

A Strategic Level Model for Supply Chain of an Automotive Industry: Formulation and Solution Approach

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ABSTRACT

This paper describes a strategic level model of supply chain management (SCM). It explains overall supply chain issues, strategic importance of SCM, and an example of mathematical formulation. A supply chain is a global network of organizations that cooperate to improve the flows of material and information between suppliers and customers at the lowest cost and the highest speed. The objective of a supply chain is customer satisfaction. At the strategic level, a supply chain can be considered as being composed of five activities: buy, make, move, store and sell. The main aim of this paper is to show a strategic level model for supply chain of an automobile industry in mathematical terms, with an example of mathematical formulation. In this paper, a mixed integer linear programming (MILP) model is formulated first, and then alternative solution procedures are introduced.

Keywords: Supply Chain Management, Echelon, MILP – Mixed Integer Linear Programming, LINGO

I. INTRODUCTION

A supply chain is a set of facilities, supplies, customers, products and methods of controlling inventory, purchasing, and distribution. The chain links suppliers and customers, beginning with the production of raw material by a supplier, and ending with the consumption of a product by the customer. Typically, a supply chain is composed of several echelons represented by suppliers, plants, warehouses, distribution centres (DCs), and customers. There are usually different supplier options for purchasing raw materials, different production options for the assembly of semi-finished and/or final products, and different distribution options to carry final products to market. Generally, the design and management of a supply chain seek to obtain the best global performances so as to achieve the better performance of single link of the chain [1].

Managers who make decisions at different levels of the supply chain need to be supported by robust tools to evaluate the impact of alternative strategies on a firm's performance, prior to making them in the real environment.

Quantitative modeling for strategic supply chain planning continues to be a fruitful research area. These models can be approached through mathematics or simulation [2]. The purpose of the modeling is usually to provide effective decision support for strategic resource allocation in the longer term, including factors such as: Selection of suppliers, configuration of manufacturers and distributors' capacities, as well as allocation of these capacities to products and so forth. The main purpose of supply chain modeling lies in minimizing or maximizing an objective function through the identification of decisions and trade-off solutions that satisfy conflicting objectives at the same time. Therefore, the use of optimization approaches, which are generally based on mathematical models, is highly recommended in order to design supply chains [3]

At present, increased world competition is forcing supply chain companies to reconsider their capacity allocation strategies, particularly given that decisions, such as capacity allocation decisions, have a significant impact on supply chain performance. Given limited raw material supplies and limited capacities for production, final product transportation and distribution centres, the capacity allocation problem determines how best to use these resources to meet final product demand. In this paper, a strategic capacity allocation problem for an automotive supply chain is considered with a series of fixed operation costs and supply, production, transportation, and distribution capacity constraints. At first a mixed level integer programming (MILP) model is formulated to solve a multi-product capacity allocation problem involving multiple suppliers,

multiple production sites and multiple distribution centres. The model objective is to maximize the overall profit of the whole supply chain, and to minimize the costs of raw material purchasing and inventory, product production, transportation and distribution, as well as inventory holding and product shortage etc. Secondly, the solution to be MILP model can be obtained by using optimization software LINGO.

The remainder of this paper is organized as follows. Section 2 presents a review of related literature and further explains the advances in the approach proposed. In Section 3, the proposed problem is specified and the mathematical model is presented. Sections 4 discuss the model solution approach. Finally, conclusions are given in Section 5

II. LITERATURE REVIEW

Supply chain management (SCM) is a subject of increasing interest to academics, and practitioners. The formulation of strategic level models for supply chain design has been a popular research topic in the field of Supply Chain Management for two decades. Most of these formulations are in the form of mixed integer programming (MIP) models. SCM can be divided into two levels: strategic and operational. Models have been developed for optimizing supply chain operations at these two levels. The primary objective of strategic optimization models is to determine the most cost-effective location of facilities (plants and distribution centers), flow of goods throughout the supply chain (SC), and assignment of customers to distribution centers (DCs). These types of models do not seek to determine required inventory levels, and customer service levels. The main purpose of the optimization at the operational level is to determine the safety stock for each product at each location, the size and frequency of the product batches that are replenished or assembled, the replenishment transport and production lead times, and the customer service levels.

