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Mathematical Model Used to Determine Supply Chain Performance in Manufacturing

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Abstract
This paper provides a detailed analysis of supply chain performance done by different models including linear programming, mixed integer programming, fuzzy modeling approach etc. where the main focus was given on production planning, inventory control and transportation. As this area of study is relatively new, previous works on different models were considered to get the trend of mathematical model mostly used in different industrial sector. On basis of mixed integer programming model which was mostly used in reviewed works by other authors, a problem statement was devised on supply chain network consisting of three echelons, multi-supplier, multiple customer and multiple distribution centres. Optimal minimization of two objective functions were done to maximize the revenue and effective transport management. In this work, LINGO algorithm is used for numerical data analysis and balancing of distribution centres in a multi-objective supply chain. Mixed integer programming modelling approach was found to be used in most of the previous works in supply chain management and can be used as parent model while considering manufacturing. Now, further researches should provide modifications to this parent model to get the maximum efficiency and optimum results in Indian scenario.

Keywords
Supply chain management, fuzzy modelling approach, mixed integer programming model, stochastic models, hybrid model.

I. Introduction

The term Supply Chain Management was first coined by Keith Oliver in 1982.In supply chain management; expertise is based on how well flow of products and services are supervised. The process of supply chain management includes the movement and storage of raw material in the inventory (American concept) to the products and services being received by wholesalers, retailers and customers. Supply chain management is very important in current scenario to gain the maximum efficiency from procurement, distribution and logistics as well as to make outsourcing more efficient and productive. Study of SCM can also make us understand how we can reduce the transportation costs of inventories. In recent decades, globalization, outsourcing and information technology have enabled many organizations such as Dell and Hewlett Packard, to successfully operate collaborative supply networks in which each specialized business partner focuses on a few strategic activities (Scott,1993). However, when the interaction between the customer and supplier or the players get complicated, the network structure fits neither "market" nor "hierarchy" categories(Powell,1990). From a systems perspective, a complex network structure can be decomposed into individual component firms (Zhang and Dilts,2004). Traditionally, companies in a supply network concentrate on the inputs and outputs of the processes, with little concern for the internal management working of other individual players. Therefore, the choice of an internal management control structure is known to impact local firm performance (Mintzberg,1979). Supply Chain Management has undergone six different phases in evolution chart which are Creation Era, Integration Era, Globalization Era, Specialization Era Part-1, Specialization Era Part-2 and Supply Chain Management (SCM 2.0) in chronological order.

For implementing SCM successfully, integration of managing individual activities in every sections is required in every important areas of supply chain process. To fully leverage the information that is shared between various constituents of supply chain management, process integration is mostly required. Supply chain business process integration involves activities which involve buyers and suppliers, joint product development, common systems, and shared information. Lambert and Cooper (2000) said that operating an integrated supply chain requires a continuous information flow. Some key chain processes stated by Lambert are like Customer relationship management (analysing data about company with customer in their database), Customer service management, Demand management style, Order fulfilment etc.

Now as this area is new in relative context and till date there has been no boundary which clearly defines supply chain management. So there are many theories like Resource based view (RBV), Transaction cost analysis (TCA), Knowledge-based view (KBV) which provides theoretical foundation over particular areas of Supply Chain Management.

II. Literature Review

The majority of the reviewed works in the current scenario can be classified according to the modelling approach used. As it is a relatively new area of research, limited sample of works were found. The modelling approaches were based on Linear Programming, Mixed Integer Programming, Integer Non Linear Programming, Multi-objective linear programming, Fuzzy Mathematical Approach and Hybrid models, etc. Major studies (Kouvelis and Rosenblatt, Alawneh et al., Cortinhal et al., Peidro, Mula and Poler, Paksoy et al.) were conducted on Mixed Integer/ Integer Linear Programming. The main findings of these works were focussed on reducing costs of transportation, production planning and inventory and optimal amount of product to be delivered from suppliers to consumers. Due to complexity in environment (e.g. increase in nodes etc.) mathematical models were also developed on non-linear programming. The models also focus on multi-interval planning and efficient decision-making in supply chain management(SCM). Several studies (Selim and Ozkarahan, Babatunde, Zhang and Xu, Peidro, Mula and Poler, Zonozi and Ali Afshari) were conducted in fuzzy environment which means the boundaries/constraints of the objective function and decision variables are not clearly defined. Similarly, stochastic models were examined by researchers (Ali and Nakade, Nickel and Ziegler) in an environment where the components of supply chain network were under uncertainty. This path of study deals with supply network configurations that are efficient/optimal for various scenarios of design variables. Many studies (Sitek and Wikarek, Almeder et al.) showed that hybrid models were faster than traditional mixed integer models.

