributor k
Inventory carrying cost:
Here we take fix carrying cost per item for any player of supply chain

$$INC = xMIC + yDIC + yRIC \tag{5}$$

Where $x = \sum_i x_i; y = \sum_i y_i$
The constraints are involved in present model are the following
All the items customer demand must be fulfill by supplier.

$$\sum_j x_{ij} \geq D_i \tag{6}$$

Quality supply by supplier to manufacturer is less than or equal to supply capacity of supplier.

$$x_{ij} \leq C_{ij} \tag{7}$$

Aggregate quality supply by supplier to manufacturer must be acceptable

$$\sum_j x_{ij} q_{ij} \leq Q_i D_i \tag{8}$$

Aggregate delivery time taken by supplier to manufacturer must be acceptable

$$\sum_j x_{ij} l_{ij} \leq L_i D_i \tag{9}$$

All the items customer demand must be fulfill by distributor.

$$\sum_k y_{ik} = D_i \tag{10}$$

Quality supply by manufacturer to distributor is less than or equal to storage capacity of distributor.

$$y_{ik} \leq C'_{ik} \tag{11}$$

Aggregate distribution area covered by distributor must be acceptable

$$\sum_k y_{ik} A^{'}_{ik} \leq A^{'}_i \tag{12}$$

Aggregate delivery time taken distributor to retailer must be acceptable

$$\sum_k y_{ik} l^{'}_{ik} \leq L^{'}_i D_i \tag{13}$$

So, for best supplier selection we have following objective function and cionstraints

$$\min f = \sum_i \sum_j x_{ij} P_{ij} \tag{14}$$

$$\bar{s}ubject\ \ to\ \ \sum_j x_{ij} \geq D_i; x_{ij} \leq C_{ij};$$

$$\sum_j x_{ij} q_{ij} \leq Q_i D_i; \sum_j x_{ij} l_{ij} \leq L_i D_i$$

And for best distributor selection we have following objective function and cionstraints

$$\min g = \sum_i \sum_k y_{ik} P^{'}_{ik} \tag{15}$$

$$\bar{s}ubject\ \ to\ \ \sum_k y_{ik} \geq D_i; y_{ik} \leq C^{'}_{ik};$$

$$\sum_k y_{ik} A^{'}_{ik} \leq A^{'}_i; \sum_k y_{ik} l^{'}_{ik} \leq L^{'}_i D_i$$

Where x_{ij} and y_{ik} are decision variables.

5. Multi objective genetic algorithm

5.1. Multi-objective optimization

A multi-objective optimization problem (MOP) can be written as

$$\min(\bar{f}(\bar{x})) = (f_1(\bar{x}), ..., f_p(\bar{x}))$$
$$subject\ \ to\ \ \bar{c}(\bar{x}) < 0$$

Where $\bar{x} \in S$(Feasible region);$f_i : R_n \rightarrow R_m$are objective functions;$\bar{c}(\bar{x})$ are constraint functions.

MOP minimizes all objective function simultaneously. If objectives are complex then it is not possible to find single solution that optimize objective functions simultaneously. So in this case we found some optimal solutions so that their values can be improved without relaxing of at least one of the other objective values. These solutions are called Pareto-optimal solution. The set of all Pareto optimal is called Pareto-optimal front. For selecting one solution from Pareto-optimal front we have different visualization methods like Scatter plot matrix, Heat map, Self-organizing maps, 3DRadVis, Parallel Coordinates Plot etc.

In proposed model we use Parallel Co-ordinates Plot to visualize the distribution, range, and trade-off among Pareto-optimal front. An M-dimensional objective is represented by polyline with vertices of M-parallel axes place among X-axis. The parallel axes are M equidistant vertical bars along the X-axis for each solution. The Y-axis corresponds to the range of values for each objective. The limitation of Parallel Co-ordinate Plot is that it does not show the shape of pareto front but it simple to construct for large number of objectives to show dependencies among objectives without the loss of data in the representation.Figure 2 repesent the example of Parallel Co-ordinate Plot.Considered a(15,35,25,55), b(10,15,3,30), c(20,5,35,20).

