4th Indian International Conference on Industrial Engineering and Operations Management
Hyderabad, Telangana, India, November 07-09, 2024
Publisher: IEOM Society International, USA DOI: 10.46254/IN04.20240013
Published: November 07, 2024

Monte-Carlo Simulation of a Single Tiered Supply Chain with Total Cost Minimization Objective

Adarsh Uday
B. Tech Student in Mechanical Engineering
Indian Institute of Technology
Madras, India
Me21b005@smail.iitm.ac.in

Uday K Jagannathan, PhD
Associate Professor
Ramaiah University of Applied Sciences
Bengaluru, India
Ujagannathan.ms.mc@msruas.ac.in

Abstract

Firms worldwide attempt to minimize the total cost of sourcing, aggregating, and delivering products to demand centers. Specifically, in this paper, we model a single-tier supply chain with *m* suppliers, *n* aggregators and *p* demand centers, each with known Latitude and Longitude. We assume a certain, fixed demand profile for a single product at the various demand centers and simulate the number of units assembled at each aggregator and fulfilled by each supplier, using random numbers, so that each simulation results in various paths from supplier to aggregator to demand center, and the sum of costs of all paths in that simulation will give the total cost. Minimum total cost across all simulations will give the optimal sourcing and assembly strategy. With the use of Latitude and Longitude, we model the transportation costs as a function of distance. In addition, truck size is also used in transportation cost calculation. Using fixed and variable cost for each assembly unit, we model the total cost for each assembly unit for the units assembled there. Inbound and Outbound transportation cost from supplier to aggregator and from aggregator to demand center is also computed using distance and truck sizes.

Keywords
Simulation, Supply Chain, Cost Minimization, Single-Tiered

1.Introduction

This research is expected to fill the gap on supply chain cost modeling, for which open-source and freeware solutions are far and few between. Moreover, the use of latitude and longitude to obtain distance between two locations and ascertaining the supply chain cost along with the use of random allocations of fulfilment units to aggregator and suppliers is not seen in existing literature. Owing to the vast number supplier/aggregator/demand center permutations possible for fulfilment units, and the infeasibility of a deterministic solution, a simulation approach is being undertaken to obtain a stochastic rather than a deterministic solution. The contribution of this research is expected to simplify sourcing, aggregator decisions when the latitude and longitude of suppliers, aggregators and demand centers are known a priori, and it is expected that with the substantial number of simulations possible, a close empirical solution can be found to the theoretical minimum total cost.

1.1 Objectives

1. The first objective in this research is to develop a model to arrive at numerous paths from supplier to aggregator to demand center with the help of Monte-Carlo simulations.
2. The second objective is to compute the distance between all supplier/aggregator and aggregator/demand center permutations.
3. The third objective is to run simulations and calculate the total supply chain cost across paths in the simulation.
4. The final objective is obtaining the minimal cost across simulations and recommending the sourcing strategy.

2. Literature Review

Bottani and Montanari (2009) employed a simulation model to analyze supply chain configurations in the fast-moving consumer goods (FMCG) industry. They assessed the impact of design parameters (such as echelon count, inventory policies, and demand information sharing) on total logistics costs and the bullwhip effect. By examining 30 configurations and performing statistical analysis on 20 representative cases, the study derived 11 key insights for optimizing supply chain design.

Pettersson & Segerstedt (2013) investigated supply chain cost (SCC) measurement and its relevance for organizations aiming to enhance net income. They introduced a suggested model for measuring SCC and interviewed representatives from 30 companies across various sectors to compare their cost measurement practices against this model. The study also explored the difference between SCC calculated based on estimated standard cost and SCC based on actual cost, emphasizing opportunities for improvement in cost and supply chain analyses.

Christopher and Gattorna (2005) analyzed deflationary markets, organizations face mounting pressure to reduce costs while maintaining margins. The authors researched that as customers and consumers prioritize value over brand loyalty, businesses must adapt. Creative pricing strategies, coupled with efficient supply chain management, offer substantial cost reduction possibilities and the potential for increased profits. This paper provided evidence supporting this perspective and proposes a supply chain alignment approach that identifies cost reduction opportunities and fosters collaborative strategies for higher profits.

