6 Strategic Network Design

Marc Goetschalcks[1] and Bernhard Fleischmann[2]

[1] School of Industrial and Systems Engineering, Georgia Institute of Technology, 765 Ferst Drive, Atlanta, Georgia, USA
[2] University of Augsburg, Department of Production and Logistics, Universitätsstraße 16, 86135 Augsburg, Germany

In this chapter we will focus on the long-term, strategic planning and design of the supply chain. Section 6.1 explains the planning situation and the problem setting. Section 6.2 outlines the formulation of the problem as mixed integer programming model and Section 6.3 describes the use of such models. Section 6.4 and 6.5 review the relevant literature and the software modules available in APS, respectively.

6.1 The Planning Environment

During the strategic planning process an organization attempts to configure a supply chain, which will enable this organization to maximize its economic performance over an extended period of time. Together with product research and development and marketing, the supply chain is one of the essential tools for a company to achieve their strategic business goals and practices. During the strategic planning process, companies identify their key products, customer markets for these products, core manufacturing processes, and suppliers of raw and intermediate materials. Virtually all organizations must redesign their supply chain from time to time to respond to changing market conditions, but the recent wave of mergers and acquisitions and the globalization of the economy have made this process even more frequent and important. For example, a company may wish to expand into a new geographical area where no infrastructure is currently in place, such as the expansion by electronics manufacturing companies into Eastern Europe after those countries adopted a market economy. Another company may wish to consolidate the duplicate distribution systems created by a merger or acquisition. Finally, strategic planning is not only used for expansion but also for consolidation and retraction, such as when the United States Armed Forces developed a strategic plan for the base closings associated with the withdrawal from Western Europe.

Typically, the planning horizon for strategic planning ranges from three to twelve years and the decisions involve the establishment or closure of manufacturing and distribution facilities, the allocation of products to facilities, and the installation of major manufacturing lines. The objective are most often financial objectives such as the maximization of the net present value

(NPV) of profit or minimization of the NPV of costs, subject to customer demand, customer service, and budget constraints. The consequences of these decisions are the configuration of manufacturing and distribution capacity and allocation of these capacities to products and customer zones. These capacities and allocations then become constraints in the Master Planning process. The Master Planning in turn determines the more detailed material flows and material storage for a number of smaller periods within a seasonal cycle.

Clearly, the decisions made in strategic network design have a major impact on the long-term profitability and competitive position of a corporation. But such far-reaching decisions typically have to be made based on data generated by very aggregate forecasts and economic trends. Demand for consumer goods in the developing nations of South America depends on the population data for that region, the global and local economic condition, and the profitability of serving that demand depends on the exchange rates during the planning period. As a consequence, corporations have become very much interested not only in the economic efficiency of their supply chain for the projected conditions, but also in the robustness and flexibility of their supply chain to adapt to changing and unanticipated conditions.

The strategic network design decisions have interrelated spatial and temporal characteristics. For example, during an expansion into a new geographical area a company may decide to manufacture its products during the first two years in existing manufacturing facilities and to transport them to the new customer area. But starting in year three, when demand has grown sufficiently, the most economic production-distribution strategy may be to manufacture the products locally. This implies that the construction of the new manufacturing plant has to be started immediately. Many of the decisions made during strategic planning are of the go/no-go type. For example, the decision may be either to build a manufacturing plant in year three or not, but it is not possible to build half a plant.

Finally, the strategic planning process is complicated by the fact that organizations execute strategic planning infrequently. A typical frequency may be during the creation of the next five-year corporate strategic plan. As a consequence, the people that performed the previous strategic planning have been promoted or left for other organizations. This implies that the new design team may have very little experience in decision support for strategic design and its associated methodologies such as model building and model solving.

To provide proper decision support for the strategic design of world-class supply chains, one has to recognize that supply chains have the following fundamental characteristics: they are holistic, global, and stochastic.