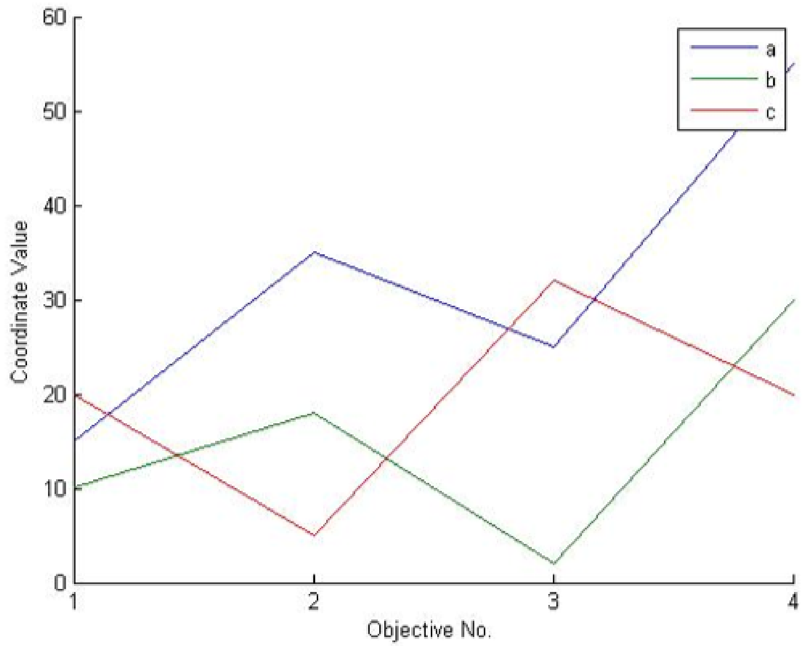

Figure 2. Parallel Co-ordinate plot for three objects

In MOP the fundamental criterion to compare solutions in terms of convergence is Pareto dominance.Parellel co-ordinates can clearly show Pareto dominance relation between two solution. As shown in Figure 2 polyline ”a” is clearly dominated by ”b” (considering minimization problem).And for polyline ”c” is domined by ”b”.So polynomial ”b” is minimum solution. Parellel co-ordinate plot display all possible solution set parallely for comparision.

5.2. Multi-objective Genetic algorithm

Genetic algorithm (GA) start with set of population, called Chromosomes. In iterations of GA, selection of individuals is done on the basis of fitness score of chromosomes for crossover and mutation to produce new chromosomes. Thus new set of population is generated for next iteration. The iterations are continuing until a solution with desired tolerance is not achieved. Since GA generates multiple solutions,it goes well with MOP as MOP require it to identify non-interior solutions.

When we use GA for MOP selection of matting pair create an issue. For resolve this issue different researcher use different methods like give different random weights to objective, separated population into subpopulation etc. Here we separate population into subpopulation on the base of items.

We have m suppliers and n distributors. So in multi objective GA total chromosomes for suppliers and distributors are 2^m and 2^n respectively. We convert multi object problem on the base of different items. Thus allocating items for best suppliers are different p linear programs.

$$\min f = \sum_i x_{ij} P_{ij} \tag{16}$$

$$\bar{s}ubject\ \ to\ \ \sum_j x_{ij} \geq D_i; x_{ij} \leq C_{ij};$$

$$\sum_j x_{ij} q_{ij} \leq Q_i D_i; \sum_j x_{ij} l_{ij} \leq L_i D_i$$

And allocating items for best distributors are different p linear programs.

$$\min g = \sum_i y_{ik} P'_{ik} \tag{17}$$

$$\bar{s}ubject\ \ to\ \ \sum_k y_{ik} \geq D_i; y_{ik} \leq C'_{ik};$$

$$\sum_k y_{ik} A'_{ik} \leq A'_i; \sum_k y_{ik} l'_{ik} \leq L'_i D_i$$

6. Numerical examples and sensitivity analysis

Consider supply chain with 3 suppliers,1 manufacturer,3 distributor and 1 retailer
$D = 50;\ L_i = Q_i = A'_i = L'_i = 3\%; P_1 = 10(\$/unit); P_2 = 8(\$/unit); P_3 = 9(\$/unit); T_1 = 1.2(\$/unit);$
$T_2 = 1.45(\$/unit); T_3 = 1.5(\$/unit); MIC = 2(\$/unit); DIC = 4(\$/unit); RIC = 1.5(\$/unit)$
supplier and distributor information are given in Table 1 and Table 2 respectively.