Sometimes in certain industries, classical methods are slow and inefficient to find an exact solution of optimization model. Heuristic and metaheuristic approaches were considered in these works (Madadi et al.) where the environment demanded a method that would surpass the efficiency of classical methods.

Authors	Focus	Findings
Selim and Ozkarahan[19]	To develop a model that can select the most reasonable numbers, locations and capacity of plants and storehouse which at the most the minimal cost can deliver the products to consumers at a service level which is satisfying for the retailers.	A supply chain network design model was established through Fuzzy Modelling Approach which takes into account the decision maker's imprecise aspiration level and fluctuation in demand. A realistic example of the model is represented to prove its applicability in market.
Kouvelis and Rosenblatt[4]	To demonstrate the results of mixed integer programming model for financing and corporate taxation issues.	When transportation cost is high, firms produce and services at the central zone. Trade tariffs affect decentralization of distribution system. Differential tax rates help more centralized production and distribution centre networks. Relatively low transportation cost to that of the final product makes the facility network more dependent on regional trading zones. Also appropriate increment in local content requirement stabilizes the base of trading zone to that country.
Habib[14]	To represent the theory of SCM and its future impacts in various sectors of manufacturing and industry. It also focuses on the evolution of SCM and aims in redesigning the Integrated Tertiary Supply Chain Management (ITSCM) model.	The paper deals with the evolution of SCM and represents the first large scale analysis that investigates the input, output and flow of materials to the redesigned ITSCM model. The model generated links educational management with general business management. When viewed through a managerial perspective, it is an approach towards attaining SCM applications in academic sectors.
Hsiung Lan, Ming Chen, Wei Chiu, Hsiu Chen[2]	To demonstrate a referenced model that focuses on multi interval planning and decision making in supply chain management.	The paper firstly introduced time factor and the developed model of Complicated Continuous Supply Chain Model (CCSCM) which has turned into Integer Non Linear Programming Model(INLP). Secondly, a computerized tool was developed to help enterprises in taking decisions on multi interval planning, multi factory production and inventory under constraints, transportation and inventory controls for multiple dealers and retailers.
Alawneh, Alrefaei, Diabat, Al-Aomar, N.Faisal [10]	To develop a linear programming formulation for Steel Industry in Supply Chain that helps to take decision regarding the amount of raw materials to be requested from the suppliers to consumers, the amount of end products to the retailers and most favourable inventory.	Through analysis in GAMS software, the approach determines a simplified Linear Programming model which helps in minimizing the annual cost of company's supply network which includes transportation, inventory level and supply of goods to the market.
Cortinhal, Costa, Lopes, Nunes[12]	To introduce a mixed integer linear programming model for solving a problem related to production and distribution involving multiple suppliers, transportations and distributors.	The model was tested with CPLEX 12.3 based on sets of variable instances of different parameters. One set with valid inequalities showed considerable improvements in terms of quality was proved to be much faster than that the set of models with no valid inequalities. The study also reveals the fact that when a fixed cost is considered for various modes of transportation, the instances become harder to resolve.
Babatunde[8]	To implement a mathematical programming model in SCM in a fussy environment through LINGO algorithm that optimizes cost of inventory, production and transportation from plants to various distributors and retailers.	The study revealed that a certain cost in supply chain is required to be diminished for the company to efficiently manage its amenities. The number of items to be delivered from each distribution centre was optimized. Keeping in mind the possibility of inflation in future, certain ranges were considered in which basis object coefficient allowable decrease was carefully examined.
Zhang and Xu[18]	To present a Multiple Object Decision Making (MODM)to solve the supply chain management problem under quantity discount policy under fuzzy environment.	The model was implemented in a SCM model and upon solving that through sensitivity analysis, possibility level α was noted.
Huynh, Lin, Park, Shi[15]	To focus on minimization of labour force and resources and building up a simplified mixed integer non-linear programming model.	The numbers of labour workers were fixed through iterative steps in a sub-optimal solution. Apart from this the work was based on importance of every factor on the production of the plant and how optimization can help in reducing a significant amount of cost.