A holistic view of a supply chain does not focus exclusively on a single aspect of the supply chain performance such as inventory, direct labor cost, or product delivery, but takes an integrated and comprehensive view of the whole supply chain from the raw material suppliers, through the various transformation facilities and transportation channels, to the final customers. In addition, the evolution of the supply chain over multiple years is considered. The "cradle to grave" approach is thus not only geographical but also temporal. Furthermore, the strategic decisions on the supply chain configuration and the related investments cannot be taken without considering the implications for the supply chain operations. Thus, supply chain design integrates the strategic capital budgeting decisions with the Master Planning. It considers purchasing, manufacturing, distribution, and transportation cost and capacities as well as the customer demand planning. It also considers the full life cycle of different products, product portfolios, supply chain resources, and mergers and acquisitions. All of these are geographically or organizationally dispersed components of a supply chain at a particular point in time. The holistic view of the supply chain requires resolving the tradeoffs between the objectives and performance measures of the various agents and organizations in the supply chain.

Supply chains in virtually every industry are becoming increasingly global, which implies that materials are purchased, manufactured, and transported to the customers without consideration of national boundaries. While at the current time duties and tariffs still play an important role, the overall trend is towards elimination of these tariff and non-tariff trade barriers. Proper supply chain design must incorporate the conditions and aspects of international trade such as the various Incoterms (*in*ternational *co*mmercial *terms*), duties and tariffs, non-tariff-based trade barriers, and exchange rates. The allocation of products to manufacturing sites in different countries can significantly impact the tax paid by a multinational corporation. The tax also depends on the internal trade and the transfer prices within the corporation. These tax related issues must be addressed as part of the overall strategic supply chain design process.

The establishment of a facility as part of a global supply chain is a very important strategic decision. The economic life of a manufacturing facility or even a distribution facility can span several decades. The economic and market data over that time horizon are inherently not known with certainty at the time the decision is made to establish the facility. The supply chain configuration not only has to be efficient with respect to the expected conditions but also robust and flexible enough to adapt to the inevitable changes in these conditions. This implies that for every possible supply chain configuration there is not just one value of profit realization but rather a profit distribution that depends on the probabilities of the occurrence of various economic conditions. Unfortunately, these probabilities cannot be determined in advance for such a long-term planning horizon. A single combination of possible values of the economic conditions and parameters is called a scenario. It is anticipated that a small number of underlying trends in the future economic conditions will be possible. A corporation typically considers an optimistic, neutral or best-estimate, and pessimistic trend. Each trend then contains one or more scenarios.

The problem is thus to design a supply chain configuration in a multi-period, with multiple scenarios, multi-country, multi-product, multi-echelon, multi-facility setting based on forecasted parameters and with bill of materials (BOM) flow conservation constraints. To a corporation, capital investments become more attractive if they have a higher expected return and/or if the variability of this return is smaller.

The complexity of this large-scale, holistic, global, and scenario-based design problem far exceeds the capabilities and insight of even the most knowledgeable and experienced decision makers. To assist the decision makers in determining the most desirable supply chain configuration in an acceptable amount of time, the help of computers and software must be enlisted. A mathematical model of the supply chain has to be constructed combined with the development of efficient methods of determining highly desirable supply chain configurations.

Clearly, the proper execution of a strategic planning effort is a very challenging task. The decision support models must be comprehensive and cover both engineering and financial constraints, and often they are company or industry specific. The models require a large quantity and variety of data, which often must be forecasted with large degrees of uncertainty. The decisions are binary and thus even the corresponding mixed-integer programming models would be very difficult to solve to optimality. But the data are typically not known with certainty, which indicates the use of scenarios. The construction of the scenarios to include is also a non-trivial problem. One would like to include all the possible scenarios that represent significant trends in the economic conditions. However, most often there exist too many combinations of major trends, so that including all the corresponding scenarios would make the design problem computationally unsolvable.

6.2 Strategic Network Design Models

6.2.1 Basic Components

As explained in the previous section, supply chain design integrates two planning levels: Strategic structural decisions on the network configuration and Master Planning decisions on the flows of goods in the network. Figure 6.1 shows the relationships between the planning levels and the objectives.