Kleijnen (2005) surveyed various simulation methods used in supply chain management, including spreadsheet simulation, system dynamics, discrete-event simulation, and business games. The choice of simulation type depends on the specific managerial question being addressed. Also, the paper delved into methodological issues related to validation, verification, sensitivity analysis, optimization, and robustness. For instance, sensitivity analysis identifies crucial factors in large simulation models, while robustness analysis optimizes controllable factors while accounting for non-controllable environmental noise. The study illustrates these concepts through a case study involving a mobile communications industry supply chain in Sweden. Overall, simulation plays a vital role in quantifying the benefits of effective supply chain management.

Terzi and Cavalieri (2004) research that in response to increased competitiveness across industrial sectors, enterprises are striving to optimize their organizational processes. This drive is further fueled by globalization and changing market demands. Companies are increasingly seeking collaboration and partnerships with their logistics counterparts. This external perspective is reflected in supply chain management (SCM) strategies. Despite the proliferation of IT solutions, challenges persist due to the complexity of logistics networks and conflicts between local objectives and network-wide strategies. Simulation techniques, particularly for what-if analysis, play a crucial role in evaluating cooperative benefits and issues within the supply chain context.

3. Methods

This new and innovative algorithm starts by assuming that data is available on m suppliers and n aggregators, p demand centers and transportation by q types of trucks. The demand profile is certain (deterministic) and does not vary.

Broadly, the assumptions in the model include:

1. Unlimited number of suppliers with known latitude and longitude
2. Only road-delivery by truck is possible, across locations with known latitude and longitude

3. The only possible delivery is by small truck, medium truck, or large truck. Each truck type is with a known Capacity and unit cost for transportation
4. Fixed and variable cost known for each aggregator
5. Static deterministic demand profile across demand centers is known at the beginning of each simulation
6. Unlimited number of demand centers, each with known demand

The first step is to set up the supplier, aggregator, and demand center data as in Figure 1 below. The second step is to generate the distance between the various supplier – aggregator as well as the aggregator – demand centers. A sample output of the computed distance is shown in Table 5. The third step is to run the algorithm for the specified number of simulations. The last step is to summarize the various simulations and obtain the least cost simulation. Once the distances are set up, the algorithm will function in the following manner as depicted in Figure 2 below:

a. Firstly, the demand at various p demand centers will be obtained from the input data.
b. Secondly, random numbers will be generated to each supplier's commitment for fulfilment. Each random number will therefore have a value between 1 and m and it is noted that in each iteration, m is an integer for the total number of suppliers with a valid remaining capacity.
c. Thirdly, random numbers will be generated for each aggregator's commitment for fulfilment. Each random number will therefore have a value between 1 and n. It is noted that in each iteration n is an integer with the total number of aggregators with a valid remaining capacity.
d. For each iteration, the demand across p demand centers will be allocated to random suppliers and random aggregators. If total demand is satisfied, the iteration terminates. If supply capacity across suppliers is exhausted, the iteration terminates. Similarly, if the aggregator capacity across aggregators is exhausted, the iteration terminates. The lower of aggregator and supplier capacity is used for allocation.
e. Within each iteration, the truck type with the least cost is selected and the cost of transportation is computed as the unit transportation cost multiplied by the distance between supplier to aggregator or aggregator to demand center. Since any one simulation may result in multiple allocations of the same supplier to aggregator or aggregator to demand center combination, the total sum of quantity for an aggregator is considered for inbound and outbound logistic costs.
f. At the end of each iteration, the supply chain path can be determined and the costs for that iteration can be computed. The total cost for the simulation is equal to the inbound transportation cost for aggregator, the fixed and variable cost for the aggregator, and the outbound transportation cost from aggregator to demand center. In addition, the percentage of demand satisfied across demand centers is also computed. Transportation cost is calculated by taking the suitable truck size among the q truck sizes available, for the number of units being transported.
g. At the end of all iterations, the least cost path will be determined as will be the maximum fulfilment percent It is noted that if capacities are set to be large in the supplier and aggregator data, the path with the least cost (as will other paths) will have 100 percent fulfilment.