In their pioneering paper, Geoffrion and Graves [4] described a multi-commodity single-period Production distribution problem and solved it by Benders Decomposition. This is probably the first paper that presents a comprehensive MIP model for the strategic design of supply chains. Cohen and Lee [5] developed a comprehensive modeling framework for linking material management activities throughout the material production distribution supply chain. The framework consists of four sub models. The optimal solution for each sub-model is solved individually under some assumptions.

However, it would be extremely difficult to find the optimal solutions if all sub models are integrated.

A. Bellabdaoui [6] presented a mixed integer programming model for producing steel making continuous casting production. The mixed integer programming formulation is solved using standard software packages. Annlie. I. Pettersson[7] analyzes supply chain cost and measurements of supply chain cost in industry. She prescribes a model for measuring supply chain cost. The study shows that general thorough cost and supply chain analyses in many companies can be improved and further developed. Kejia Chen and Ping Ji [8] present a MIP model which gives system integration of the production planning and shop floor scheduling problems. The objective of the model is to seek the minimum cost of both production idle time and tardiness. The output of the model is operation schedules with order starting time and finish time.

Jolaymi and Olorunniwo [9] provided a deterministic model for planning production quantities in a multi-plant, multi-warehouse environment with extensible capabilities. When the production cannot meet demand the model allows shortfalls to be met through subcontracting or the use of inventory. Syarif et al.[10] considered the logistic chain network problem formulated by 0-1 mixed integer linear programming model. The design tasks of that model involve the choice of the plants and distribution centers to be opened and the distribution network design to satisfy the demand with minimum cost. Chan et al. [11] developed a hybrid genetic algorithm for production-distribution problems in a supply chain with multi-plants. Their mathematical model is proposed in linear programming form.

III. MODEL STRUCTURE AND FORMULATION

1. Problem Description

The supply chain structure of the automobile industry under study consists of four echelons viz. suppliers, manufacturing plants, distribution centers (DCs) and customers as shown in figure 1. Each supply chain echelon has a set of control parameters that affects the performance of other components. The present work aims for the strategic level modeling of supply chain for a section of automobile industry having two manufacturing plants located at different places and manufacturing two types of products. Both the products are manufactured on the two plants.

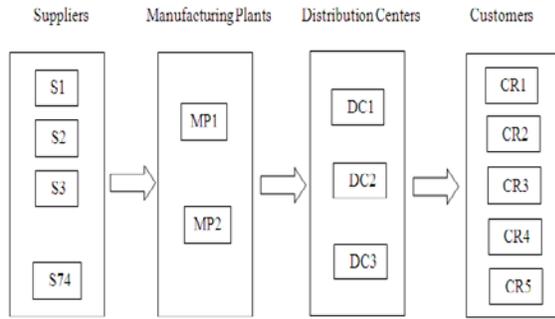


Fig. 1 Various Echelons of the Supply Chain

The strategic level modeling is the long term planning which decides the basic configuration of the supply chain and determine the optimum number of the suppliers out of the approved list, plants and distribution centers to keep under operation and the assignment of customers to distribution centers with an objective of minimizing the total cost of supply chain.

All the supply chain activities are controlled by the corporate office using a network of information flow between the corporate office and various echelons. The industry under investigation receives the customer orders at its corporate office. The customer orders primarily include the three key information i.e. the quantity required, delivery dates and penalty clause for late delivery. All customers' demands are aggregated and the annual production distribution planning is done by the corporate office. At the strategic level decision, the corporate office decides the suppliers and the allocation of the quantities of the raw materials to the selected suppliers, optimum production quantity allocation to various manufacturing plants, the assignment of the distribution centres to the manufacturing plants and also the assignment of the customers to the distribution centres.

2. Assumptions of the Model

Overall, the study is based on the following assumptions:

- It has been assumed that production of one unit of a product requires one unit of plant capacity, regardless of type of product. The similar assumption is adopted for distribution centres also.
- The components/raw materials procurement and finished product inventory at stores follow a continuous-review inventory control policy.
- The demand for the finished products is deterministic and the demand rate is constant over time horizon under study.

