A De Novo Programming Model for Optimal Distribution Network Design in a Supply Chain

A Proposal for the Faculty Research Grant, 2002

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Summary
Supply Chain Management is one of the latest concepts that are revolutionizing the way businesses plan and manage their operations. This proposal examines the distribution network design of a supply chain. The distribution network is basically the infrastructure through which material, information and finances flow between suppliers, manufacturers, distributors, transporters, retailers, and the customers. Currently, the design of these networks, in the supply chain research literature, is enabled using complex optimization models. More often than not, the complexity of these models acts as a deterrent in using them in practice. This study proposes an alternative method to designing the network. The alternative proposed is transparent and easy to understand making it amenable to implementation in practice.

Introduction

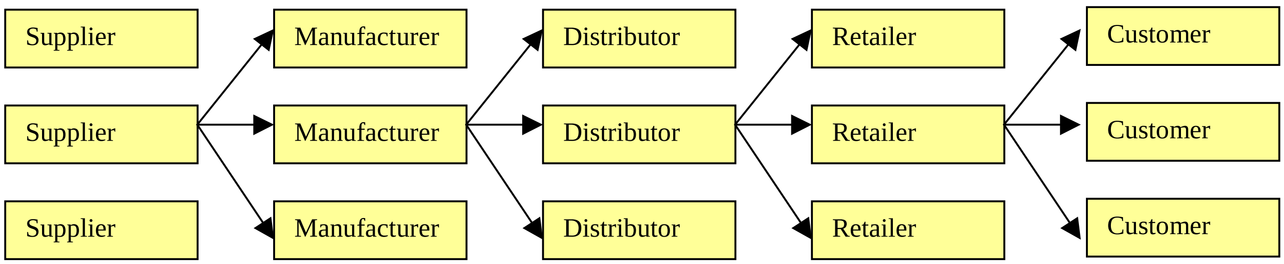
The traditional approach to managing a business was to view the firm as a collection of functional silos. The silos being the typical functional areas such as marketing, operations, logistics, procurement, distribution, finance, accounting, etc. These functional silos were managed independently without much cross-functional coordination. The lack of coordination often resulted in sub-optimal decisions that were caused by the lack of visibility of the organization and it's environment as a whole system.

Progressive companies have for some time recognized the need for coordination between functional areas in order to facilitate higher efficiency, quicker response times, increased operational flexibility, and better customer service. The advances in computational and communication technology coupled with the systems view of the firm have created a paradigm shift in the philosophy of managing a business. The management landscape, both in academics and practice, is strewn with success stories of utilizing new approaches such as mass customization, lean production, customer relation management, vendor management, and global sourcing. Each of these new approaches is made possible primarily by the precise coordination of the firm's functional areas and it's environment. The new thinking is to consider the firm's functional areas and it's environment as a supply chain and to coordinate and manage this supply chain for best results.

A supply chain consists of all stages involved, directly or indirectly, in fulfilling a customer request (Chopra and Meindl, 2001). The supply chain not only includes the all the functional areas of the manufacturer, but also the suppliers, transporters, warehouses, retailers, and the customers themselves. In a broad sense a supply chain consists of two or more legally separated organizations, being linked by materials, information and financial flows. These organizations may be firms producing parts, components and end products, logistics service providers, and even the customer (Stadtler, 2000). The philosophy behind supply chain management is to focus on managing the whole supply chain where the independent participants are considered as partners. This philosophy is very different from the traditional methods where each participant is managed independently. The traditional method optimized results at the participant level (the micro level) resulting in sub-optimal solutions at the supply chain level (the macro level). The approach in supply chain management is to optimize at the macro level and then to optimize at the micro level based on the macro level decisions.

Current Situation

The focus of this study is on the distribution network design of the supply chain. The distribution network is basically a network of facilities through which products and information are moved from one end of the supply chain to the other. The distribution network usually has several stages, including suppliers, manufacturing plants, distribution warehouses, and markets consisting of retailers and/or end customers. A simplified schematic of the supply chain is given below:



The fundamental decisions to be made during the distribution network design phase are the location of facilities and the capacity allocated to these facilities. The facility location decision pertains to where to locate the various facilities with consideration to economic and customer related factors. The capacity allocation decisions pertain to how much activity to allocate to each facility given the rest of the distribution network. The economic factors that influence the above facility location and capacity allocation decisions include the manufacturing costs, the cost of storage and the cost of transportation. Other factors that also influence the decision are the capacity at the facilities and the customer demand forecasts. A common approach to designing an economically optimal distribution network is to develop and solve a mathematical programming model, such as a linear program or an integer program. The mathematical program determines the ideal locations for each facility and allocates the activity at each facility such that the costs are minimized and the constraints of meeting customer demand and facility capacity are satisfied.