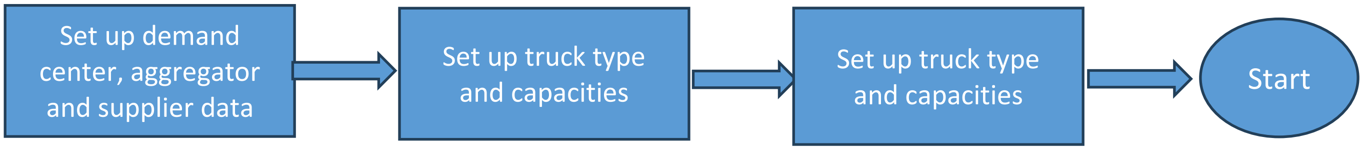

Figure 1. Initial data set up for supply chain cost minimization

Data Set up for suppliers:

Table 1. Initial data set up for suppliers

	A	B	C	D
1	***supplier data***			
2	**#**	***Latitude***	***Longitude***	***Capacity***
3	1	12.971599	77.59457	300
4	2	17.4065	78.476	500
5	3	13.0843	80.2705	150
6	4	22.3072	73.1812	150
7	5	12.2958	76.6394	100

Table 1 above contains sample supplier data. Each supplier number should be unique, and user generated. The Latitude and Longitude should be obtained accurately for each supplier and should be entered. The capacity can be entered for each supplier and if 999 is entered, it implies *"infinite"* capacity for the supplier and when the simulation is run, each supplier with capacity greater than zero will have an equal probability of getting selected for allocation. Error messages will be generated when the latitude or longitude are not entered, invalid or negative or non-numeric data is entered in the capacity column. If the wrong latitude or longitude are entered, unpredictable results can happen. It is assumed that all suppliers are supplying the product at the same cost to the aggregator and eventually to all the demand points. There is no limit on the number of suppliers.

Data Set up for Aggregators

Table 2. Initial data set up for aggregators

aggregator data					
#	***Latitude***	***Longitude***	***Capacity***	***Fixed Cost***	***Var Cost***
6	23.2599	77.4126	300	50,000.00	40.00
7	22.3072	73.1812	600	75,000.00	25.00
8	12.2958	76.6394	400	1,25,000.00	35.00
9	12.9716	77.59457	500	1,50,000.00	30.00

Table 2 above contains data for aggregators. Each aggregator number should be unique, and user generated. The Latitude and Longitude should be obtained accurately for each aggregator and should be entered. The capacity can be entered for each aggregator and if 999 is entered, it implies *"infinite"* capacity for the aggregator and when the simulation is run, each aggregator with capacity greater than zero will have an equal probability of getting selected for allocation. Error messages will be generated when the latitude or longitude are not entered, invalid or negative or non-numeric data is entered in the capacity column. If the wrong latitude or longitude are entered, unpredictable results can happen. The fixed cost and unit cost (variable cost) for each aggregator can be entered and must be a valid value greater than or equal to zero. There is no limit on the number of aggregators. Cost data is currency independent, so the model works for all currencies. However, consistency in the use of currency is required across the model.

Data Set up for Demand Centers

Table 3. Initial data set up for Demand Centers

demand data			
#	Latitude	Longitude	Units
10	19.076	72.8777	100
11	28.7041	77.1025	200
12	22.5744	88.3629	250
13	22.3072	73.1812	750
14	12.2958	76.6394	50

Table 3 above contains data for demand centers and demand center number should be unique, and user generated. The latitude and longitude should be obtained accurately for each demand center should be entered. The demanded units can be entered for each demand point. Error messages will be generated when the latitude or longitude are not entered, invalid or negative or non-numeric data is entered in the units column. If the wrong latitude or longitude are entered, unpredictable results can happen. There is no limit on the number of demand centers.