Table 1. Supplier Information

Supplier	Supplier 1			Supplier 2			Supplier 3		
Items	1	2	3	1	2	3	1	2	3
Price($)	8	7	9	11	12	7	9	11	14
Supplier capacity	180	120	80	100	120	160	150	120	100
Quality (%)	0.1	0.7	0.2	0.6	0.1	0.1	0.1	0.2	0.3
Late delivery(years)	0.1	0.3	0.3	0.4	0.5	0.2	0.2	0.3	0.1

Table 2. Distributor Information

Distributor	Distributor 1			Distributor 2			Distributor 3		
Items	1	2	3	1	2	3	1	2	3
Price($)	20	28	19	23	27	20	24	25	22
Supplier capacity	280	120	480	320	80	400	240	160	260
Distributor area (%)	0.2	0.3	0.2	0.1	0.2	0.1	0.4	0.2	0.1
Late delivery(years)	0.2	0.1	0.3	0.2	0.1	0.1	0.2	0.1	0.3

Supplier selection:

Using multi objective GA in Matlab14a we get set of optimal solutions.Those show in Table-5(Appendix)

Using parallel co-ordinate method we visualize appropriate optimal solution from Pareto-optimal front. That visualize by Figure 3. As shown in Figure 3 X-axis represent solutions and Y-axis repesent related total cost f_1, f_2 and f_3 for the three items.

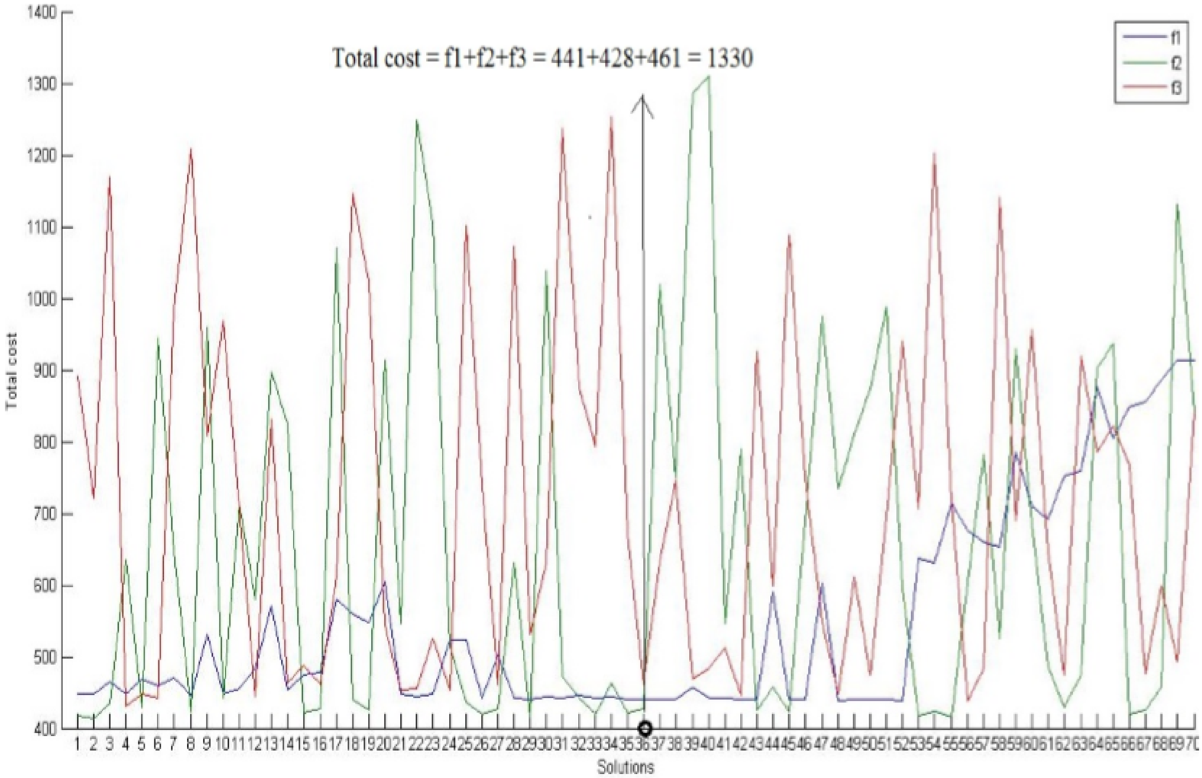

Figure 3. Visulization of Pareto-optimal front representation to select supplier

From Table 5 (Appendix) and Figure 3 it is clear that 36^{th} solution is best because it minimize the cost and full fill the required demand. So manufacturer order quatity from different supplier's are given in Table 3 and manufacturer pay total 1330 ($).