A general form of the model for the distribution network is given below both in mathematical and "structured English" format. Those of us not inclined to mathematics can skip the equations by reading the "structured English" summaries to get the general gist of what each equation is set to accomplish.

m = number of demand points (retailers)
f = number of factory locations
s = number of suppliers
w = number of distribution warehouse locations
Di = Annual demand at demand point i
C_j = Annual potential capacity at factory j
S_k = Annual supply capacity of supplier k
W_l = Annual potential distribution warehouse capacity at l
F_j = Fixed annual cost of locating factory at site j
F_l = Fixed cost of locating distribution warehouse at location l

C_{kj} = Cost of shipping one unit form supplier k to factory j
C_{jl} = Cost of producing and shipping one unit from factory j to distribution warehouse l
C_{li} = Cost of distributing one unit from distribution warehouse l to customer i
Y_j = 1 if factory is located at site j, 0 otherwise
Y_l = 1 if warehouse is located at site l, 0 otherwise
X_{li} = units shipped annually from distribution warehouse l to customer i
X_{jl} = units shipped annually from factory j to distribution warehouse l
X_{kj} = units shipped annually from supplier k to factory j

Using the above notations the problem can be formulated as follows:

Objective Function- Minimize total cost

$$\sum_{j=1}^{f} F_j Y_j + \sum_{l=1}^{w} F_l Y_l + \sum_{k=1}^{s}\sum_{j=1}^{f} C_{kj} X_{kj} + \sum_{j=1}^{f}\sum_{l=1}^{w} C_{jl} X_{jl} + \sum_{l=1}^{w}\sum_{i=1}^{m} C_{li} X_{li}$$

Subject to the following constraints:

1. Units sent from supplier to factory cannot exceed supplier capacity

$$\sum_{j=1}^{f} X_{kj} \le S_k \quad \text{for k = 1 to s}$$

2. Units shipped out of factory cannot exceed units of materials received from suppliers

$$\sum_{k=1}^{f} X_{kj} - \sum_{l=1}^{w} X_{jl} \ge 0 \quad \text{for j = 1 to f}$$

3. Units produced in factory cannot exceed factory capacity

$$\sum_{l=1}^{w} X_{jl} \le C_j Y_j \quad \text{for j = 1 to f}$$

4. Amount shipped out of warehouses cannot exceed quantity received from factories

$$\sum_{j=1}^{f} X_{jl} - \sum_{i=1}^{m} X_{li} \ge 0 \quad \text{for l = 1 to w}$$

5. Amount shipped through warehouses should not exceed warehouse capacity

$$\sum_{i=1}^{m} X_{li} \le W_l Y_l \quad \text{for l = 1 to w}$$

6. Amount shipped to customer must equal the customer demand

$$\sum_{l=1}^{w} X_{li} = D_i$$

$$Y_j, Y_l \in \{0,1\}$$

The above problem can be modified to accommodate economies of scale in transportation and inventory related costs. However, even without the modifications, these large mixed integer linear programming problems are difficult to solve using regularly available optimization software. In addition, the complexity and the resultant lack of transparency in these types of models make them very difficult to "sell" to top management.

Project Plan

The goal for this study is to propose an alternative to solving such problems. The alternative will be easier to understand and make more practical sense, and thus should be easier to "sell" to top management. The alternative proposed here utilizes the application of the De Novo programming approach suggested by Zeleny (1982) in solving the capacity allocation problem. Unlike the usual optimization using mathematical models where level of resources, the right hand side of the equations, are assumed to be fixed or known, the De Novo approach considers the level of resources as being decision variables that affect the value of the objective function.

The following example from Zeleny's paper illustrates the De Novo approach. Assume that a small company has been producing two versions of a highly profitable decorative material. The units produced of the products are denoted as x and y. The objective function provides the profit function where the coefficients represent the per unit profit. Each constraint represents one of the five resources required to produce these products. The right hand side of each equation provides the amount of each resource available to produce the two products. The traditional approach is to determine the optimal product-mix (the amount of each item to be made) using a linear program where the level of each resource is pre-determined based on some criteria such as inventory cost analysis and operating budget limitations. Given below is the linear program:

Objective function (maximize profit)

Maximize $z = 400x + 300y$

Subject to the following constraints

$4x \le 20$

$2x + 6y \le 24$

$12x + 4y \le 60$

$3y \le 10.5$

$4x + 4y \le 26$

$x,y \ge 0$

The solution to the above problem is $x = 4.25$, $y = 2.25$ and $z = \$2375$.