- The model considers the demands generated at each distribution centre independently from each other.
- The processing time, which is the time to perform the operation, is a linear function of the quantity of the products produced.
- Transportation times of components/raw materials, subassemblies and finished products between the stages of the production cycle have been assumed to be same in the present model.
- A type of product can be produced in more than one plant, and each plant can produce at least one type of product.
- The transportation time, waiting time, setup time and production processing times have been assumed to be fixed.
- The plants usually hold raw material stock to maintain production.

3. Limitations of the Model

- The model has not considered the global considerations like import/export regulations, duty rates and exchange rates etc.
- The model will be applicable in supply chains involved in manufacturing and distribution industry.
- Modeling is not having the flexibility of supplying the finished products from manufacturing plants to the customers directly.
- Modeling is unable to handle the risk factors at various stages of the supply chains.
- Preference of various supply chain members have not been considered in the modeling.

4. Mathematical Model

A mathematical programming model is formulated in order to solve the problem. The notations that will be used to describe the problem and algorithm are as follows:

T	Index on product, where $t = 1, \dots, T$, T is number of types of products produced
Z	Index on manufacturing plant, where $z = 1, \dots, Z$, Z is the number of manufacturing plants
D	Index on distribution center, where $d = 1, \dots, D$, D is the number of distribution centers
C	Index on customer, where $c = 1, \dots, C$, C is the number of customers
S	Index on supplier, where $s = 1, \dots, S$, S is the number of suppliers
b_d	Binary variable for distribution centre

	'd'
b_{dc}	Binary variable for distribution centre 'd' serving customer 'c'
b_z	Binary variable for plant 'z'
CP_z	Production capacity of plant 'z' (number of products/year)
D_{tc}	Demand of customer 'c' for product 't' (number of products/year)
F_d	Fixed cost of distribution centre 'd' (Rupees/year)
F_z	Fixed cost of plant 'z' (Rupees/year)
$MaxPV_{tz}$	Maximum production capacity for product 't' at plant 'z' (number of products/year)
$MaxTP_d$	Maximum throughput capacity of distribution centre 'd' (number of products per year)
$MinPV_{tz}$	Minimum production volume required for product 't' at plant 'z' to keep the plant operational (number of products/year)
$MinTP_d$	Minimum throughput required at distribution centre 'd' to keep the distribution centre operational (number of products/year)
PC_{ms}	Unit cost of component/raw material 'm' of supplier 's' (Rupees per component or Rupees per Kg)
Q_{tz}	Quantity of product 't' produced at plant 'z' (number of products per year)
Q_{tzd}	Quantity of product 't' shipped from plant 'z' to distribution centre 'd' (number of products/year)
Q_{msz}	Quantity of component/raw material 'm' shipped from supplier 's' to plant 'z' (number of products/year)
UCT_{td}	Unit throughput cost (handling and inventory) of product 't' at distribution centre 'd' (Rupees/product)
UPC_{tz}	Unit production cost for product 't' at plant 'z' (Rupees/product)
UTC_{tdc}	Unit transportation cost of product 't' from distribution centre 'd' to customer 'c' (Rupees per product)
UTC_{tzd}	Unit transportation cost of product 't' from plant 'z' to distribution centre 'd' (Rupees per product)
UTC_{msz}	Unit transportation cost of component/raw material 'm' from supplier 's' to plant 'z' (Rupees per unit of component/raw material)
w_1, w_2	Weight factors for plant and distribution centre volume flexibility
Z	Total cost of entire supply chain (Rupees/year)

Objective function

The objective function of the strategic model is to minimize the total cost of entire supply chain. The total cost of the supply chain includes the cost of raw materials, various transportation costs of components/raw materials and finished products between various echelons and various fixed and variable costs associated with the plants and distribution centres. The objective function which is the sum of various costs is represented in mathematical form as:

$$\text{Min } Z = \text{Cost 1} + \text{Cost 2} + \text{Cost 3} + \text{Cost 4} + \text{Cost 5} + \text{Cost 6} + \text{Cost 7} + \text{Cost 8}$$

where all the costs are represented as:

Cost	Type	Equation
Cost 1	Total cost of components/raw materials supplied by suppliers	$\sum_{msz} (PC_{ms} \times Q_{msz})$
Cost 2	Transportation cost of components/raw materials from suppliers to the manufacturing plants.	$\sum_{msz} (UTC_{msz} \times Q_{msz})$
Cost 3	Fixed cost associated with plant operations	$\sum_z (F_z \times b_z)$
Cost 4	Variable costs associated with plant operations	$\sum_{tz} (UPC_{tz} \times Q_{tz})$
Cost 5	Fixed cost associated with distribution centre operations	$\sum_d (F_d \times b_d)$
Cost 6	Variable cost associated with distribution centre operations	$\sum_{tdc} (UCT_{td} \times D_{tc} \times b_{dc})$
Cost 7	Transportation cost of products from plants to the distribution centres	$\sum_{tzd} (UTC_{tzd} \times Q_{tzd})$
Cost 8	Transportation cost of products from distribution centres to customers	$\sum_{tdc} (UTC_{tdc} \times D_{tc} \times b_{dc})$

Finally the expression for objective function to minimize the total cost of entire supply chain is given by Eq. 1.1

$$\begin{aligned} \text{Min } Z = & \sum_{msz} (PC_{ms} \times Q_{msz}) \\ & + \sum_{msz} (UTC_{msz} \times Q_{msz}) + \sum_z (F_z \times b_z) + \\ & \sum_{tz} (UPC_{tz} \times Q_{tz}) + \sum_d (F_d \times b_d) + \\ & \sum_{tdc} (UCT_{td} \times D_{tc} \times b_{dc}) + \\ & \sum_{tzd} (UTC_{tzd} \times Q_{tzd}) + \sum_{tdc} (UTC_{tdc} \times D_{tc} \times \\ & b_{dc}) \end{aligned}$$

(1.1)

Constraints

For an MIP supply chain design model, there are many generic constraints to be considered. In the present supply chain design model, constraints are put on the volume flexibility, the balance constraints of components/raw materials and finished products, the capacity limit and throughput limit. These constraints are given by Eqs. 1.2-1.14 explained in brief below:

(i) Volume Flexibility: The total volume flexibility is the weighted sum of plants volume flexibility and distribution centres volume flexibility. This should satisfy the minimum volume flexibility requirement. The total volume flexibility is expressed as given by Eq. 1.2 whereas the constraint on volume flexibility is represented by Eq. 1.3.

$$\begin{aligned} \text{Total weighted volume flexibility, } W &= \text{Plant volume flexibility} \times w_1 + \\ &\text{Distribution volume flexibility} \times w_2 \\ W &= [\sum_z (b_z \times CP_z - \sum_t Q_{tz})] \times w_1 + \\ &[\sum_d (b_d \times \text{Max } TP_d - \sum_{tc} (D_{tc} \times b_{dc}))] \times w_2 \end{aligned} \quad (1.2)$$

$$W \geq W_{min} \quad (1.3)$$

(ii) Supplier's Capacity Limits: This constraint ensures that the quantities of raw materials supplied by a supplier to all the allocated plants are within the supply capacity.

$$\sum_s Q_{msz} \leq CP_{ms} \quad \forall m, s \quad (1.4)$$

(iii) Materials Requirements of Plants: This constraint ensures that the raw materials quantities arriving from various suppliers fulfill the materials requirements of the plant for production of both types of products.

$$\sum_t (UR_{mt} \times Q_{tz}) \leq \sum_s Q_{msz} \quad \forall r, z \quad (1.5)$$

(iv) Production Capacity Limits of the Plants: This constraint specifies that the total production quantities of both types of products do not exceed plant capacity.

$$\sum_t Q_{tz} \leq CP_z \times b_z \quad \forall z \quad (1.6)$$

(v) Lower and Upper Bounds on Capacities of Plants: This constraint enforces the minimum and maximum production capacities for plants.

$$\text{Min } PV_{tz} \times b_z \leq Q_{tz} \leq \text{Max } PV_{tz} \times b_z \quad \forall t, z \quad (1.7)$$

(vi) Lower and Upper Bounds on Throughput Capacities of Distribution Centres: This constraint enforces the minimum and maximum throughput capacities for distribution centres and ensures that customer assignments can be made only to distribution centres satisfying the above

$$\text{Min } TP_d \times b_d \leq \sum_{tc} (D_{tc} \times b_{dc}) \leq \text{Max } TP_d \times b_d \quad \forall d \quad (1.8)$$

