Supply Chain Management : Modeling And Algorithms : A Review

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***Abstract*—.**
In today's competitive business environment, supply chain performance is one of the most critical issues in various industries. Over, the past two decades, several frameworks and systems have been developed to meet this need. Prior to the popularization of the term supply chain to describe the network of suppliers, manufacturers, transporters, warehouses, there are models which used the term multi – echelon to represent multiple stages that the materials undergo right from the suppliers up to reaching the customers. This paper discusses the strategic, operational and tactical issues involved in a supply chain management from the perspective of modeling and analysis and presents the models dealing with those issues from the literature. It also discusses the challenges posed by the real – world supply chain problems to the modelers such as huge data, complex interactions among the chain members and uncertainty, etc. This paper also discusses the opportunities created by the latest developments in hardware, information technology and mathematical modeling such as variations in the formulation of the problem and algorithmic methods to deal with the real world problems. From the literature review it is observed that lot of progress took place in the supply chain management in terms of the applications of the models in the last decade. Also large number of papers were found applying meta heuristics to the supply chain network design, optimizing the production, inventory and distribution etc. Also real life supply chain problems with thousands of variables have been solved using decomposition methods. But the literature found that not much work has been done in the field of networking of various supply chain entities such as suppliers, plants, distributors and customers to share the data in online manner. Presently it is found from the literature that the above tasks will be performed off-line. In this regard, cloud computing is found to be appropriate for the supply chain networking, so that data and other algorithms (for optimization of production, inventory, distribution costs) can be stored in a central web server and can be shared by all the supply chain entities. Also the future work, must focus on developing libraries of supply chain algorithms for various models and their software programs, so that it is not required to begin from scratch for the future researchers.

Key Words: - **Supply Chain Management, SCM, SCM review, SCM modeling, SCM analysis**

1. Introduction:-

The cost of a product plays an important role in the demand for that product. Cost reduction is an

an on-going process. Many models have been developed in this regard, to minimize the costs of supply chain. The main components of a supply chain are supply, production, inventory, distribution; the various levels of a typical supply chain are raw material and component suppliers, plants/factories, distribution centers/warehouses, agents, customers. The research on supply chain management focused on problems such as supplier selection problem, Integrated models which integrates the functions of supply, production, inventory distribution between various levels such as suppliers, plants, distribution centers and customers. The vehicle routing problem is another problem which is widely studied in the literature. Several variants of VRP such as capacitated vehicle routing problem, vehicle routing problem with time windows (VRPTW), multiple-depot vehicle routing vehicle routing problem (MDVRP), etc have been formulated and solved. Some models have been formulated in the literature to co-ordinate planning and scheduling of production and distribution.

2. Characteristics of a good model of real-world problems:-

1. The model should make as little assumptions as possible.
2. The data used in the model should be collected from a reliable source.
3. The model should be as abstract as possible
4. The model should give consistent results

5. The model should produce reliable results.

6. The model should be robust.

3. **Algorithms to solve real-world supply chain problems**:-

3.1 Exact algorithms :(1) Linear Programming, (2) Transportation (network), (3) Flow models,

Many of the supply chain management problems such as the integrated production – inventory-distribution problems and decentralized production-distribution problems can be formulated as linear programming problems. But some distribution problems have a special structure and these can be formulated as transportation problems and can be solved by efficient algorithms available in the literature. Also, many of the real world supply chain management problems can be represented as a graph (network) problem. These can be used to solve problems such as shortest path from one node to other node and maximum flow from source node to terminal node in case of a flow problem. There are efficient algorithms such as Djkstra's algorithm and Floyd Algorithms to do the above tasks. The flows problem arise when one want to analyze the flow of parts from one department to other department in a plant or from a plant to a distribution center in case of a supply chain.

3.2 **Integer Programming based algorithms** :

In real world supply chain problems, many of the decision variables cannot be assumed to take decimal values, for example the number of machines or number of workers can take only integer values. Integer programming problems are a special case of linear programming problems where the decision variables can take only integer values. In some situations, where some variables are continuous and some variables are integer, Mixed Integer Programming (MIP) problems are used. Also, in some applications the variables may take either 0 or 1 value. In such cases, Binary Integer Programming (BIP) algorithms are used. There are two main algorithms to solve Integer Programming problems, viz., Branch and Bound (B&B), Cutting plane methods.