In the De Novo approach the above problem is formulated by including the level of resources (denoted by b_i) as decision variables that affect the objective function. Given below is such a formulation:

Maximize $z = 400x + 300y$

Subject to

$4x - b_1 = 0$

$2x + 6y - b_2 = 0$

$12x + 4y - b_3 = 0$

$3y - b_4 = 0$

$4x + 4y - b_5 = 0$

$$30b_1 + 40b_2 + 9.5b_3 + 20b_4 + 10b_5 = 2600$$
$$x,y,b_1,b_2,b_3,b_4,b_5 >= 0$$

The additional constraint reflects the budget and is an example of adding constraints to facilitate an adequate number of basic variables.
The solution to the above problem is $x = 7.34$, $y = 0$, $b_1 = 29.4$, $b_3 = 88$, $b_4 = 0$, $b_5 = 29.4$ and $z = \$2936$. The De Novo model not only furnishes a higher value for the objective function but also produces a tight system in terms of the productivity of the resources.

The De Novo approach is especially useful in the distribution network design stage of the supply chain where inefficiencies even at one stage are detrimental to the performance of the whole supply chain. In linear program under study, the De Novo approach can be brought about by representing the capacity at the factory (C_j) and distribution warehouse (W_l) stages as variables and adding the necessary constraints to ensure the required number of basic variables. This approach will rid the problem of the binary variables that are primarily responsible for the complexity. The approach makes intuitive sense since the capacity of these facilities should depend on some budgetary constraints. In addition, the approach facilitates an optimal system rather than attempting to optimize a given sub-optimal system. The results obtained from the model will then be tested against neighboring values in order to draw conclusions on their effect on the total cost to the overall system.

The data necessary for the project will be collected from existing companies. I have had preliminary conversations with representatives of the makers of Weber Grill and office products maker, Boise Cascade, for data and have been given assurances on the availability of data. Students in our graduate program who are senior level representatives of these companies are making the data available. The outcome of this study should be beneficial to these students and the companies involved. In addition, most of the other graduate students in our supply chain graduate program can experientially benefit from the study.

This is my first year of a tenure track appointment at Elmhurst College. My year so far has been taken up with coordinating the new graduate program, developing and teaching the graduate courses (I have developed and taught five of the ten courses offered to date), and teaching undergraduate courses. I need to step up on my research during the summer and this grant will be of great help

Faculty Expertise
My doctoral training and years of academic and consulting expertise are in the areas of operations management, supply chain management, and optimizing business systems. In addition, my undergraduate training is in engineering. The proposal in this study is very much within the realm of my expertise.

Plans for Evaluation and Dissemination
The results from this study will be submitted for publishing to journals that are pertinent to supply chain management research. In addition, I plan on presenting summary results

at the Research/Scholarship Forum on campus and the annual Midwest Business Academy Conference.

Time Line
I am teaching a graduate course during the summer. This is not a voluntary assignment but a necessity since I am the only faculty in the program qualified to teach the course. My teaching assignment is one night a week, which should give me ample time to conduct this project. My current estimate is that it should take me a month to collect and clean the data, another month to model and test the problem, and about two weeks to write the final article.

Budget
Faculty Salary and Software* = $3500
*I plan on using the Solver optimizer available in Microsoft Office Software. However, Solver is not a dedicated optimization package and is limited in its capabilities. In the case that Solver is not adequate I will use part of the budget to purchase the MatLab software package that, in my experience, will be adequate.

Publications
Thomas, R., A Comparison of Optimal Flexible Manufacturing System Performance Using Differing Objective Criteria, *Proceedings of the Annual Production and Operations Management Society Conference, 2002.*

Kathawala, Y., Abdou, K. and Thomas, R., Supply Chain Evaluation in the Services Industry: A Framework Development Compared to Manufacturing, *Proceedings of the Midwest Business Administration Association Annual Meeting, 2002.*

Kathawala, Y., Abdou, K. and Thomas, R., Malcolm Baldrige Applied to Education: The Online MBA Case, *Proceedings of the Midwest Business Administration Association Annual Meeting, 2002.*

References
Chopra, S. and Meindl, P., *Supply Chain Management: Strategy, Planning and Operation*, Prentice-Hall Inc., 2001

Stadtler, H., *Supply Chain Management and Advanced Planning: Concepts, Models, software and Case Studies*, Springr-Verlag Berlin Heidelberg New York, 2000

Zeleny, M., *Multiple Criteria Decision Making*, McGraw Hill Book Company, New York, 1982