Table 3. Optimal order quantity by manufacturer to suppler to minimize total cost

	Supplier 1	Supplier 2	Supplier3
Item 1	20	5	25
Item 2	33	5	12
Item 3	38	4	10

Distributor selection: Using multi objective GA in Matlab14a we get set of optimal solutions.Those Pareto-optimal front solutions are given in Table 6.(Appendix)

Using parallel co-ordinate method we visualize appropriate optimal solution from Pareto-optimal front. That visualize by Figure 4. As shown in Figure 4 X-axix represent solutions and Y-axix repesent related total cost g_1, g_2 and g_3 for the three items.

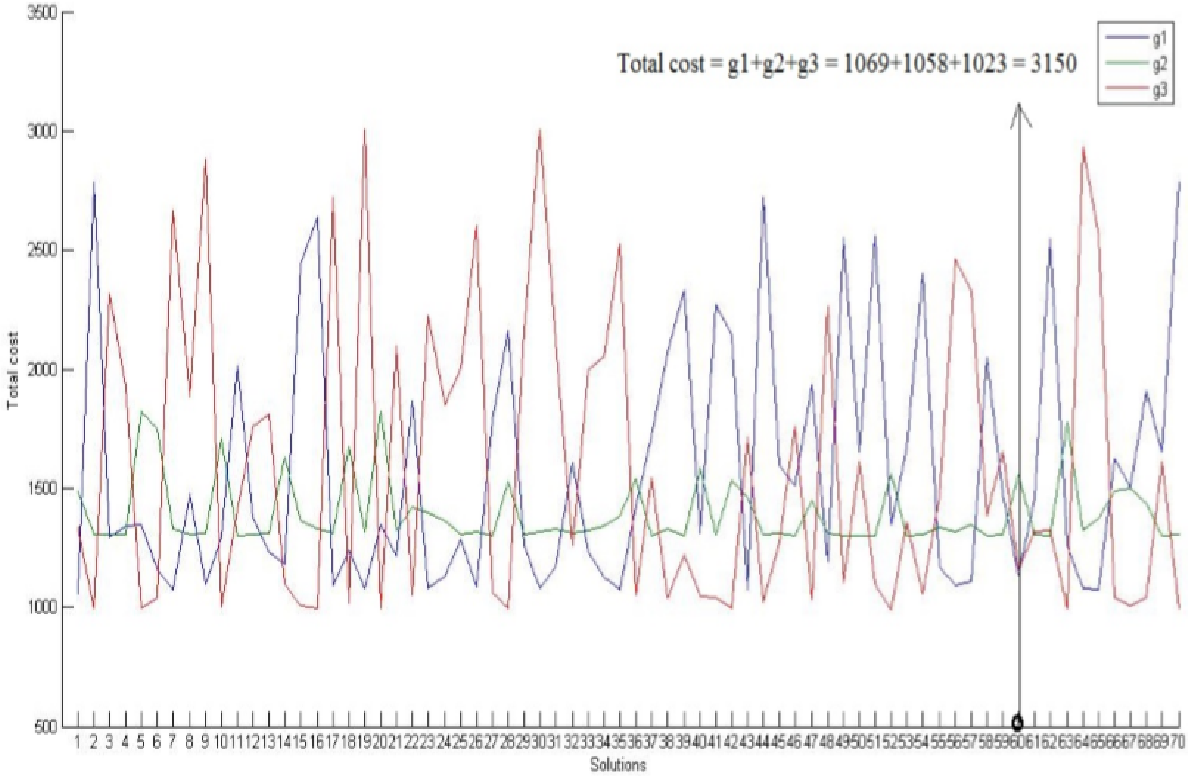

Figure 4. Visulization of Pareto-optimal front representation to select distributor

From Table 6 (Appendix) and Figure 4 it is clear that 60^{th} solution is best because it minimize the cost and full fill the required demand. So manufacturer supply quantity to different distributors are given in Table 4 and for that he pay total 3150 ($).