Some of the variants of integer programming problems are mainly (1) set partitioning problems, (2) set covering problems, and (3) Bin packing problems.

The applications of these techniques to solve supply chain problems are mentioned below:

Set partitioning formulation has been used in solving the vehicle routing problem with time windows (VRPTW). Marielle Christiansen (2002), (2004) has used set partitioning formulation to solve the ship routing and scheduling problem with time windows.

Set covering problems, (Taha), (2002) can be used in supply chain management problems to assign vehicle routes to customers to minimize the distance travelled by all vehicles to cover every customer.

Jacques Renaud (2002) has developed a sweep- based algorithm for the fleet size mix and vehicle routing problem. He also suggested a method to modify the sweep procedure to deal with non Euclidean problems.

Ugur Eliiyi et al (2009) have described the various applications of Bin Packing Problem (BPP) in supply chain management such as vehicle and container loading, cutting stock, packaging design, resource allocation, project management and financial budgeting.

3.3 **Dynamic programming based algorithms**: Dynamic Programming is a method for solving a difficult problem by dividing the difficult big problem into smaller sub problems and solving each sub problem, and storing the solutions to sub problems in a particular manner in a data structure form. Finally the solution to the original problem is arrived from the solutions of sub problems.

3.4 Heuristics

Exact algorithms can solve only relatively small problems. For practical real-world supply chain problems heuristic methods are applied. Heuristic methods are approximate algorithms which computes the lower bound in case of a maximization problem (upper bound in case of a minimization Problem) and iteratively increases the lower bound (for a maximization problem), until there is no further increase in the lower bound. There are mainly, three important heuristic methods available for supply chain problems: (1) Heuristics based on lagrangian relaxation, (2) Heuristics based on Dantzig-wolfe decomposition, and (3) Heuristics based on Bender's decomposition. Some of the applications of these methods to supply chain problems available from the literature are mentioned below:

3.4.1 Heuristics based on lagrangian- relaxation

Lanshun Nie (2008) has developed a method for collaborative planning in supply chains by using lagrangian relaxation and genetic algorithm to coordinate and optimize the production planning of the independent partners linked by material flows in multiple tier supply chains.

3.4.2 Heuristics based on Dantzig-wolfe decomposition

Dantzig-Wolfe decomposition is an optimization technique for solving large scale, block structured, linear programming (LP) problems. Problems from many different fields such as production planning, refinery optimization, and resource allocation may be formulated as LP problems. Where there is some structure arising from repeated components in the problem, such as the handling of multi-periods, multi-locations, or multi-products, the problem may potentially be solved using Dantzig-Wolfe decomposition

James Richard Tebboth (2001) has performed a computational study of Dantzig-wolfe decomposition algorithm. They were able to solve problems of up to 83,500 rows, 83,700 columns, and 622,000 non-zero elements, and one important instance was solved in 63% of the time taken by a commercial implementation of the simplex method. If we were content with a solution guaranteed to be within 0.1% of optimality, then the solution time can be cut by a further 32%. Using parallel hardware the solution time can be cut further: by 59% on a four processor PC (equivalent to a speed-up of 2.42) or 81% on seven processors of a Silicon Graphics workstation (a speed-up of 5.22).

3.4.3 Heuristics based on Bender's decomposition

Xu Yang (2009) has developed a model for Real time optimization of an integrated production-inventory-distribution problem. He applied a modified Bender's decomposition method to solve the integrated production-inventory-distribution planning problem involving 22 plants, 7 distribution centers, 8 customers dealing with 9 products using 16 inbound-shipment carriers, 16 outbound-shipment carriers for 12 time periods. This problem involved 370,764 continuous variables, 2,376 binary variables with 378,829 constraints. According to his report, it took 118,455.02 seconds to solve this problem.