Peidro, Mula, Poler[5]	To derive a model through FMILP in which different cases with uncertainties can be examined in a multi-level supply chain management.	Fuzzy mixed integer linear programming model has proven better than deterministic model when there is lack of information related to supply and demand. Efficiency of computational analysis has been same for both the cases of model solved by FMILP and deterministic model.
Zandhessami, Zonozi, Ali Afshari[1]	To demonstrate a fuzzy multi-objective non-linear mixed integer programming model to make the effective use of material flow and transportation cost between all echelons.	Due to increase in nodes in the supply chain network, genetic algorithm has proved much better than fuzzy non-linear mixed integer programming model as better results were obtained in a limited time.
Umeda and Zhang[9]	To present a simulation model that combines discrete event and system dynamics model i.e. hybrid model framework and also its application in supply chain in a real world scenario.	The hybrid simulation model was presented and in this model it was observed that as demand increases, the lead time becomes more and service level decreases. So the framework helped to understand the system performance with varying production status.
Sitek and Wilkarek [3]	To present a hybrid model for supply chain management where the strengths of integer programming and constrained logic programming were integrated. The model was tested in both mathematical and hybrid environments.	Effective results were found faster by this approach. The possibility to determine the range and value of the decision variable also increases efficiency in such type of problems. All types of LINGO solvers can also be used in hybrid models.
Paksoy, Ozceylan, Weber[7]	A multi-objective mixed integer programming model was designed for multi-echelon supply chain network in order to reduce the total cost which includes transportation costs, ordering costs and holding costs.	This model found optimal amount of products or services that should be supplied from supplier to the customers in a supply chain. In this problem, a single distribution centre (DC) was allotted for each customer which prevented unnecessary complications in balancing.
Almeder, Preusser, F.Hartl[6]	To present a general framework that combines optimization model and discrete event simulation model i.e. hybrid model.	The model has advantages of both its parent models and when applied to different examples and it gave faster results than traditional mixed integer models in a stochastic environment.
Ali and Nakade[11]	The paper aims in proposing a stochastic programming approach to manage the various deranges of the supply chain giving emphasis on product demand and uncertainty in disruption.	The author used Monte Carlo sampling method for sampling a given probability distribution of stochastic parameters. The model was coded on GAMS 24.1.3 and run by CPLEX (12.5.1.0). The model is very effective in analysing supply chain disruptions planning and managing in an industry so that it can contribute efficiently in the business operations.
Nickel, Saldanha-da-Gama, Ziegler[17]	To design a stochastic programming approach for risk aware supply chain design problems.	The problem was constructed as a multi-stage stochastic mixed –integer linear programming problem to maximise the net financial interest. A methodology was discussed which aims in solving and measuring the values of the stochastic solutions in the problem. Computer tests confirm that stochastic approach is worth considering in such sorts of problems.
Stich and Meyer[20]	The approach utilises the hybrid theory to supply chains and uses the advantages of its subsystem to reach an optimum result.	The paper is about the application of hybrid system theory on supply chains. After a descriptive overview of all the previous types of methods for the design of supply chain is given, a technique for a customer-to-customer oriented supply chain design is presented. A case study was conducted to demonstrate the application of the hybrid theory approach on supply chains.
Dotoli, Fanti, Iacobellis and Mangini [13]	The paper focuses on an effective and modular model based on first order hybrid Petri Nets (PNs). PNs are used in first order fluid approximation.	A supply chain case study was formed and various control strategies evaluated the performance on basis of system inventory and time. The results showed that the fluid approximation method led to an effective installation of management policies.
Madadi, E.Kurtz, Mason, M.Taaffe [16]	The focus of the paper is to select the optimum capacity and location of the plants and distribution centres, such that at a minimal cost, an efficient customer demand is satisfied.	A mixed integer programming model of the problem was formulated and it was solved using a harmony search meta-heuristic procedure which included two sub-procedures. Some sample models were solved to examine the accuracy and speed of the method.