The financial objectives are affected directly by the strategic decisions on investments and configuration as well as by the yearly financial variables resulting from the Master Planning. The Master Planning decisions are constrained by the investment and configuration decisions. For instance, the investment in a new machine can change the variable production cost significantly. Other objectives will be discussed in Section 6.3.

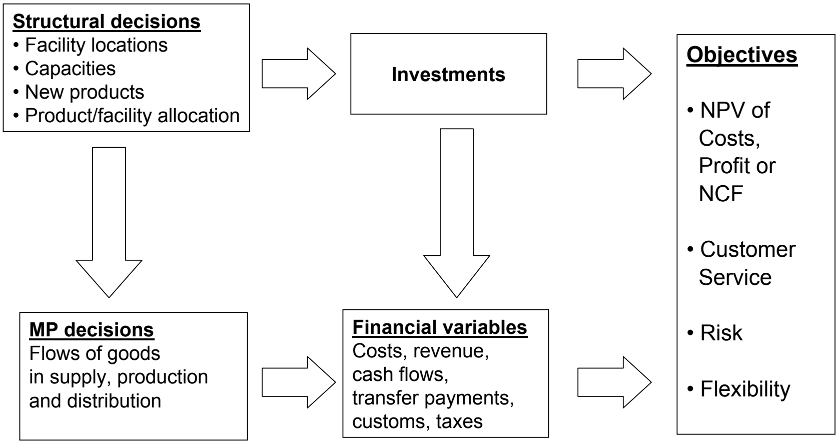

Fig. 6.1. Interdependence between strategic and Master Planning (MP) levels

Corresponding to the two planning levels, a supply chain design model contains two major types of decision variables: binary structural variables and continuous flow variables. Both are required to model the main components of a supply chain, i.e. products, customers, vendors and suppliers, manufacturing and distribution sites and facilities, different countries, and planning periods. For strategic planning, the planning periods are usually years. Typical structural variables are $Status_{k,t}$ indicating whether a site k is "open" in year t or not, and similarly $Status_{k,j,t}$ indicating, whether a new machine j is available at site k in year t. $Alloc_{p,k,t}$ may indicate if product p is allocated to a manufacturing site k in year t. Fixed costs may be attached to all these variables. The evolution of the supply chain is driven by investment decisions. For example, $Invest_{k,j,t}$ may indicate if an investment takes place in year t for machine j in site k. The capital investments, which constitute a major component of the cash flow, are attached to these variables.

The flow variables express the quantities per time period for the various supply chain processes, e.g. $Production_{p,k,t}$ denotes the quantity of product p manufactured in site k in year t.

Four types of constraints are common in supply chain design models: conservation of flow, capacity, consistency or linkage constraints, and equality constraints used to compute intermediate quantities, such as components of the objective function. Each type will next be discussed in further detail.

One type of conservation of flow constraints focuses on the material balance between different products, facilities, and transportation channels. They represent the fact that all material flow entering a facility or the total supply chain inevitably also must leave that facility or the supply chain, albeit in a different form. The general format of material balance constraints is

$$Inflow_{p,k,t} + Production_{p,k,t} = Outflow_{p,k,t} + Consumption_{p,k,t} \; \forall \, p,k,t \quad (6.1)$$

where $Inflow_{p,k,t}$ is the amount of product p entering in year t from all sources into site k, $Outflow_{p,k,t}$ is the amount leaving to all destinations, and $Consumption_{p,k,t}$ is the amount removed by customer demand or by transformation into other products. The latter quantity is calculated from the production quantities using the bill of materials (BOM) data of the successor products.

A second type of constraints ensures that the model creates a feasible configuration by assigning capacities to different resources in the supply chain. Capacity constraints typically occur for production processes and may concern a simple product or a group of products sharing the capacity. These constraints also enforce consistency between the product-site allocation, the status of a site or machine, and the flow through that site or machine. An example of a capacity constraint for a single product p at site k is given next.

$$Production_{p,k,t} \leq Capacity_{k} \cdot Alloc_{p,k,t} \; \forall \, t \quad (6.2)$$

where $Capacity_k$ is the total capacity of the site k for the product p during year t.

