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Applications of Operations Research in Supply Chain Management

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Abstract:- Operations Research (OR) is the analytical method of decision making and problem solving with the use of mathematics and logic. This is extremely useful in the management of organizations and is used by various industries all over the world. Through the study and research of this project, the overall OR practices of the chosen topic- Supply Chain Management are determined and analyzed. This project focuses on the applications, objectives and limitations faced in the industry. Our aim is to elucidate our readers on the three most critical aspects of the chosen topics, these being- Production, Inventory Routing and Transportation. It also studies the various methodologies used to solve problem and optimize resources used in the organization. The findings and research have helped us attain the objective of the project which was to acquire conceptual clarity of operations research as a subject and its applications in the global context.

Keywords:- *Supply Chain Management, Linear Programming, Optimization, Operations Research, Transportation, Inventory Routing, Simplex Method, Production.*

I. INTRODUCTION

"It's not the organizations that are competing, it's the Supply Chains that are competing." The global supply chain management market was worth approximately 16 billion U.S. dollars in 2020 and is expected to grow at a CAGR of 10.3% to reach 41.7 billion by 2026 [1]. Furthermore, with an increase the size of value-adders, combined with the demand for greater value-centricity and convenience; the evolution of supply chains in this dynamic environment has been characterized by agility, transformation and an increased adoption of the best practices by MSMEs. Thus, it is of mammoth importance for any business organization to have an efficient supply chain.

The Indian Domestic Furniture market is largely unorganized and dominated by small and medium sized enterprises. It is expected to grow at a rapid pace due to the rising disposable incomes, the burgeoning middle class, and the growing number of urban households. Congregate- based development will enable all players to synergize resources and reap the mutual benefits of better technology and distribution channels. Efficient Supply Chain Management is a lingering impetus for this industry, besides brand management and cost minimization. Realizing the existing dearth of an analysis on the Supply Chain Management process with the applications of Operations Research techniques in a furniture manufacturing concern, our paper aims to illustrate how to optimize the supply chain of furniture manufacturing business (a small sized enterprise producing sofas and chairs).

The key applications of Operations Research have been applied at the three most pertinent stages of the supply chain – Sourcing of Raw Materials, Production and Inventory Routing. We have used Vogel's Approximation (VAM) and Modified Distribution Method (MODI) to solve the Transportation Problem while sourcing raw materials from 3 different suppliers. Using the VAM and MODI methods enabled us to account for the costs associated with different routes and to optimize the transportation schedule by arriving at the least cost while computing improvement indices. The Simplex Method, which can be employed to LLPs irrespective of the number and nature of decision variables and constraints; has been applied to arrive at the product mix which maximizes profits. It also indicates the level of resource utilization. The Inventory Routing problem has been solved to arrive at the optimum levels of inventory which must be sent to the showrooms, while accounting for the demand at the showrooms, their storage capacity and distance between the point of supply and the showrooms. The method applied by us begins with a Natural Solution, proceeding to the Optimized Solution for each month; which further highlights the powerful application OR Techniques in our research topic.

Thus, the objectives of our study are as follows:
1. To identify and understand the different methods of Production, Inventory Management and Transportation in the process of Supply Chain Management.
2. To identify various roadblocks faced in the process of delivering value to customers, and to understand the applications of Operations Research to overcome these.
3. To apply the OR techniques of Transportation Problem, Simplex and Inventory Routing to optimize the supply chain of a hypothetical small furniture manufacturing concern Treasure Ltd., and to analyze the results.

II. LITERATURE REVIEW

Supply Chain Management is the integration and coordination between different processes and activities involved in delivering value (products, services or experiences) to the end consumers through upstream and downstream linkages [2]. It is the 'value-creation engine of the modern organization', which provides a competitive advantage. Streamlining cross-company processes is the next great frontier for reducing costs, enhancing quality, and speeding operations [3]. Managers and supply chain practitioners around the world would manage risks by analyzing probabilities, which would make the decision-making process predictable to some extent, thus allowing them to make prudent and responsible supply chain decisions. The pandemic has led to huge uncertainty about how life would play out, and this uncertainty has led to unpredictable factoring of many variables in the decision-making process leading to difficulties in assessing probabilities of demand and supply volumes, which has brought to the fore the importance of efficient supply chain management [4].