4. Meta – heuristics

Meta-heuristics are inspired by the natural phenomenon, such as the solidification of molten metal's (simulated annealing), evolution of species (genetic algorithm), foraging behavior of insects (ant colony optimization, & artificial bee colony optimization), and foraging behavior of birds (particle swarm optimization). The number of applications of these techniques to supply chain problems is increasing year by year. Some of the applications of these techniques to supply chain problems are mentioned below:

4.1 Genetic algorithm

Fulya Altiparmak et al (2009) have developed a steady-state genetic algorithm for multi-product supply chain network design problem. By using this algorithm, he planned which plants and distribution centers should be open , and which customer should be served by which distribution center, quantity of raw materials shipped from suppliers to plants, quantity of products to be produced at plants, distribution quantities from plants to distribution centers and from distribution centers to customers.

Fulya Altiparmak (2006) et al has developed a genetic algorithm approach for multi-objective optimization of supply chain networks. In this work, he has considered three objectives: (1) Total cost of the supply chain network, which includes the fixed costs of operating and opening plants and distribution centers, the variable costs of transportation raw material from suppliers to plants and the transportation of the product from plants to customers through distribution centers , (2) The total customer demand (in%) that can be delivered within the stipulated access time,(3) The equity of the capacity utilization ratio for plants and distribution centers , and it is measured by mean square error(MSE) of capacity utilization.

4.2 Ant colony algorithm

C.A.Silva (2009) has developed a distributed supply chain management using ant colony optimization. This Paper introduced a new supply chain management technique, based on modeling a generic supply chain with suppliers, logistics and distributors, as a distributed optimization problem. He mentioned that the simulation results show that the new methodology is more efficient than a simple decentralized methodology for different instances of a supply chain.

4.3 Particle swarm optimization

Z.H.Che (2012) has developed a particle swarm optimization algorithm for solving unbalanced supply chain planning problems. In this work, he developed a decision methodology for the production and distribution planning of a multi-echelon unbalanced supply chain. To make a quality decision in supply chain planning, they first proposed an optimization mathematical model which integrates cost and time criteria. Then, a particle swarm optimization (PSO) solving method called MEDPSO is proposed for obtaining acceptable results.

4.4 Artificial bee colony optimization

Ernesto Mastrocinque et al (2013) has developed a Multi-Objective Optimization for Supply Chain Network Using the Bees Algorithm in which a swarm-based optimization method, namely, the bees algorithm is proposed in dealing with the multi-objective supply chain model to find the optimum configuration of a given supply chain problem which minimizes the total cost and the total lead-time. The supply chain problem utilized in this study is taken from literature and several experiments have been conducted in order to show the performance of the proposed model;

4.5 **Simulated annealing**,

A.N.Balaji et al (2010) have developed a simulated annealing algorithm for a two-stage fixed charge distribution problem of a supply chain, where two kinds of costs are involved : (1) a continuous cost that linearly increases with the amount transported between a source and a destination, and (2), a fixed charge, that incurs whenever there exists a transportation of a non-zero quantity between a source and a destination. The objective criterion is the minimization of the total cost of distribution.

Vaidyanathan Jayaraman (2003) has used a simulated annealing methodology for distribution network design and management. He developed a system called PLOT (Production, logistics, outbound, Transportation), by using which he designed the Production, distribution (inbound and outbound) systems

5. Problems faced in the implementation of supply chain models to solve real- world problems:-

1. Combinatorial nature of real world problems,

Many real world supply chain problems are combinatorial in nature. The number of decision variables increases exponentially when number of plants, products, time periods etc is increased. This requires extensive overhead on computers memory and slows down the execution speed.

2. Randomness of variables

The variables in a real world supply chain are characterized by randomness. The variables do not have a single value; instead their values are spread over a range. In such cases stochastic programming techniques may be applied.

3. Large volume of data

In real world supply chain problems the data required to model is very large and hence this data is stored in a database. The computing time increases exponentially with the increase in the database size.

4. Complex interactions among variables

Real world supply chain problems are characterized by complexity. For instance, the plant managers may not be willing to share the data about their plant operations with distribution managers, and the distribution managers also do not like to share the information about their domain to plant managers. But both of them may negotiate with each other regarding possible production quantity and distribution quantity. Hence the models developed for these cases should reflect this phenomenon of complex interaction and modeling.