Data Set up for Truck type

Table 4. Initial data set up for Truck Type

truck type		
type	Cost/kmu	Capacity
SML	7	500
MED	12	1,000
LRG	15	1,500

Table 4 above contains data for truck type and the associated unit cost per kilometer and the capacity for a single truck of that type**.** These truck types are useful to estimate the supplier's transportation cost to aggregator and from the aggregator to demand points. The unit cost and capacities should be numeric values greater than zero, otherwise suitable error messages will display. In the above example, three truck types are being used. Cost data is currency independent, so the model works for all currencies. However, consistency in the use of currency is required across the model.

Distance Table between supplier, aggregator, and demand centers (Table 5) (Generated upon user Request)

Table 5. Distance Table depicting distance between various suppliers, aggregator, and demand centers

S	A	*distance*	A	D	*distance*
1	6	1,209	6	10	699
1	7	1,203	6	11	640
1	8	135	6	12	1,187
1	9	-	6	13	472
2	6	698	6	14	1,291
2	7	821	7	10	381
2	8	636	7	11	859
2	9	530	7	12	1,648
3	6	1,237	7	13	-
3	7	1,342	7	14	1,238
3	8	426	8	10	903
3	9	307	8	11	1,928
4	6	472	8	12	1,783
4	7	-	8	13	1,238
4	8	1,238	8	14	-
4	9	1,203	9	10	893
5	6	1,291	9	11	1,849
5	7	1,238	9	12	1,649
5	8	-	9	13	1,203
5	9	135	9	14	135

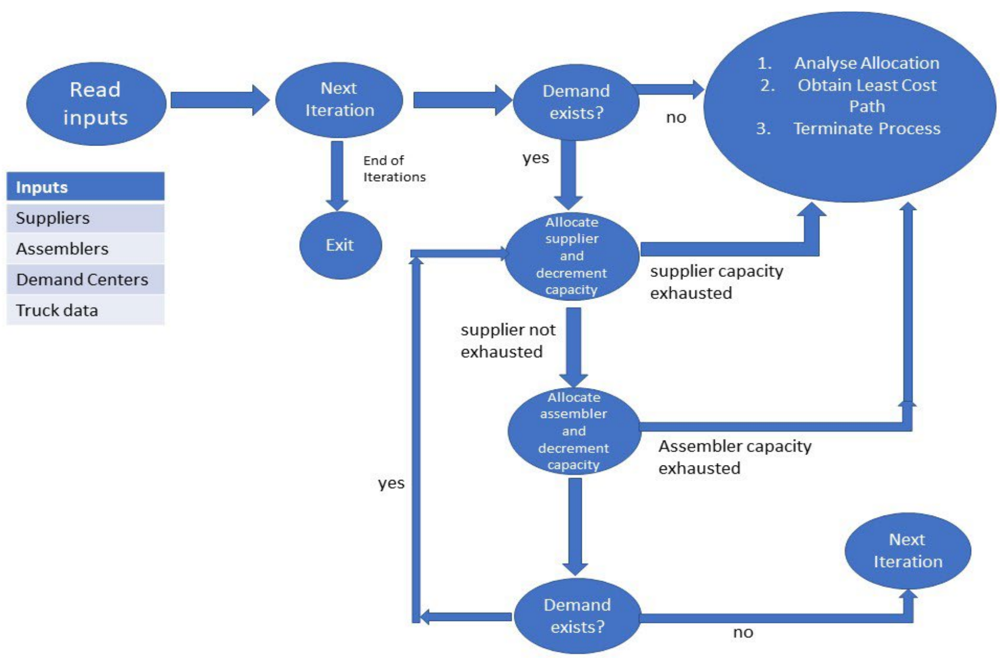

Figure 2. Algorithm for single tier supply chain cost optimization

4. Data Collection

Data is generated using simulations and the descriptive statistics obtained are both tabulated and graphed below.