The pertinence of the supply chain management framework has increased more in this ever competitive environment as a supply chain is no longer viewed as a static strategic element of business, but as a panarchy of dynamic, adaptive cycles [5]. Two of the main cost drivers in the supply chain are inventory which includes planning, production, and maintenance of the optimum levels of finished deliverables and transportation which involves transport planning, vehicle routing and scheduling, delivery execution and shipment tracking, and performance management. Thus, to obtain supply chain optimization, it is necessary to ensure that these closely interrelated functions are performed to yield the best trade-offs in such a way that inefficiencies are negated and customer service levels are high.

Production is the process of transforming resources into finished products in the form of goods and services; the objective of production is to satisfy the demand for such transformed resources. The methods contributing to the improvement of productivity are Method Study and Work Measurement by Reducing Work Content and Ineffective time. Work content is the amount of work "contained in" a given product or process measured in labour-hour or machine-hour terms. Actual operations time always exceed the expected theoretical minimum due to various roadblocks such as machine malfunctions, labour inefficiencies, non-availability of resources, ineffective time which is the time for which the worker or machine or both are idle due to the shortcomings of the management or the worker, making both the methods relevant and important [6]. The objective of any entrepreneur owning factors of production is profit maximisation through improving efficiencies, minimising costs, and thereby improving margins. Linear Programming Problem (LPP) was introduced by Kantorovich in 1939, to improve efficiency by reducing army costs. Linear programming is a mathematical technique used to find the best possible solution to a mathematical problem given the constraints. The basic objective is to optimise, be it to maximise or minimise a function to values of variables given the constraints. LPP has great economic application as it can be used to maximise profits, minimise various costs, and improve time efficiency by solving the problem in graphical, algebraic or simplex form. The Simplex format is one where the problem is solved by using surplus, artificial, and slack variables in a tabular form [7].

An organization's inventory is one of its most significant resources. A deficiency or an excess of stock when and wherever required are both non-lucrative for any firm. For organizations with complex stock chains and assembling measures, adjusting the dangers of stock excesses and deficiencies is particularly troublesome. To accomplish these equilibriums, firms have fostered a few strategies for inventory management, incorporating in the nick of time (JIT) and materials prerequisite arranging (MRP) [8],[9]. A conventional transportation problem in operational research is concerned with finding the minimum cost of transporting a single commodity from a given number of sources (e.g. factories) to a given number of destinations (e.g. warehouses). However, these can be further expanded to minimise time and distance and maximise speed. Both, a Balanced (demand = supply) and an Unbalanced (demand >/< supply) problem can be solved by 3 methods- North West Corner, Lowest Cost Entry and Vogel's Approximation. An optimal solution meeting the objective function can be reached upon by using either the Stepping Stone Method or the Modified Distribution Method (MODI) [6].While a Transportation Problem assumes that the sources of demand and supply cannot simultaneously act as both destinations, a Transshipment Problem deals with more realistic scenarios of a single destination being the source and the point of consumption. Works on Transshipment Problems yield the Dual Matrix Method for optimization. This acts as an alternative to the Stepping Stone Method and uses matrix operations to achive an optimal solution [10].