Table 4. Optimal order quantity from manufacturer to distributor to minimize total cost

	Distributor 1	Distributor 2	Distributor 3
Item 1	30	11	9
Item 2	10	14	26
Item 3	17	13	20

So total cost for supply chain is $TC = PUC + PRC + TRC + INC = 4055.2(\$)$

7. Conclusion

Last many decades, supplier section process in MOP were solved by researcher using different methods like AHP, fuzz AHP, DEA, fuzzy multi-objective linear programming, fuzzy multi-objective goal programming. In proposed model, we have selected supplier and distributor under different criteria using multi-objective GA. Their optimal solution visualization is presented by Parallel Co-ordinate Plots. Since this model considered many parameters while selecting best suppliers and distributors item wise, it can be used by and supply chain to minimize their total cost. Its optimal solution is obtained within few minutes while running on a standard PC. The results show that it just not satisfy only customer requirement under constraint but also offer a best minimum cost for supply chain.

REFERENCES

1. A. Pryke, S. Mostaghim, and A. Nazemi, *Heatmap visualization of population based multi objective algorithms.*, Evolutionary multicriterion optimization, pp. 361–375, 2007.
2. A. Ibrahim, S. Rahnamayan, M. V. Martin, K. Deb, *3D-RadVis Antenna: Visualization and Performance Measure for Many-objective Optimization.*, Swarm and Evolutionary Computation, 2017.
3. C.A. Weber, and J.R. Current, *A Multi objective Approach to Vendor Selection.* , European Journal of Operational Research,vol. 68,pp. 173–184,1993.
4. C. A. Weber, J. R. Current, and A. Desai, *An Optimization Approach to Determining the Number of Vendors to Employ.*, Supply Chain Management: An International Journal,vol. 5, no.2,pp. 90–98, 2000.
5. C. Basnet, and A. Weintraub, *A Genetic Algorithm for A Bicriteria Supplier Selection Problem*, International Transactions in Operational Research 16,pp. 173–187,2009.
6. D. Roman, S. R. Helena, M. Teresa T. Monteiro C.Lino, E. S. Isabel, F. Delfim, M. Torres, *Multiobjective approach to optimal control for a dengue transmission model* Statistics, Optimization & Information Computing 3 , 206-C220, 2015.
7. E. Timmerman, *An approach to vendor performance evaluation.*, J. Suppl. Chain Manag.,vol. 143,pp. 2–8.,1986
8. G. T. Parks, and I. Miller, *Selective breeding in a multi-objective genetic algorithm. Proceedings of the Parallel Problem Solving from Nature*, Springer, Berlin, Germany. vol.5, pp. 250–259,1998.
9. I. Talati, P. Mishra *Optimal production integrated inventory model with quadratic demand for deteriorating items under inflation using genetic algorithm* Revista investigacion operacional, Vol. 40 , No. 3,pp. 342–355, 2019
10. J. D. Schaffer, *Some experiments in machine learning using vector evaluated genetic algorithms.*, Doctoral Dissertation, Vanderbilt University, Nashville, Tennessee,1984.
11. K. R. Shaw, S. S. Shankar, S. S. Yadav, and L. S. Thakur, *Supplier Selection Using Fuzzy AHP and Fuzzy Multi Objective Linear Programming for Developing Low Carbon Supply Chain.*, Expert Systems with Applications,vol.39, pp. 8182–8192,2012.
12. M. Izadikhah, F. Saen, and K. Ahmadi, *How to Assess Sustainability of Suppliers in the Presence of Dual-Role Factor and Volume Discounts: A Data Envelopment Analysis Approach*, Asia-Pacific Journal of Operational Research vol.34, no.03, 1740016.(25 pages), 2017
13. M. Li, L. Zhen, and X. Yao, *How to read many-objective solution sets in parallel coordinates.*, eprint arXiv:1705.00368,2017.
14. M. Seifbarghy, and N. Esfandiari, *Modeling and solving a multi-objective supplier quota allocation problem considering transaction costs.*, Journal of Intelligent Manufacturing,vol. 24, no.1,pp. 201–209, 2013.
15. N. Srinivas, and K. Deb, *Multi-Objective function optimization using non-dominated sorting genetic algorithms,*, Evolutionary Computation, vol.2, no.3, pp.221–248.1995
16. P. Mishra, I. Talati *Optimizing Integrated ProductionCInventory Model for Time-Dependent Deteriorating Items Using Analytical and Genetic Algorithm Approach* Soft Computing for Problem Solving, Springer, Singapore, pp. 535-546, 2019
17. R. Verma, *Multiobjective fractional programming problems and second order generalized hybrid invexity frameworks*, Statistics, Optimization & Information Computing 2 , 280-C304, 2014.
18. S. Obayashi, and D. Sasaki, *Visualization and data mining of Pareto solutions using self-organizing map.*, Evolutionary multicriterion optimization, pp. 796–809, 2003
19. S.H. Amin, and G. Zhang, *An integrated model for closed-loop supply chain configuration and supplier selection: Multi-objective approach.*, Expert Systems with Applications, vol. 39, no. 8, pp. 6782–6791, 2012.
20. T. Murata, H. Ishibuchi, and H. Tanaka, *Multi-objective Genetic Algorithm and its Applications to Flowshop Scheduling.*, Computers and Industrial Engineering,vol.30 no.4, 957–968,1996.
21. T. Tusar, and B. Filipic, *Visualization of Pareto front approximations in evolutionary multiobjective optimization: A critical review and the prosection method.* IEEE Transactions on Evolutionary Computation, vol. 19, no. 2, pp. 225–245, 2015.
22. Y. Cao, X. Luo, C. K. Kwong, J.Tang, *Supplier pre-selection for platform-based products: a multi-objective approach.*, International Journal of Production Research, vol.52, no.1,pp.1–19, 2014.
23. Z. He, and G. G. Yen, *Visualization and performance metric in many-objective optimization*, IEEE Transactions on Evolutionary Computation, vol. 20, no. 3, pp. 386–402, 2016.