If capacities are limiting for a combination of products, then they are modeled using resources. Typical examples of resources are machine production hours or warehouse storage volume. The general format of such constraints is given next for a machine j processing products $p \in P$.

$$\sum_{pinP} ResourceRequirement_{p,k,t} \cdot Production_{p,k,t} \leq Capacity_{k,j,t} \cdot Status_{k,j,t} \; \forall \, t \quad (6.3)$$

$Capacity_{k,j,t}$ is the capacity of machine j at site k during period t, e.g., the available production hours in year t, $ResourceRequirement_{p,k,j}$ is the amount of resource required per unit of product on machine j.

The third type of constraints ensures the consistency between different structural variables, for example, the consistency between the investment and the status variables. An example of a constraint related to the status of machine j at site k and the corresponding investment is given next.

$$Status_{k,j,t} = Status_{k,j,t-1} + Invest_{k,j,t} \; \forall \, k,j,t \quad (6.4)$$

where $Status_{k,j,0}$ is the current initial status, which is an input parameter. Thus, the status of a new machine j that is currently not established can only jump to being used if an investment takes place. For any product p that requires machine j the following constraint set exists.

$$Alloc_{p,k,t} \leq Status_{k,j,t} \; \forall \, k, t \tag{6.5}$$

Similarly, a product can only be allocated to an open site k:

$$Alloc_{p,k,t} \leq Status_{k,t} \; \forall \, p, k, t \tag{6.6}$$

A typical linkage constraint in the automotive industry is the irreversibility of a product-site allocation

$$Alloc_{p,k,t} \geq Alloc_{p,k,t-1} \; \forall \, k, t \tag{6.7}$$

Often a limit $MaxCount_k$ on the number of products that can be allocated to site k exists:

$$\sum_{p} Alloc_{p,k,t} \leq MaxCount_k \; \forall \, k, t \tag{6.8}$$

Further examples of constraints on the configuration are limits on the number of facilities, either/or facility constraints which require one out of a set of facilities to be established, or ordering of facilities which require one facility to be open before other facilities can be used. Finally, the consistency constraints can be used to ensure that a minimum quantity or usage of a machine or site occurs if this machine or site is established. The fourth type of constraints are equalities that compute intermediate or derived variables. A typical use is the computation of the components of the objective function. The objective of the strategic supply chain design process is to maximize the long-term economic performance of the corporation. This objective has to be expressed in the financial performance measures familiar to corporate-level decision makers. For strategic supply chain configurations the primary performance measure is the net present value (NPV) of the streams of net cash flows (NCF).

$$NPVNCF = \sum_{t=1}^{T} NCF_t \cdot (1+cdf)^{-t} = \sum_{t} \left(\sum_{c \in C} \frac{NCF_c t}{er_c t} \right) \cdot (1+cdf)^{-t} \tag{6.9}$$

$NCF_{c,t}$ is the net cash flow for a country c in the currency of that country during a year t. $er_{c,t}$ is the exchange rate for the currency of country c expressed in the currency of the home country. cdf is the capital discount factor for the global corporation.

A general definition of the NCF is based on the earnings before interest, taxes and amortization (EBITA) (see Choi 1997).

$$EBITA = SalesRevenue - FixedCosts - VariableCosts - Depreciation \quad (6.10)$$

$$NCF = (1 - TaxRate) \cdot (EBITA - Interest) + Depreciation - Amortization \quad (6.11)$$