With supply chains becoming more complex and dynamic, chains transition into 'networks'. In SCM, optimization of multi criterion problems such as total costs, customer service level, inventory level, manufacturing lead times, are encountered by decision makers (DM), which may be limited with some constraints, and affect each other in nature [11]. One of the major conflicting objectives faced by decision makers is of maximising customer service levels by meeting demand and minimizing the cost of holding inventory and transportation. This makes it a bi-objective problem, involving a trade-off, which can be integrated by formulating a problem having features and criteria of both a Vehicle Routing Problem (VRP) and an Inventory Routing Problem (IRP). A VRP, which is a combinatorial optimization and linear programming problem; generates constraints such as vehicle capacity, asymmetric distances, multiple routes, number of deliveries and pick-ups etc. [12]. Inventory Routing is applicable when a supplier needs to deliver products to a number of customers, subject to a series of constraints. The model meeting both objectives will include an objective function to minimise inventory and vehicle routing costs, while meeting the demand requirements and consider a single-period scenario with deterministic demand in which the supplier has a limited quantity of the product, and the goal is to maximize revenue less transportation and shortage costs subject to supply and demand availability, and vehicle capacity constraints [13]. A simpler version of the VRP is a TSP: Travelling Salesman Problem, which aims to minimize costs while travelling through a network of nodes, passing through each only once and returning back to the departure point. Network Optimization can also be achieved using simulation models of Multi- Integer Linear Programming and other stochastic models [14].

III. METHODOLOGY

The application of Operations Research tools in supply chain management is profound and to understand the application better we would like to apply Operations Research techniques to the Supply Chain process of a fictitious company which would result in getting a holistic view.

In the spirit of thorough understanding, we have created a furniture company called 'Treasure Ltd.' which manufactures Sofas and chairs at their workshop. They later sell these products to consumers through their retail showrooms. The supply chain of manufacturing furniture starts with sourcing raw materials to distributing finished goods. We have then applied different Operations Research techniques at three key stages of the supply chain, them being sourcing of raw materials, production, inventory routing.

IV. ANALYSIS AND FINDINGS

A. Sourcing of Raw Materials

For the purpose of manufacturing sofas and chairs, Treasure Ltd. requires three principal raw materials - Plywood, Foam and Cloth, in different quantities. It currently sources these from three suppliers, namely Supplier A, Supplier B and Supplier C, who have different costs of transporting raw materials to the production facility. All suppliers supply all three raw materials. The company needs to decide the optimal quantity, optimal price for each raw material to be ordered from each supplier, so that raw material costs can be minimized. To solve this problem, we will use a well-known Operations Research technique called Transportation Problem. "Table I" shows the costs (per unit) at which different suppliers can transport each type of raw material to Treasure Ltd.'s production facility:

TABLE I.

Supplier ↓	Plywood P	Cloth Q	Foam R	Supply
A	81	20	28	2000
B	77	19	23	4800
C	73	17	21	200
Demand	1400	5400	800	

(Source: Authors)

Solution:
Step 1: The first step is to determine the demand and supply and if the problem is balanced or unbalanced.

AD = 1400+5400+800 = 7600
AS = 2000+4800+200 = 7000

Since, $AD \neq AS$ <u>Unbalanced</u>

Step 2: Find the Initial basic feasible solution by Vogel's approximation method (IBFS by VAM).
This method takes the two lowest costs in a row and column, then takes their difference and allocates units where the opportunity cost is highest. "Table II" illustrates the same:

TABLE II.

Supplier ↓	Plywood P	Cloth Q	Foam R	Supply	I_1	I_2	I_3	I_4
A	81	[2000] 20	28	~~2000~~	8	8	(8)	-
B	[800] 77	[3200] 19	[800] 23	~~4800~~ ~~4000~~ 3200	4	4	4	4
C	73	[200] 17	21	~~200~~	14	(14)	-	-
D'	[600] 0	0	0	~~600~~	-			
Demand	~~1400~~ ~~800~~	~~5400~~ ~~5200~~ 3200	~~800~~	7600				
I_1	(73)	17	23					
I_2	4	2	5					
I_3	4	1	5					
I_4	(77)	19	23					

(Columns and Rows in Red indicate cancelled columns and rows)
(Source: Authors)

Step 3: Test for Optimality: "Table III" uses the Modified Distribution (MODI) Method:

TABLE III.