(vii) Distribution Centre Customer Assignment: This constraint specifies that any particular customer must be assigned to only single distribution centre.

$$\sum_d b_{dc} = 1 \quad \forall c \quad (1.9)$$

(viii) Plant's Output Balance: This constraint ensures that the quantity shipped from a plant to the various allocated distribution centres is equal to what is available at that plant.

$$Q_{tz} = \sum_d Q_{tzd} \quad \forall t, z \quad (1.10)$$

(ix) Demand Requirements at Customers: This constraint ensures that, for both types of products, the total shipments from the plants to the distribution centres are exactly equal to the total demand requirements of all the customers.

$$\sum_{zd} Q_{ztd} = \sum_c D_{tc} \quad \forall t \quad (1.11)$$

(x) Demand Balance at the Distribution Centres: This constraint ensures that all the incoming quantities of the products at the distribution centre from the allocated plants matches with all the outgoing quantities of the products from the distribution centres to all allocated customers.

$$\sum_z Q_{ztd} = \sum_c (b_{dc} \times D_{tc}) \quad \forall t, d \quad (1.12)$$

(xi) Non-negativity: This constraint ensures that all the variables are non-negative.

$$Q_{tz}, Q_{tzd}, Q_{msz} \geq 0 \quad \forall m, t, s, z, d \quad (1.13)$$

(xii) Binary variables: This constraint ensures the variables to be binary

$$b_z, b_d, b_{dc} = 0 \text{ or } 1 \quad \forall z, d, c \quad (1.14)$$

IV. SOLUTION TO MILP MODEL

The use of conventional tools for solving the MIP problem is limited due to the complexity of the problem and the large number of variables and constraints, particularly for realistically sized problems. LINGO an Operations Research software tool is used to solve the strategic MILP model for supply chain of the said automobile industry. LINGO solves the problems by using branch and bound methodology. The main purpose of LINGO is to allow a user to quickly input a model formulation, solve it, assess the correctness or appropriateness of the formulation based on the solution, quickly make minor modifications to the formulation, and repeat the process. LINGO features a wide range of commands, any of which may be invoked at any time. LINGO optimization model has two attributes: objective function of problem and constraints of problem.

1. Inputs to the MILP Model

For obtaining solution by LINGO solver, following data from automobile industry has to be collected and given as input:

- Unit production cost at plants
- Unit throughput cost (inventory and handling) per product at distribution
- Unit transportation cost of products from plants to distribution centers
- Fixed cost of plants
- Fixed costs of distribution centers
- Production capacities of the plants
- Minimum throughput cost (inventory and handling) capacity to keep the distribution centers operational
- Maximum throughput (inventory and handling) capacity of distribution centers
- Minimum production volume to keep the plants operational
- Maximum production capacity of plants for each product
- Annual demand of the products
- Number of components/raw materials per product noted from Bill of Materials
- Utilization rate of components/raw materials per product
- Identified suppliers, their capacities and per unit cost of components/raw materials
- Unit transportation cost of components/raw materials from the suppliers to the plants
- Unit transportation cost of finished products from distribution centers to the customers
- Minimum required volume flexibility (weighted sum of volume flexibility at plants and distribution centers) has been restricted to be greater than or equal to zero.

2. Output of MILP Model

After giving the above as input, the strategic model, given by Eq. 1.1 is able to give the following outputs:

- Quantities of products produced at the plants.
- Quantities of raw materials shipped from the suppliers to the plants.
- Quantities of products shipped from plants to the distribution centers.
- Quantities of products shipped from the distribution centers to the customers.
- Total volume flexibility.
- Total cost of the entire supply chain.

V. CONCLUSION

The major aim of the work presented in this paper is to provide a cost-effective approach that

would enable manufacturing organizations to gain competitive edge in the global market by coordinating between supplier and buyer to create a win-win situation for a decentralized model. This work formulates the strategic MILP model of an automotive supply chain. The main objective of the model is to minimize the total cost of the entire supply chain. The solution to the MILP model can be obtained by using optimization software LINGO. The present model mainly tackles material flow across the supply chain; the information flow may also be incorporated in the design.

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