Appendix

Table 5. Pareto-optimal front solutions to select supplier

	x_{11}	x_{12}	x_{13}	f_1	x_{21}	x_{22}	x_{23}	f_2	x_{31}	x_{32}	x_{33}	f_3	TC
1	13	6	31	449	34	3	13	417	42	33	7	892	1758
2	14	6	31	449	34	3	13	415	43	21	7	721	1585
3	14	6	33	465	32	6	13	435	39	53	11	1168	2068
4	14	6	30	449	34	18	17	634	33	2	15	432	1515
5	15	6	32	468	33	5	12	429	37	3	10	448	1345
6	15	6	30	460	32	14	50	944	35	3	12	443	1847
7	16	6	31	471	29	12	28	646	39	40	11	986	2103
8	16	5	28	446	33	4	13	424	41	55	9	1208	2078
9	16	8	35	532	28	11	58	960	38	28	11	808	2300
10	16	5	29	448	29	8	13	442	38	40	10	969	1859
11	16	6	28	455	29	12	33	714	37	21	11	708	1877
12	18	6	30	484	32	13	18	581	35	3	13	444	1509
13	18	18	25	570	28	11	52	898	38	30	11	831	2299
14	18	5	27	453	29	15	40	825	34	6	11	463	1741
15	18	9	25	475	34	4	12	422	39	5	9	488	1385
16	19	5	30	478	33	5	12	427	38	4	9	462	1367
17	19	15	29	581	28	11	67	1070	36	15	11	612	2263
18	19	9	35	560	33	6	13	441	41	51	9	1147	2148
19	19	13	27	548	33	4	13	425	39	44	9	1023	1996
20	19	18	29	605	29	14	49	915	36	10	12	545	2065
21	19	5	26	449	33	6	22	546	37	3	10	453	1448
22	19	6	25	444	29	15	79	1249	33	5	12	456	2149
23	20	7	24	449	29	12	69	1104	36	9	12	526	2079
24	20	7	33	524	33	11	14	515	36	3	11	454	1493
25	20	7	33	524	32	6	13	437	39	48	11	1101	2062
26	20	5	25	443	34	4	13	420	39	24	7	738	1601
27	20	11	25	503	33	5	12	427	38	4	9	462	1392
28	20	5	25	443	31	10	28	631	40	45	11	1072	2146
29	20	5	25	441	34	3	12	416	42	7	8	532	1389
30	20	5	25	445	28	12	64	1039	36	16	11	631	2115
31	20	6	24	443	32	9	13	473	41	56	11	1237	2153
32	20	6	24	446	31	7	13	442	39	32	10	874	1762
33	20	6	24	442	34	3	13	419	41	27	8	793	1654
34	20	6	25	445	32	9	12	464	41	57	11	1254	2163
35	20	5	25	441	34	4	13	422	42	17	8	671	1534
36	20	5	25	441	33	5	12	428	38	4	10	461	1330
37	20	5	25	441	28	13	60	1020	36	16	12	633	2094
38	20	5	25	441	29	12	36	750	37	24	11	747	1938
39	20	6	25	457	28	15	83	1285	33	6	12	469	2211