Supplier ↓	Plywood P	Cloth Q	Foam R	u_i
A	78 (-3) 81	2000 20	24 (-4) 28	1
B	800 (-) 77	3200 (+) 19	800 23	0
C	75 (+2) 73	200 (-) 17	21 (-10) 21	-2
D'	600 0	-58 (-58) 0	-54 (-54) 0	-77
v_j	77	19	23	

(Source: Authors)

No. of allocations = 6
= m+n-1
= 3+4-1
= 6→ Non – Degenerate

Taking $u_2 = 0$,
ɏ Δ ij not < = 0
Therefore, the solution is Not Optimal

ϴ = min (200,800)
ϴ = 200

Total Cost = Rs. (40000+61600+60800+18400+3400+0)
= **Rs. 1, 84,200**

"Table IV" shows the Improved Solution:

TABLE IV.

Supplier ↓	Plywood P	Cloth Q	Foam R	ui
A	78 (-3) 81	2000 20	24 (-4) 28	1
B	600 77	3400 19	800 23	0
C	200 73	15 (-2) 17	19 (-12) 31	-2
D'	600 0	-58 (-58) 0	-54 (-54) 0	-77
vj	77	19	23	

(Source: Authors)

No. of allocations = 6
= m+n-1
= 3+4-1
= 6→ Non – Degenerate

Taking $u_2 = 0$,
ɏ Δ ij < = 0
Therefore, the solution is Optimal & Unique

Total Cost = Rs. (40000+46200+64600+18400+14600+0)
= **Rs. 1, 83,800**

Step 4: "Table V" is the Transportation Schedule:

TABLE V.

Allocation	*Units*	*Rate*
A – Q	2000	20
B – P, Q, R	600+3400+800=4800	77,19,23
C – P	200	73

(Source: Authors)

Thus, by using the Vogel's Approximation Method, Treasure Ltd. was able to optimize transport costs. Had the company simply given orders based on the Least cost method, the cost would have been Rs. 189800/-, as compared to the cost under this method. (Difference = Rs (189800-183800) = Rs. 6000/-. Even under this method, post-optimization, Treasure Ltd. was able to save Rs. (184200-183800) = Rs. 500/-

B. Production

The aim of any production activity is maximizing profits given the raw material constraints or minimizing costs for producing a given quantity, which makes it a perfect application of Liner Programing Problems. The simplex method is usually the go to method for solving a production-based Liner Programing Problem as it can solve problems with multiple decision and constraint variables. The production cycle for Treasure Ltd. lasts 2 months of 2400 labor hours with 1400, 5400, and 800 units of plywood, cloth, and foam available respectively. Sofa production requires 8 hours of labor and 5, 20, 3 units of plywood, cloth, and foam respectively, whereas Chair production requires 2 hours of labor and 2, 10, and 1 unit of plywood, cloth, and foam respectively. The profit earnt per unit of Chair and Sofa would be Rs 1000 and Rs 3000.

Simplex Linear Programming Method

Problem Definition:

Considering chair as x_1 and sofa as x_2, the Linear Programing Problem would be:

Max Z= $1000(x_1) + 3000(x_2)$

Subject to:

$2(x_1) + 5(x_2) <= 1400$ constraint 1
$10(x_1) + 20(x_2) <= 5400$ constraint 2
$(x_1) + 3(x_2) <= 800$ constraint 3
$2(x_1) + 8(x_2) <= 2400$ constraint 4
$(x_1), (x_2) >= 0$

Standardization:

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Introducing S_1, S_2, S_3, S_4 as slack variables for constraints 1, 2, 3 and 4 respectively

$2(x_1) + 5(x_2) + S_1 < = 1400$ constraint 1

$10(x_1) + 20(x_2) + S_2 < = 5400$ constraint 2

$(x_1) + 3(x_2) + S_3 < = 800$ constraint 3

$2(x_1) + 8(x_2) + S_4 < = 2400$ constraint 4

Standard LPP

Max $Z= 1000(x_1) + 3000(x_2) + 0S_1 + 0S_2 + 0S_3 + 0S_4$

Subject to:

$2(x_1) + 5(x_2) + S_1 + 0S_2 + 0S_3 + 0S_4 < = 1400$ constraint 1

$10(x_1) + 20(x_2) + 0S_1 + S_2 + 0S_3 + 0S_4 < = 5400$ constraint 2

$(x_1) + 3(x_2) + 0S_1 + 0S_2 + S_3 + 0S_4 < = 800$ constraint 3

$2(x_1) + 8(x_2) + 0S_1 + 0S_2 + 0S_3 + S_4 < = 2400$ constraint 4

$(x_1), (x_2), S_1, S_2, S_3, S_4 > = 0$

First Simplex Table: "Fig.1" shows the First Simplex Table

Fig. 1. First Simplex Table

	basis	X1	X2	S1	S2	S3	S4	bi	bi/X2
S1	0	2	5	1	0	0	0	1400	280
S2	0	10	20	0	1	0	0	5400	270
S3	0	1	3	0	0	1	0	800	800/3
S4	0	3	8	0	0	0	1	2400	300
	Cj	1000	3000	0	0	0	0	Z=	0
		0	0	1400	5400	800	2400		
	Zj	0	0	0	0	0	0		
Δj		1000	3000	0	0	0	0		

(Source – Authors)

Since ∀ Δj is not <= 0 the solution is not optimal

Θ = 3

Second Simplex Table: "Fig.2" shows the Second Simplex Table

Fig. 2. Second Simplex Table

	basis	X1	X2	S1	S2	S3	S4	bi	
S1	0	1/3	0	1	0	-5/3	0	200/3	
S2	0	10/3	0	0	1	-20/3	0	200/3	
S3	3000	1/3	1	0	0	1/3	0	800/3	
S4	0	1/3	0	0	0	-8/3	1	800/3	
	Cj	1000	3000	0	0	0	0	Z= 3000 x 800/3	
		0	0	1400	5400	800	2400	Z = rs 800000	
	Zj	0	0	0	0	0	0		
Δj		1000	3000	0	0	0	0		

(Source – Authors)

Since ∀ Δj is <= 0, optimal

Product Mix and Utilization:

$x_1 = 0$, $x_2 = 800/3$, Z = Rs 800000

S_3 is fully utilized as it is not a part of basis; S_1, S_2, and S_4 are unutilized by 200/3, 200/3, and 800/3 units respectively.

Results indicate that Treasure Ltd. would earn a maximum profit of around Rs: 8, 00,000 if they produce 266 sofas while not producing any chairs. Thus, Treasure Ltd. should shift their focus to producing only sofas as they earn the maximum returns given the current constraints for them.

C. Inventory Routing

An important aspect of the supply chain would be creating distribution channels so as ensure smooth flow of inventory by minimizing delivery costs, deciding quantities, and optimizing transport routes. To understand the concept better we have created an Inventory Routing Problem inspired by one of the pioneer papers in the field of inventory routing.

Treasure Ltd. has 4 consumer showrooms namely A, B, C, and D. These showrooms have inventory storage capacities of 50,30,20,40 units a month, and the monthly demand of these showrooms is of 10, 30, 20, and 15 respectively. Treasure (TM) has two vehicles with the capacity to transport 50 units which operates on the first day of every month. The cost of transportation is Rs 500 per km travelled. "Table VI" shows this data.

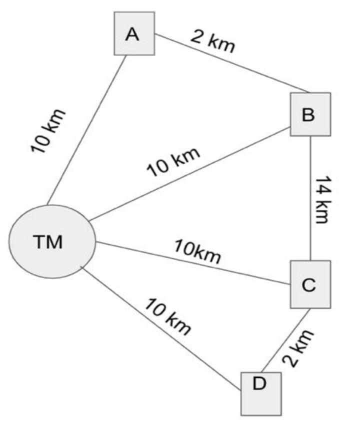
TABLE VI.