5. Results and Discussion

5.1 Numerical Results

Table 6. Descriptive Statistics of Aggregator Cost, Transportation Cost and Total Cost, *n=100 simulations*

	Aggregation Fixed Cost	*Aggregation Var Cost*	*Aggregation Total Cost*	*Transportation Cost*	*Total Cost*
Mean	3,80,000.00	37,985.00	4,17,985.00	87,791.97	5,24,226.69
Median	4,00,000.00	38,250.00	4,37,625.00	87,972.61	5,26,962.78
St Dev	45,226.70	1,502.87	45,406.54	9,939.80	26,182.14
1at quartile	4,00,000.00	36,750.00	4,36,000.00	82,310.52	5,18,536.28
3rd quartile	4,00,000.00	39,062.50	4,38,812.50	93,900.33	5,36,249.65
Min	2,50,000.00	34,000.00	2,87,500.00	66,161.28	3,54,861.85
Max	4,00,000.00	41,000.00	4,40,500.00	1,14,386.58	5,65,002.57

Table 7. Tabulation and Distribution of the Total Cost across simulations, *n = 100 simulations*

Interval	*Start Cost*	*End Cost*	*Cumulative Count*	*Count*
1	3,54,861.85	3,79,646.20	5	5
2	3,79,646.21	4,04,430.55	11	6
3	4,04,430.56	4,29,214.90	11	0
4	4,29,214.91	4,53,999.25	14	3
5	4,53,999.26	4,78,783.60	19	5
6	4,78,783.61	5,03,567.95	20	1
7	5,03,567.96	5,28,352.30	68	48
8	5,28,352.31	5,53,136.65	100	32

Descriptive Statistics on the Aggregator Fixed Cost, Aggregator Variable Cost and Transportation Cost are presented in Table 6, Table 8 and Table 10, where the number of simulations varies from 100 to 1,000. The minimal cost across simulations was attained when the number of simulations was 1,000 and the achieved minimal cost was 3,37,293.00. Graph in Figure 6 shows the Minimal Total Cost when plotted against the number of simulations and corresponds to data in Table 12. Figure 3 corresponds to data in Table 7 and similarly Figure 4 corresponds to data in Table 9 while Figure 5 corresponds to data in Table 11.

Table 8. Descriptive Statistics of Aggregator Cost, Transportation Cost and Total Cost, *n=500 simulations*

	Aggregation Fixed Cost	***Aggregation Var Cost***	***Aggregation Total Cost***	***Transportation Cost***	***Total Cost***
Mean	3,81,600.00	37,757.00	4,19,357.00	88,548.40	5,07,905.40
Median	4,00,000.00	37,750.00	4,37,500.00	88,514.86	5,23,971.79
St Dev	41,531.79	1,699.26	41,991.74	12,674.88	46,204.06
1at quartile	4,00,000.00	36,500.00	4,35,937.50	79,965.44	5,08,880.08
3rd quartile	4,00,000.00	39,062.50	4,39,000.00	97,738.35	5,33,951.17
Min	2,50,000.00	33,500.00	2,87,000.00	54,583.17	3,44,721.54
Max	4,00,000.00	41,000.00	4,40,750.00	1,25,852.22	5,63,852.22

Table 9. Tabulation and Distribution of the Total Cost across simulations, *n = 500 simulations*

Interval	***Start Cost***	***End Cost***	***Cumulative Count***	***Count***
1	3,44,789.78	3,72,316.38	11	11
2	3,72,316.39	3,99,842.99	36	25
3	3,99,843.00	4,27,369.60	46	10
4	4,27,369.61	4,54,896.20	60	14
5	4,54,896.21	4,82,422.81	89	29
6	4,82,422.82	5,09,949.42	123	34
7	5,09,949.43	5,37,476.03	400	277
8	5,37,476.04	5,65,002.64	500	100