In the supply chain design model, the NCF has to be restricted to those components that can be influenced by the decisions considered. Usually, decisions on interest and amortization payments are not included explicitly. Instead, interest is implicitly considered by discounting the NCF. Thus, the relevant $NCF_{c,t}$ to be used in the objective criterion 6.9 is

$$NCF_{c,t} = (1 - TaxRate_c) \cdot (Sales_{c,t} - VariableCosts_{c,t} - FixedCosts_{c,t}) + TaxRate_c \cdot Depreciation_{c,t} - InvestmentExpenditure_{c,t} \quad (6.12)$$

where each component is obtained by summing up over all activities within country c in year t. Sales and variable costs are linear functions of the corresponding flow variables, the fixed costs are determined by the *Status* and *Alloc* variables and the investment expenditures by the *Invest* variables. The depreciation allowance depends on the tax laws of the country and can be determined using the depreciation fractions in the relative years $s = 0, 1, 2, \ldots$ after the investment has been made. For example, the depreciation in year t due to an investment of the amount $I_{j,k}$ in machine j at site k in one of the years $t - s$ is

$$Depr_{k,j,t} = \sum_{s=0}^{t-1} DepreciationFraction_s \cdot I_{k,j} \cdot Invest_{k,j,t-s} \quad (6.13)$$

For example, the *DepreciationFraction* for a machine using straight-line depreciation over a five-year period would be 20% for every year.

While each decision variable and each constraint in itself is simple, the total number of variables and constraints creates very large problem instances. The creation and maintenance of the model formulation, data, and model solution requires significant information technology and computational resources. Typical comprehensive strategic supply chain design models may contain thousands of the binary variables and millions of the continuous variables in tens of thousands of constraints. For example, Santoso et al. (2005) report solving a formulation with 1.25 million continuous variables for an industrial case and Papageorgiou et al. (2001) report that 3000 binary variables are present in a small illustrative example.

6.2.2 Extensions

A few extensions to the basic model of Section 6.2.1 are introduced next.

Transfer Payments

Transfer payments between the national subsidiaries of a multinational company affect the sales revenues and the purchasing costs of the subsidiaries concerned. Modeling this impact requires the specification of the rules that govern internal trade and transfer prices (see Papageorgiou et al. 2001). If the transfer prices are considered as decision variables, a difficult nonlinear optimization model is obtained even for the operational level with fixed supply chain configuration (see Vidal and Goetschalckx 2001).

Demand Constraints

In most network design models, the given demand per product, region and year must be fully satisfied. The capacities for production and distribution processes, which are variables in the model, are adapted to the given demand in the solution of the model. In this case, the sales revenue is fixed by the given demand data and can be omitted from the NCF in 6.12. However, there are situations where the structural decisions also affect the demand. For instance, the installation of a new manufacturing site may increase the demand in the corresponding country and the demand for a new product is only generated by its introduction into the market. The demand then starts in the year of the launch and is developing according to its life cycle. Therefore, models with given demand can support the decisions whether or not to develop a new product and where to produce it, but not *when* to launch it. The latter decision requires a variable allocation of the life cycle demand to the years. This type of model has only been proposed by Popp (1983).

Time Aspects

The duration of production or transportation processes can be influenced by the choice of the production technology or of the transport mode, respectively. As shorter lead times may establish an important competitive advantage, a time criterion can be included in the objective function. This is of particular importance in a very dynamic business like the computer industry. Arntzen et al. (1995) use a weighted sum of costs and lead times as objective function.

Inventories

The structural decisions may have significant impact on the inventories in the supply network. The way to model this impact depends on the type of inventories:

The *work in process (WIP)* in a production or transporation process is equal to the flow in this process muliplied by the transit or process flow time. Hence it is a linear function of the flow variable. WIP was considered by Arntzen et al. (1995) and Vidal and Goetschalckx (2001).

Cycle stock is caused by a process running in intermittent batches and is one half of the average batch size both at the entry and at the exit of the process. It is a linear function of the flows only if the number of batches per period is fixed.

Seasonal stock is not contained in a strategic network design model with yearly periods. For smaller periods, it can be registered simply as end of period stock like in a Master Planning model (see 8).

Safety stock is influenced by the structural decisions via the flow times and the number of stock points in the network. This relationship is nonlinear and depends on many other factors such as the desired service level and the inventory policy. It should therefore be considered outside the network design model in a separate evaluation step for any solution under consideration.