Consumer Showroom	A	B	C	D
Monthly Demand (Units)	10	30	20	15
Storage Capacity (Units)	50	30	20	40

(Source – Authors)

The location of the showrooms from the manufacturing centre is equidistant with each of them being 10kms from the centre. The pairs of A and B, C and D are located close to each other with a distance of 2 kms between them, while there is a 14km distance between B and C, as shown in "Fig. 3".

Fig. 3. Network Diagram

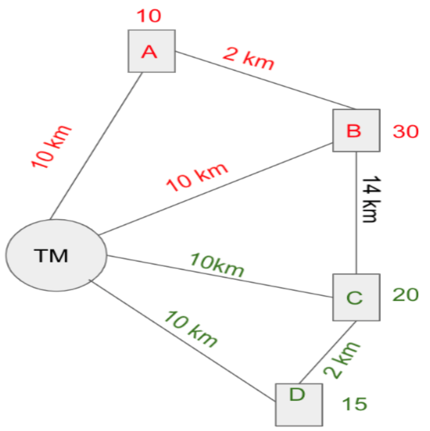


(Source – Authors)

Natural Solution: shown in "Fig. 4"

The Natural Solution would be to group A and B, and C and D and have the vehicle service each of the months since the pairs are very close to each other and B and C must restock each month due to their high demand and limited storage spaces. The monthly cost thus coming to Rs 22000 (44kms * 500 Rs per km) bringing the yearly cost to Rs 2, 64,000.

Fig. 4. Natural Solution



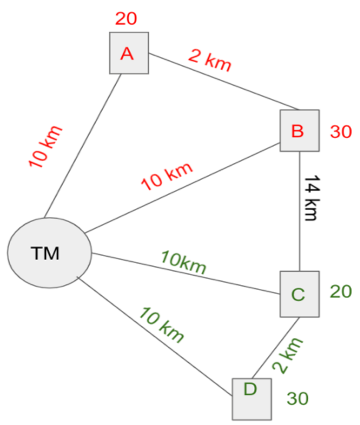
(Source – Authors)

Optimized Solution:

A better approach to this problem would be to create a cycle of months with different transport networks for alternate months. In the first month A and B would be served by the first vehicle with A getting 20 units twice its monthly demand and B getting 30 units, similarly the pair of C and D served by the second vehicle with C getting 20 units and D getting 30 units twice its monthly demand. In the second month only centers B and C would have to be restocked as A and D would enough inventory for another month, thus B and C would be restocked by a single vehicle.

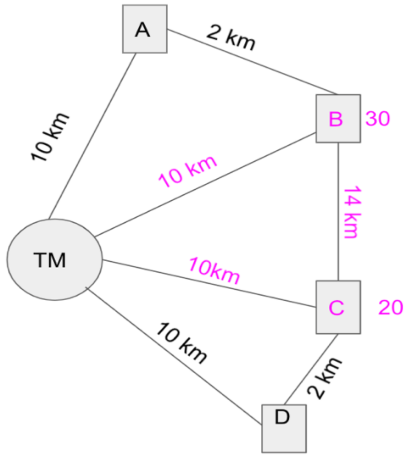
Optimized Solutions for 2 months have been illustrated in "Fig. 5" and "Fig. 6" respectively.

Fig. 5. Optimized Network for the First Month



(Source – Authors)

Fig. 6. Optimized Network for the Second Month



(Source – Authors)

The total distance covered in the first month would be 44kms, whereas the distance covered in the second month would only be 34 kms bringing the total for the cycle to 78 kms leading to a expense of Rs. 39000 (78* 500 Rs). The Total cost for the year would be Rs 234000. The adoption of this new method would lead to a saving of Rs 30,000 or a reduction in transport cost by about 11.36%. This was a basic example, but inventory routing could be done for problems which are much more complex by modeling, creating algorithms, using stochastic calculus to optimize inventory networks.