Table 10. Descriptive Statistics of Aggregator Cost, Transportation Cost and Total Cost, *n=1000 simulations*

	Aggregation Fixed Cost	***Aggregation Var Cost***	***Aggregation Total Cost***	***Transportation Cost***	***Total Cost***
Mean	3,80,500.00	37,872.50	4,18,372.50	89,593.36	5,07,965.86
Median	4,00,000.00	38,000.00	4,37,500.00	89,564.45	5,24,608.63
St Dev	42,474.16	1,775.11	42,937.09	12,969.73	47,127.39
1at quartile	4,00,000.00	36,500.00	4,35,750.00	80,606.28	5,08,783.15
3rd quartile	4,00,000.00	39,250.00	4,39,000.00	98,767.34	5,35,550.26
Min	2,50,000.00	33,500.00	2,87,000.00	49,543.25	3,37,293.25
Max	4,00,000.00	41,000.00	4,40,750.00	1,45,870.38	5,84,870.38

Table 11. Tabulation and Distribution of the Total Cost across simulations, *n = 1000 simulations*

Interval	*Start Cost*	*End Cost*	*Cumulative Count*	*Count*
1	3,37,293.25	3,68,240.39	11	11
2	3,68,240.40	3,99,187.54	81	70
3	3,99,187.55	4,30,134.69	98	17
4	4,30,134.70	4,61,081.85	141	43
5	4,61,081.86	4,92,029.00	206	65
6	4,92,029.01	5,22,976.15	466	260
7	5,22,976.16	5,53,923.30	976	510
8	5,53,923.31	5,84,870.45	1000	24

Table 12. Tabulation and Distribution of the Minimum Cost for varying number of simulations

number of simulations	*Minimum Cost*
100	3,54,861.00
500	3,44,721.00
1,000	3,37,293.00
2,500	3,38,717.00
5,000	3,41,613.00
10,000	3,41,925.00

5.2 Graphical Results
Graphical figures are showed in Figure 3, 4, 5, 6.

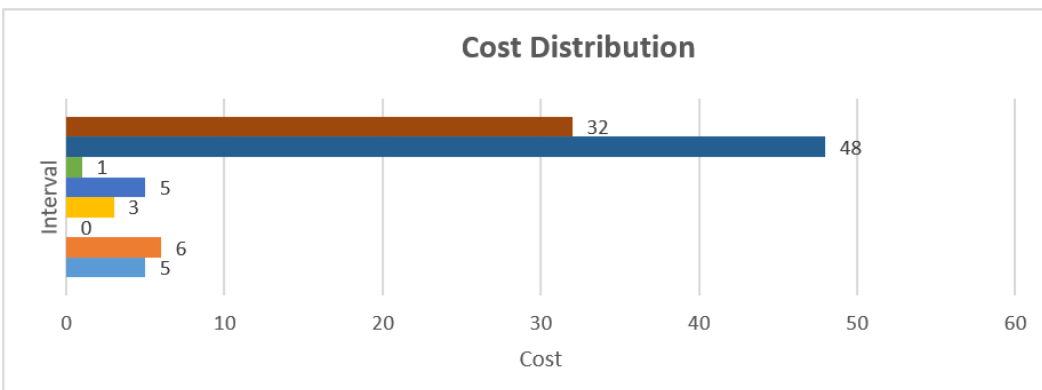

Figure 3. Distribution of the Total Cost across simulations, *n = 100 simulations. Refer Table 7 for data*