6. Approaches to tackle the above problems:-

1. Data reduction: - The data for a real world supply chain will be taken from databases consisting of past records. It is very likely that this data may be very large and also some features of the data may be redundant. In such situations the data may be reduced by techniques such as principal component analysis.

2. Randomness: - The supply chain model developed may contain variables which are random in nature. In such cases, techniques such as discrete event simulation may be employed. There are many commercial discrete event simulation packages which contain a number of features useful for practical supply chain managers such as facility to do optimization of the simulation models etc.

3. Complicated models: - Some supply chain models are very complicated. These models may involve many sub-models. For instance, T.william Chen et al (1989) have developed a methodology for integrated inventory allocation and vehicle routing problem. Their formulation contains two sub-problems: (1) An inventory allocation sub-problem and (2) The customer assignment/vehicle utilization sub-problem. The first sub-problem is a continuous knapsack

problem and can be solved efficiently by a greedy heuristic; the second sub-problem consists of the commodity flow variables and the vehicle route variables. They developed a lagrangian-based heuristic which solves the two sub-problems and computes a lower bound on the integrated (original) problem. This iterative process continues until there is no increase in the lower bound. For real world supply chain problems this divide and conquer policy may be used. Other decomposition methods such as Dantzig-wolfe decomposition, James Richard Tebboth (2001) and Bender's decomposition, Xu Yang (2009) are also applied in the literature on supply chain management.

7. Supply chain planning and scheduling approaches:-

Centralized Vs Decentralized Planning and Scheduling

7.1 Centralized planning :- Xu Yang (2009) has developed a model for Real time optimization of an integrated production-inventory-distribution problem. He applied a modified Bender's decomposition method to solve the integrated production-inventory-distribution planning problem involving 22 plants, 7 distribution centers, 8 customers dealing with 9 products using 16 inbound-shipment carriers, 16 outbound-shipment carriers for 12 time periods. This problem involved 370,764 continuous variables, 2,376 binary variables with 378,829 constraints. According to his report, it took 118,455.02 seconds to solve this problem.

7.2 Decentralized planning

Georgios K.D.Saharidis in supply chain management (2011) has contributed a chapter on supply chain optimization, where he discussed the centralized Vs decentralized planning and scheduling systems. He elaborated the implementation of centralized and decentralized deterministic planning by taking an example of a company manufacturing aluminum doors. He also discussed the implementation of deterministic centralized Vs decentralized Centralized scheduling by means of a case study on a petrochemical industry. He also discussed the centralized Vs decentralized control policies by means of a case study of a company manufacturing aluminum doors with stochastic demand.

Hosang Jung et al (2005) have developed a decentralized production-distribution planning system using collaborative agents in supply chain network. In their work, they developed two collaborative agents, viz., production agent and distribution agent who will communicate with each other regarding desired production quantity by the distribution agent and the possible production quantity by the production agent. They illustrated the implementation of this system by taking a numerical example. For the example they considered, they got the final production and distribution plans which are acceptable to both the agents, in the 7th iteration.

Tatsushi Nishi (2006) has developed an autonomous decentralized supply chain planning and scheduling system. In his work, he considered three subsystems: (1) Material requirement planning subsystem, (2) A scheduling subsystem, and (3) a distribution planning subsystem. A near-optimal plan for the entire supply chain is derived through the repeated optimization at each subsystem and exchanging data among the subsystems. To illustrate the working of his system he considered an example where he used 4 products for a planning horizon of 12 time periods. For the scheduling part, he considered 3 stages where the four products are processed in a flow shop manner with sequence dependent set-up times. For the implementation of his system, he used simulated annealing algorithm, for the scheduling subsystem, which he coded in C++ language. For the material requirement planning subsystem and distribution planning systems he used mixed integer programming and used CPLEX as the solver.

Wen-Yau Liang et al (2006) has developed an agent-based demand forecast in multi-echelon supply chain, where he has mentioned that demand forecast taking inventory into consideration is an important issue. He also mentioned that there are many diverse inventory systems which are operated by entities (companies).Hence, he mentioned that in order to increase supply chain effectiveness, minimize total cost, and reduce bullwhip effect, integration and coordination of these different systems in the supply chain are required using information technology and effective communication. They developed a multi-agent system to simulate a supply chain, where the agents operate these entities with different inventory systems. Agents are coordinated to control inventory and minimize the total cost of a supply chain by sharing information and forecasting knowledge.