The application of OR techniques in the three key stages of the supply chain led to reduction of costs, improvement in efficiency, optimum utilization of resources, and maximization of profits. We find that OR techniques can be applied to a business of any scale regardless of it having a simple or complex supply chain.

V. LIMITATIONS AND RECOMMENDATIONS

While working on this research paper, we used various methods of Operations research for our analysis. However, in the process of applying those methods, we found that each method had certain limitations and would not work under certain situations.

They are as follows:

Limitations of LPP (by Simplex Method)

1. When a Linear Programming Problem contains more than two variables, the Simplex Method requires that at least 3 to 4 simplex tables be made. This is a tedious and lengthy process if done manually.
2. The graphical method of LPP can be illustrated for maximum 2 variables. We cannot have a graphical solution with more than 2 variables. This is another limitation.

Limitations of Transportation Problem:

1. Transportation Problem method is less realistic in the real-world business scenario. This is because it considers the source and destination at different places. For example, a company may want to send some goods from Factory A to Factory B in order to meet an increase in demand. In this case, Factory B becomes a source as well as a destination.
2. Vogel's Approximation method gives only an approximate solution to the problem

Limitations of Inventory Routing Problems:

1. Not all businesses are equipped with professionals and technology to solve inventory routing problems, which require complex modeling, algorithms and various stochastic processes, which is the domain to professional statisticians.
2. The problem requires demand figures as an input, which in real world business scenario, can be only estimated at best. Moreover, these figures change every day, week, month, and year which makes it a tedious job to determine optimal routes every time we need to send goods.

Now that we are aware of the limitations of the methods used in this research paper. It would be prudent to find out the possible ways or methods that can be adopted to overcome those limitations. Our recommendations are as follows: -

1. One of our objectives was to find out optimal inventory routing for the goods of Treasure Ltd. Instead of using simplistic methods, we could use network optimization software (which are built with algorithmic programs and stochastic models) that can process input quickly and give accurate and reliable results.
2. Instead of using a Transportation Problem for sourcing raw materials and/or goods, we can use Transshipment Problems, which has the flexibility w.r.t one place the source and destination for different locations.
3. Many missing values in the company characteristics and inventory performance measures reduced the researcher's ability to compare the effect of company characteristics on the relationship between supply chain management activity implementation level and inventory performance. In addition, direct and indirect relationship between SCM activity and inventory performance could not be compared. To solve this kind of problem, additional pilot work should be done to refine the variables.

VI. CONCLUSION

This research paper has provided a background, overview, and discussion on a number of supply chain management practices and technologies. The complexity and issues faced by managers and engineers with supply chain management topics continue to increase. The growth of this field is necessary as environmental burdens from industrial and supply chain operations continue. There are still substantial gaps and future directions for which managers and engineers need to be made aware.

Advancements in the field of mathematics, science, and technology have helped develop various Operations Research techniques which have a wide application in various field of study. Supply Chain management is a complex activity with various stages, and to optimize the entire chain a combination of various Operations Techniques could be used. A tailor-made Operations Research technique for every individual stage of the supply would not only increase performance at the micro level, but also exponentially boost the efficiency of the entire process.

Throughout the paper, we saw how Operation Research Techniques could help businesses in aspects such as transportation, production, inventory routing, and capital allocation. As a result, business could make better decisions regarding various aspects like sourcing of material, choice of labor, and production techniques just to name a few. Although the paper has focused on three Operations Research techniques, businesses could come up with several models, simulations, techniques specific to their activities to optimize operations.

India Supply Chains for most of its processes are unorganized or semi-organized, often operating at low profitability margins attributable to high costs and low efficiency. Application of Operation Research Techniques to the Indian supply chain industry could help formalize this process and give impetus to local operators and businesses involved in this process to gradually have a multiplier effect on the economy.

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