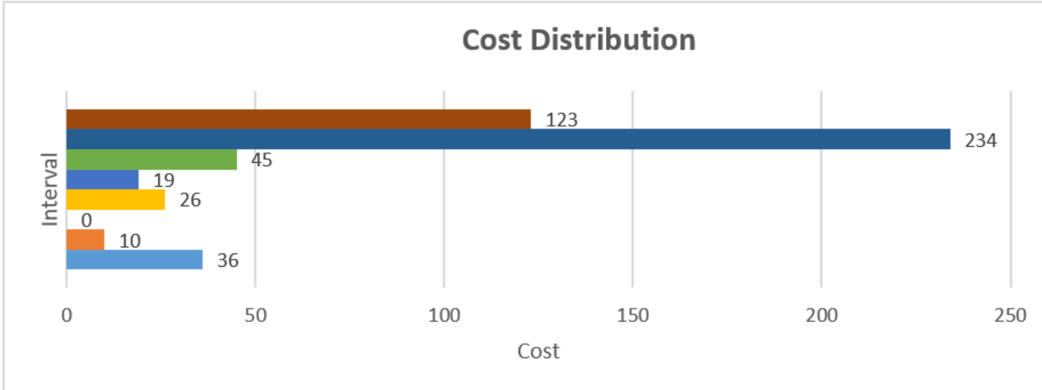

Figure 4. Distribution of the Total Cost across simulations, *n = 500 simulations. Refer Table 9 for data*

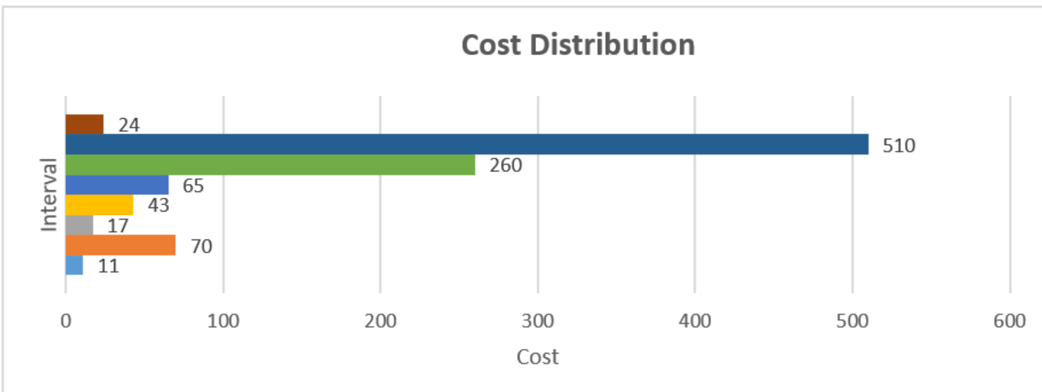

Figure 5. Distribution of the Total Cost across simulations, *n = 1000 simulations. Refer Table 11 for data*

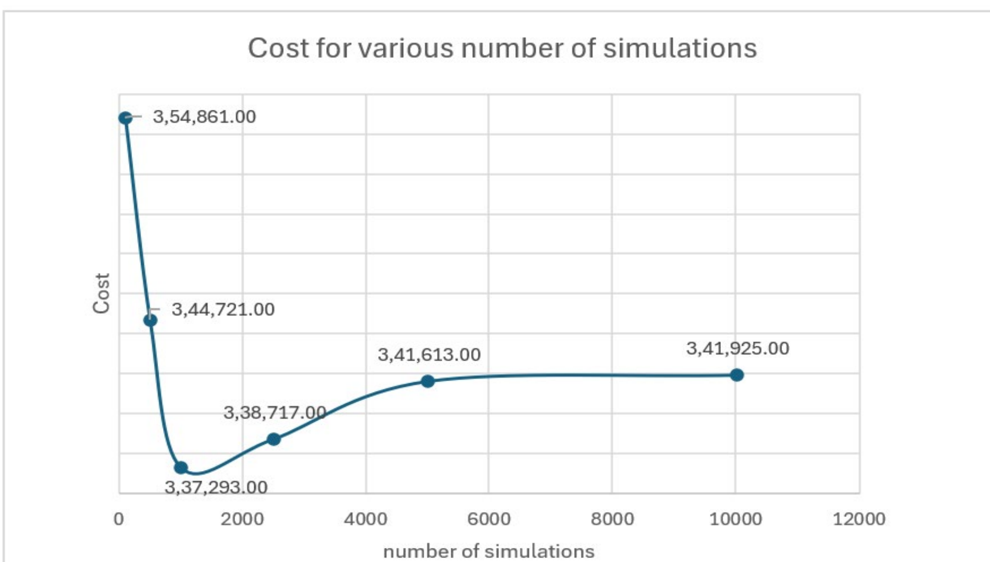

Figure 6. Distribution of the Minimum Total Cost, across varying number of simulations

