Chapter 4

Optimal Design and Operation of Supply Chain Networks under Demand Uncertainty

Michael C. Georgiadis
University of Western Macedonia, Greece

Pantelis Longinidis
University of Western Macedonia, Greece

ABSTRACT

This chapter considers a detailed mathematical formulation for the problem of designing supply chain networks comprising multiproduct production facilities with shared production resources, warehouses, distribution centers and customer zones and operating under time varying demand uncertainty. Uncertainty is captured in terms of a number of likely scenarios possible to materialize during the life time of the network. The problem is formulated as a mixed-integer linear programming problem and solved to global optimality using standard branch-and-bound techniques. A case study concerned with the establishment of Europe-wide supply chain is used to illustrate the applicability and efficiency of the proposed approach. The results obtained provide a good indication of the value of having a model that takes into account the complex interactions that exist in such networks and the effect of inventory levels to the design and operation.

INTRODUCTION

The "problem" of supply chain network design is very broad and means different things to different enterprises. It generally refers to a strategic activity that will take one or more of the following decisions (Shapiro, 1999):

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- Where to locate new facilities (be they production, storage, logistics, etc.).
- Significant changes to existing facilities, e.g. expansion, contraction or closure.
- Sourcing decisions – what suppliers and supply base to use for each facility
- Allocation decisions – e.g. what products should be produced at each production fa-

cility; which markets should be served by which warehouses, etc.

These decisions aim in some way to increase shareholder value. This means that models are employed to try to exploit potential trade-offs. These may include (Shapiro, 2003):

i. Differences in regional production costs.
ii. Distribution costs of raw materials, intermediates and products.
iii. Differences in regional taxation and duty structures.
iv. Exchange rate variations.
v. Manufacturing complexity and efficiency (related to the number of different products being produced at any one site).
vi. Network complexity (related to the number of different possible pathways from raw materials to ultimate consumers).

Most companies do not aim to quantify the latter two explicitly, but rather employ policies (e.g. single-sourcing of customer zones; exclusive product-plant allocation) to simplify operation to the desired degree.

A relatively rare instance of this class of problems is the "greenfield" design of a new supply chain where no significant assets exist at the time of the analysis (e.g. design of a future hydrogen infrastructure). A more common instance occurs when part of the infrastructure already exists, and a retrofit activity is being undertaken, where products may be re-allocated between sites, manufacturing resources may be restructured, the logistics network may be restructured, etc.

Models for the design and operation of supply chain networks may be steady-state or dynamic and may be deterministic or deal with uncertainties (particularly in product demands). Research in this field started very early on, with location-allocation problems forming part of the early set of "classical" operations research problems, see e.g. Geoffrion and Graves (1974) who consider the problem of distribution system layout and sizing and DC-customer allocation. It was recognised early on that systematic, optimisation-based approaches should be used, and that "common-sense" heuristics might lead to poor solutions (Geoffrion and van Roy, 1979). These early models tended to focus on the logistics aspects. Clearly, much more benefit could be achieved by simultaneously considering the production aspects and other issues related to integration of inventory, transportation, supplier selection, and investment budgeting decisions (Melo, Nickel and Saldanha da Gama, 2006).

Almost in the begging of 90's the concept of supply chain began to emerge as one of the most popular field of research and study until today. Chopra and Meindl (2004) describe the supply chain as a dynamic network of collaboration that consists of many parties such as suppliers, manufacturers, transporters, warehouses, distribution centers, retailers, customers etc. and its objective is to maximize the overall value generated for all the members of supply chain.

Since companies recognized the potential competitive advantages, gained through a holistic management of their supply chain, the academic community has been developing several models that describe their design and operation. Flexibility, supplier selection and coordination of supply chain members are the most popular current issues in the field.

The role of flexibility in supply design and modeling has been discussed in a special issue edited by Chandra and Crabis (2009). In this issue, flexibility was mainly assessed in terms of product flexibility aspects (Francas and Minner, 2009; Hallgren and Olhager, 2009; Hasuike and Ishii, 2009). Supplier selection in the supply chain context was discussed in the work of Cakravastia, Toha and Nakamura (2002) and Xu and Nozick (2009). Cakravastia et al. (2002) developed a model for the selection of suppliers during the design of a supply chain. Prices and lead times measured the performance of customers' dissatisfaction whereas