Hyun Soo Kim et al (2010) have developed a supply chain formation using agent negotiation. In their work, they used agent negotiation as a way to allocate numerous orders to many participants for supply chain formation in order to build a strategic cooperative relationship based on information sharing. Agent negotiation provides a coordination mechanism in which all the participants, including buyers, manufacturers, and suppliers are able to attain their own profits. In their study, they have taken into consideration that both tardiness and earliness production costs occur in the Single Machine Earliness Tardiness (SET model) scheduling and that participating members are in a competitive relationship. They developed a heuristic branch-and-

bound for Decentralized Supply Chain Formation Problem (DSCFP).
O.M.Akanle et al (2008) has developed an agent-based model for optimizing supply-chain configurations, which is of importance to Original Equipment Manufacturers (OEM), to optimally configure their supply chains to meet customer demand with minimum cost. They proposed a methodology for optimizing supply-chain configurations to cope with customer demand over a period of time. They used a multi-agent system to model resource options available in a supply chain as well as dynamic changes taking place at the resources and their operational environment.

Khalili (2016) have proposed an uncertain centralized/ decentralized production- distribution planning problem in multi-product supply chains: Fuzzy mathematical optimization approaches. In this paper, the author has introduced uncertainty concept in the demand data of product. He solved the proposed uncertain multi product supply chain problem with centralized and decentralized models. To introduce the uncertainty in the demand data, he used two terms, core demand and forecasted demand. The core demand is the demand estimated based on firm orders and forecasted demand is the expected demand estimated. Naturally, the variation in demand for core demand is less than that of forecasted demand. In this paper, the author used fuzzy approach to solve the uncertain centralized/decentralized production-distribution planning in supply chains.

8. Supply Chain Management Issues:-

S.No	Supply Chain Function	Issues		
		Strategic	Operational	Tactical
1	Procurement (purchase)	Buyer-supplier relationship, vendor development, entering contracts, agreements, selection of supplier	Taking advantage of global suppliers to increase the quality level.	Material requirements planning (MRP)
2	Production (Plant)	Production system design : selection and acquisition of plant location ,selection and adoption of layout, product-mix, selection of type, size and number of facilities (machines)	Aggregate planning, Master production scheduling (MPS)	Scheduling and control of production, work center loading
3	Inventory	Storage system design : selection of type, number and capacity of storage facilities, storage methods, warehouse location, ordering policies	ABC analysis	Order placement and follow up, stock taking, reviewing the stocks
4	Distribution	Distribution system design : selection of mode of transport (rail, road, water, air), selection of type, capacity and number of distribution facilities (trucks, tempos, etc), entering contracts with Transporters (in case of hiring)	3PLS (Third Party Logistics), leasing local warehousing, and negotiating with regional logistics companies.	Routing and scheduling of distribution

9. CONCLUSION :-

The field of Supply chain management has grown rapidly in the last 30 to 40 years and is growing steadily in this decade also. Many advances have occurred in this field in the last 10 years. This paper reviewed the literature of supply chain management from the point of Modeling and Algorithms developed to solve the Production inventory distribution problems that typically occur in a supply chain From the literature review it is observed that lot of progress took place in the supply chain management in terms of the applications of the models in the last decade. Also large numbers of papers were found applying Meta heuristics to the supply chain network design, optimizing the production, inventory and distribution etc. Also real life supply chain problems with thousands of variables have been solved using decomposition methods. But the literature found that not much work has been done in the field of networking of various supply chain entities such as suppliers, plants, distributors and customers to share the data in online manner. Presently it is found from the literature that the above tasks will be performed off-line. In this regard, cloud computing is found to be appropriate for the supply chain networking, so that data and other algorithms (for optimization of production, inventory, distribution costs) can be stored in a central web server and can be shared by all the supply chain entities. Also the future work, must focus on developing libraries of supply chain algorithms for various models and their software programs, so that it is not required to begin from scratch for the future researchers.

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