6.3 Implementation

A network design model as described before yields an optimal solution for the given data and objective. However, in the strategic supply chain planning process, a single solution is of little value and may even give a false sense of efficiency. Defining or determining the "optimal supply chain configuration" is impossible for several reasons. First, the data required in the long-term planning horizon are highly uncertain, second, a supply chain configuration has to satisfy multiple objectives, and third, several of those objectives cannot even be quantified.

Besides the well defined financial objective $NPVNCF$, other objectives are also important (see Figure 6.1): *Customer service* depends on the strategic global location decisions. For instance, the establishment of a new production site or distribution center will tend to improve the customer service in the respective country. But the increase in customer service and its impact are difficult to quantify. The *risk* which can be expressed as the variability of some financial objective can only be quantified if there are probabilities known for the different scenarios of the unknown data. The *flexibility* of a structural design is its ability to adapt to unanticipated changes of the environment. Some aspects of flexibility can be evaluated through the use of different scenarios, e.g. the volume flexibility of the supply chain to adapt to changes of the demand of certain products. However, other aspects of flexibility, are difficult to quantify. For instance, installing a general purpose machine allows the production of future products that are not yet conceived . This decision contributes to greater product flexibility than installing a dedicated machine for existing products but may increase the variable production cost as compared to the dedicated machine. The tradeoffs between flexibility and efficiency are very difficult to quantity. Finally, criteria such as the political stability of a country or the existence of an established and fair legal system are very important, but not quantifiable.

In the typical case when several, partly unquantifiable objectives and unknown probabilities of the scenarios exist, the strategic planning process iteratively runs through the following steps as shown in Figure 6.2 (see Ratliff and Nulty 1997):

Generate alternatives: Solving the optimization problem defined above for different objectives and using a variety of scenarios provides various alternative supply chain configurations. In order to keep the optimization tractable, an aggregate model should be used, which contains only a rough approximation of the Master Planning level. Objectives that are not used in the current optimization can be considered in form of constraints. Additional alternatives can be generated by intuition and managerial insight.

Evaluate alternatives: For any design alternative, the operations can be optimized using a more detailed operational model under various scenarios. The main objective on this level is cost or profit, since the network configuration is given. A more detailed evaluation can be obtained by simulating the operations. This allows the incorporation of additional operational uncertainties, e.g. the short-term variation of the demand or of the availability of a machine, resulting in the more accurate computation of performance measures such as service levels or flow times.

Benchmarking: The key performance indicators obtained in the evaluation step are compared to the best-practice standards of the respective industry. This provides an additional evaluation of the quality of a supply chain configuration and allows a rudimentary validation of the proposed configuration.

Select alternatives: Finally, the performance measures computed in the previous steps and the consideration of additional non-quantifiable objectives can be used to eliminate inefficient and undesirable configurations. This can be done based on internal discussions by the project team and by presentations to the final decision makers, such as the board of directors. During this process, suggestions for the investigation of additional scenarios and objectives or modified alternatives may arise. This whole process may go through several iterations.

Many authors report that large numbers of alternatives have to be investigated in a single network design project. Arntzen et al. (1995) report hundreds of alternatives, and the model of Ulstein et al. (2006) was solved several times even in strategic-management meetings.

6.4 Review of Models in the Literature

A comprehensive review of all the models available or used in the design of supply chain systems is not possible within the confines of a single chapter. Because of its widespread application and significant financial impact, the