III. Problem Statement

A company's management wishes to design a Supply Chain network consisting of three echelons, multiple supplier, multiple customer and multiple distribution centre problem. By considering the goals of management to achieve optimization of costs, we designed a multi-objective mixed integer non-linear programming model. In this process, we assumed that the plant capacities are known and products are supplied from a single centre.

Variables and parameters are shown below:
a = number of customers (1,2,3...N)
b = number of distribution centres (1,2,3...N)
c = number of manufacturing plants (1,2,3...N)
d = number of suppliers (1,2,3...N)
q_m = quantity of raw materials supplied to manufacturing plant
q_d = quantity of products supplied to distribution centre
q_c = quantity of products shipped to customers
D = demand of products
t_c = unit transportation cost from distribution centre to customer
t_d = unit transportation cost from manufacturing plant to distribution centre
t_p = unit transportation and unit buying cost for raw materials from supplier to manufacturing plant
h = holding cost per year
o = ordering cost
Now the objective functions are defined as follows:
F1 (t_p,t_d,t_c,q_m,q_d,q_c) = first objective function that defines the total cost of transportation of the entire supply chain network.
F2 (qd,h,o,d,) = second objective function that defines as a summation of ordering costs of all suppliers and handling costs of material where Economic Order Quantity (EOQ) is purchased at a time.
Now, the two objective functions are minimized to get the optimum results for management.

IV. Mathematical Example

Following data were accumulated from industries and are shown below:

Table 1: Transportation costs between suppliers and manufacturers

Suppliers					
Manufacturers	**1**	**2**	**3**	**4**	**5**
1	0.7	0.2	0.6	0.3	0.4
2	0.4	0.5	0.5	0.7	0.5
3	0.5	0.5	0.4	0.6	0.6

Table 2: Transportation Costs Between Manufacturers and Distribution Centres

Manufacturers			
Distribution Centres	**1**	**2**	**3**
1	1.6	0.9	1.1
2	1.2	0.9	1.0
3	1.5	0.9	0.8

Table 3: Transportation cost values between distribution centres and customers

Distribution Centres			
Customers	**1**	**2**	**3**
1	0.8	0.6	0.6
2	0.7	0.9	0.7
3	0.9	0.5	0.8
4	0.6	0.9	0.7

Table 4: Capacity of manufacturers, suppliers, distribution centres and customer demands

	Suppliers	**Manufacturers**	**DCs**	**Customers**
1	5100	6600	6500	3200
2	5400	7000	6300	3200
3	5150	6400	6100	3200
4	4850	-	-	3200
5	4600	-	-	-

Table 5: Results obtained by LINGO Programming

Decision	**Value**	**Decision**	**Value**
$X_{1,3}$	1900	$Y_{3,2}$	3500
$X_{2,1}$	2500	$Y_{3,3}$	3000
$X_{2,2}$	3000	$Z_{1,4}$	3300
$X_{3,1}$	500	$Z_{2,2}$	2900
$X_{5,3}$	4600	$Z_{2,3}$	3200
$Y_{1,2}$	2700	$Z_{3,1}$	3100
$Y_{2,1}$	3000	Objective	13798

V. Conclusion

This study presents an analysis of mathematical models used to determine supply chain performance in production planning, inventory control and transportation. Most of the previous works on this topic were based on data collected from various industries. It was observed that mixed integer programming modelling approach was extensively used in most of the works. The purpose of this approach has always been to optimise the total cost of the supply chain, thereby maximizing the revenues and effective transport management. In a numerical data analysis through LINGO algorithm, balancing of distribution in a multi-objective supply chain network has also been shown to demonstrate the practical use of this method.
Further researches can be conducted in this field to check whether mixed integer programming approach can be effectively implemented in industrial sectors in the Indian scenario. While applying the mixed integer model, several discrepancies in efficiency may be counteracted by several modifications to the programming approach.

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