5.3 Proposed Improvement

Improvements can be made to increase the depth in the number of tiers of suppliers. In the present analysis, only a single-tier supplier network is considered. Sensitivity analyses can also help in delineating boundaries of optimality. Breaking of loads across truck types can also be a potential improvement.

5.4 Validation

Data in Table 12 is further analyzed, and the mean of the minimal total cost is 343,188 while the standard deviation is 6,284. Assuming a normal distribution for the mean of minimal total cost, we conclude that the minimal total cost does not deviate from the mean of minimal cost statistically. We further state the confidence interval for 2 standard deviations from the mean of minimal cost as [3,30,620 3,55,755] and all values in Table 12 are well within the confidence interval depicted.

6. Conclusion

Simulation is useful in situations where deterministic solutions are impossible or impractical. In this paper, we develop an algorithm to perform simulations in which we randomly allocate quantities from suppliers and fulfil them through randomly selected aggregators. The truck costs and aggregator fixed and variable costs, in addition to the transportation distance between the supplier/aggregator and aggregator/demand centers allow us to compute the Total supply chain cost for each simulation. The minimal supply chain cost across simulations is the sourcing strategy, which is given for n = 1000 simulations as below, as an example in Table 13 below. It is noteworthy that no two simulation runs are likely to give the same minimal total cost, even when n is held the same (example, n = 1,000)

Table 13. Sourcing strategy for n=1000 (results vary for multiple simulation runs for n=1000 or other number)

Grand Total Cost		3,47,057.63	
supply point	aggregation point	demand point	Qty
2	7	10	100
3	6	11	150
2	6	11	50
2	7	12	250
1	8	13	300
4	7	13	150
5	7	13	100
2	6	13	100

aggregation Cost Breakup				
aggregation point	Qty	Fixed	Variable	Total
7	600	75,000.00	15,000.00	90,000.00
6	300	50,000.00	12,000.00	62,000.00
8	300	1,25,000.00	10,500.00	1,35,500.00
Total	1,200	2,50,000.00	37,500.00	2,87,500.00

Transport Cost Breakup					
Truck Type	Qty	Cost	supply point	aggregation point	demand point
SML	350	5,744.32	2	7	
SML	150	8,659.67	3	6	
SML	150	4,882.78	2	6	
SML	300	946.73	1	8	
SML	150	-	4	7	
SML	100	8,667.60	5	7	
SML	100	2,667.40		7	10
SML	200	4,482.88		6	11
SML	250	11,536.35		7	12
SML	300	8,667.60		8	13
SML	250	-		7	13
SML	100	3,302.29		6	13
Total	2,400	59,557.63			

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Biographies

Adarsh Uday is a fourth-year student in Mechanical Engineering at Indian Institute of Technology, Madras (IIT -M). He is interested in topics related to Mechanical and Industrial Engineering. He has completed several challenging courses at IIT-M related to Mathematics, Computing and Mechanical Engineering with a CGPA of 8.0 on a 10.0 scale. He wishes to continue his quest for excellence in improvement of supply chains and logistics in Industrial Engineering, with simulation tools and industrial automation.

Uday K Jagannathan is an Associate Professor at Ramaiah University of Applied Sciences. He has a bachelor's degree from IIT-M and an MBA (Master of Business Administration) from UCLA. He completed a PhD in Management from Ramaiah University of Applied Sciences and has published over 30 articles in peer-reviewed journals and conferences in Financial Management and Simulations (Analytics).