	x_{11}	x_{12}	x_{13}	f_1	x_{21}	x_{22}	x_{23}	f_2	x_{31}	x_{32}	x_{33}	f_3	TC
40	20	5	25	443	29	15	85	1311	33	7	12	484	2238
41	20	5	25	442	30	10	20	547	34	9	11	512	1501
42	20	5	25	441	32	12	38	789	35	3	12	447	1677
43	20	5	24	441	33	4	13	426	38	37	9	925	1792
44	20	9	36	589	33	6	14	457	38	13	11	600	1646
45	20	5	25	441	33	4	13	423	42	47	9	1088	1952
46	20	5	25	440	30	11	31	689	37	24	11	750	1879
47	20	9	37	603	29	12	57	974	35	11	12	549	2126
48	20	5	25	439	33	16	28	734	34	3	14	449	1622
49	21	5	25	440	29	12	43	811	37	14	12	611	1862
50	21	5	25	440	29	15	45	875	34	6	12	474	1789
51	21	5	24	440	28	12	59	988	36	21	11	696	2124
52	21	5	25	439	31	10	24	596	38	37	11	940	1975
53	21	10	40	637	34	3	13	418	42	19	8	706	1761
54	21	11	39	631	33	4	13	423	41	55	9	1202	2256
55	21	12	46	715	34	3	13	416	42	20	7	715	1846
56	21	17	36	676	33	14	18	605	35	3	13	439	1720
57	21	11	41	659	29	10	42	783	36	6	11	484	1926
58	21	11	40	653	32	10	17	525	40	50	11	1140	2318
59	21	17	47	786	28	12	54	930	36	20	11	690	2406
60	22	14	42	711	29	11	32	686	38	39	11	956	2353
61	22	13	41	692	29	11	14	487	38	17	10	649	1828
62	22	13	48	751	34	5	12	429	38	5	9	475	1655
63	22	13	49	759	30	6	17	474	39	35	11	919	2152
64	22	21	52	877	28	11	52	903	37	27	11	785	2565
65	22	17	49	804	28	11	56	937	38	29	11	821	2562
66	22	20	50	848	34	3	13	419	41	25	7	768	2035
67	22	21	50	856	34	5	12	426	39	4	9	476	1758
68	22	21	53	886	33	6	14	457	38	13	11	600	1943
69	23	22	54	915	29	15	69	1131	35	7	12	494	2540
70	23	22	54	915	29	10	47	843	38	30	11	841	2599

Table 6. Pareto-optimal front solutions to select Distributor

	y_{11}	y_{12}	y_{13}	g_1	y_{21}	y_{22}	y_{23}	g_2	y_{31}	y_{32}	y_{33}	g_3	TC
1	35	7	8	1055	17	12	27	1486	12	11	41	1336	3877
2	34	55	35	2785	9	13	29	1307	12	36	3	996	5088
3	34	17	10	1294	9	14	27	1306	56	16	42	2316	4916
4	35	14	13	1342	9	13	29	1304	50	19	27	1932	4578
5	31	16	14	1345	25	19	25	1821	22	23	5	993	4159
6	33	10	12	1161	23	16	27	1749	20	20	12	1038	3948
7	30	11	10	1076	10	15	25	1327	85	22	28	2665	5068
8	34	19	15	1479	9	13	27	1307	39	18	36	1885	4671
9	29	12	11	1097	10	15	25	1311	99	23	25	2880	5288
10	32	15	13	1297	21	17	26	1711	23	20	7	1001	4009
11	36	39	16	2014	8	12	29	1301	12	15	40	1407	4722
12	32	21	10	1373	10	13	27	1308	42	19	26	1757	4438
13	34	14	9	1235	10	13	27	1312	37	17	35	1810	4357
14	33	10	12	1183	18	18	25	1628	19	17	18	1096	3907
15	34	46	29	2438	10	14	28	1362	15	32	4	1006	4806
16	34	51	33	2637	10	13	28	1331	13	34	3	996	4964
17	29	11	10	1094	10	15	25	1313	90	23	26	2721	5128
18	32	13	12	1236	20	17	26	1674	22	20	9	1018	3928
19	28	11	11	1080	11	15	25	1320	105	24	25	3003	5403
20	31	16	14	1345	25	19	25	1821	22	23	5	993	4159
21	33	13	10	1215	10	14	26	1321	61	19	26	2100	4636
22	34	16	35	1866	11	15	29	1420	14	33	5	1050	4336
23	32	9	9	1082	13	14	26	1395	62	17	32	2226	4703
24	33	11	9	1131	12	14	26	1362	51	16	26	1851	4344
25	34	13	12	1283	9	13	28	1306	53	20	27	2001	4590
26	28	12	11	1084	10	15	25	1318	84	22	25	2601	5003
27	34	34	14	1788	9	12	29	1303	12	14	25	1065	4156
28	33	38	26	2163	16	15	27	1529	16	30	4	995	4687
29	33	14	12	1259	9	13	27	1307	62	20	27	2164	4730
30	28	11	11	1080	11	15	25	1320	105	24	25	3002	5402

	y_{11}	y_{12}	y_{13}	g_1	y_{21}	y_{22}	y_{23}	g_2	y_{31}	y_{32}	y_{33}	g_3	TC
31	32	12	10	1171	11	14	26	1330	52	21	32	2116	4617
32	35	27	12	1605	9	13	28	1310	19	21	22	1259	4174
33	33	14	10	1235	10	14	26	1326	52	21	27	1998	4559
34	32	11	9	1125	11	15	26	1341	56	21	26	2052	4518
35	31	10	10	1073	13	14	26	1384	78	19	31	2522	4979
36	33	15	18	1425	16	16	27	1536	23	20	10	1051	4012
37	36	34	9	1718	8	12	29	1300	11	9	52	1545	4563
38	34	39	20	2070	10	13	28	1329	13	22	16	1039	4438
39	35	46	24	2333	9	13	29	1302	12	20	26	1219	4854
40	32	16	12	1315	17	17	26	1584	24	20	9	1044	3943
41	34	46	22	2268	9	13	28	1307	15	29	8	1039	4614
42	33	38	26	2144	16	15	27	1532	16	30	4	995	4671
43	33	8	9	1072	16	13	26	1457	37	15	32	1714	4243
44	34	54	33	2719	9	13	29	1305	13	32	7	1026	5050
45	34	15	23	1595	9	13	28	1310	18	22	22	1270	4175
46	35	25	9	1510	9	13	29	1302	27	13	45	1761	4573
47	33	35	19	1937	12	17	26	1446	24	22	6	1036	4419
48	30	15	10	1194	10	14	26	1310	63	20	30	2262	4766
49	35	50	30	2554	9	13	29	1302	15	24	16	1101	4957
50	36	33	7	1650	8	12	29	1300	11	9	56	1613	4563
51	35	50	30	2556	9	13	29	1302	15	24	16	1099	4957
52	32	18	12	1348	16	17	26	1562	25	20	5	987	3897
53	34	31	12	1671	9	13	29	1303	18	14	33	1357	4331
54	34	43	30	2397	9	13	28	1305	16	24	12	1056	4758
55	34	11	10	1170	12	13	26	1334	17	22	32	1464	3968
56	29	11	10	1091	10	15	25	1319	76	22	26	2460	4870
57	30	11	10	1108	11	15	25	1344	72	22	24	2333	4785
58	36	40	17	2046	8	13	29	1301	12	15	39	1385	4732
59	33	23	12	1475	10	13	27	1308	37	21	24	1650	4433
60	30	11	9	1069	10	14	26	1058	17	13	20	1023	3150
61	34	14	18	1452	9	13	28	1308	21	21	22	1317	4077
62	35	47	32	2546	8	13	29	1302	12	22	30	1325	5173
63	32	14	13	1262	25	17	25	1777	22	22	6	997	4036
64	28	12	11	1083	11	15	25	1322	101	24	25	2929	5334
65	31	10	10	1074	12	14	26	1372	79	19	30	2555	5001
66	33	25	16	1623	14	16	27	1490	21	23	8	1040	4153
67	32	23	13	1505	15	16	26	1500	23	20	8	1004	4009
68	34	19	33	1909	12	15	28	1436	15	33	5	1042	4387
69	36	33	7	1650	8	12	29	1300	11	9	56	1613	4563
70	34	55	35	2785	9	13	29	1307	12	36	3	996	5088