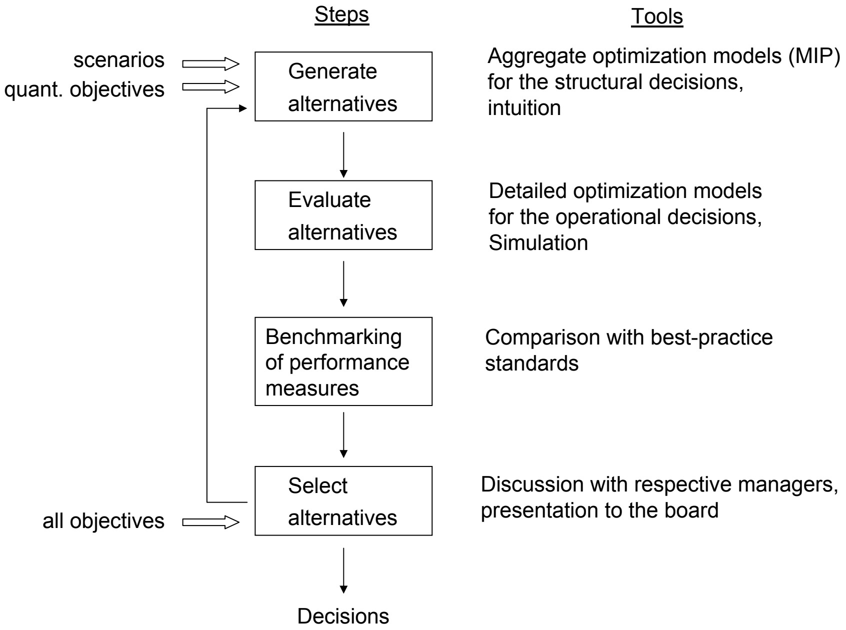

Fig. 6.2. Steps of the strategic network design

strategic supply chain design problem has received a significant amount of attention in the research literature. Geoffrion and Powers (1995) provided a comprehensive review and evaluation of research. Fundamentally, international models have the same characteristics, variables, and constraints as single-country models but, in addition, they model exchange rates, tax rates, duties, tariffs, and local content laws. Vidal and Goetschalckx (1997) provide tables summarizing the features of strategic models for the design of domestic and global supply chain systems. A recent review of modeling and algorithms for the design of supply chain systems is given in Schmidt and Wilhelm (2000). Simchi-Levi et al. (2004) and Shapiro (2007) provide sections focusing on strategic design of supply chain systems.

Examples of detailed models for strategic supply chain design are given in Dogan and Goetschalckx (1999) for seasonal demands, Vidal and Goetschalckx (2001) for global supply chains with transfer prices, Papageorgiou et al. (2001) for product portfolio selection, and Fleischmann et al. (2006) for a global automotive assembly system configuration. Laval et al. (2005) advocate the use of an approach combining optimization and domain expert knowledge and intuition to determine the European network of postponement locations for the distribution of printers. Ulstein et al. (2006) developed a model for site and capacity sizing for a global manufacturing corporation of highly specialized materials in the steel and semi-conductor materials processing industries.

6.5 Strategic Network Design Modules in APS Systems

A Strategic Network Design (SND) module in an APS has to include the Master Planning level as shown in Figure 6.1. Therefore, it also can be used for Master Planning (see Chapter 7) and is, in some APS, identical with the Master Planning module. It always provides a modeling feature for a multi-commodity multi-period flow network, as explained in Section 6.2. In addition, an SND module permits the modelling of the strategic decisions on locations, capacities and investments by means of binary variables. SND modules contain an LP solver, which is able to find the optimal flows in a given supply chain for a given objective, even for large networks and a large number of products and materials. However, the strategic decisions require a MIP solver, which is also available in the SND module, but may require an unacceptably long computation time for optimizing these decisions. Therefore, SND modules also provide various heuristics which are usually proprietary and not published. In contrast with other modules, the SND module is characterized by a relatively low data integration within the APS and with the ERP system. Therefore, it is often used as a stand-alone system. Current data of the stocks and of the availability of the machines are not required for SND. Past demand data from the ERP data warehouse can be useful, but they need to be manipulated for generating demand scenarios for a long-term planning horizon. Technical data of the machines, like processing times and flow times, can be taken from the ERP data as well. But a major part of the data required for SND, such as data on new products, new markets and new machines, is not available in the ERP system. The same is true for data on investments, such as investment expenditures, depreciation and investment limitations. The modeling tools that are available in the SND module differ in the various APS. Some APS contain a modeling language for general LP and MIP models, which allows the formulation of various types of models as discussed in the Section 6.2. Other APS provide preformulated components of an SNP model, which describe typical production, warehousing and transportation processes. They allow the rapid assembly of a complex supply chain model, even using click–and–drag to construct a graphical representation on the screen and without LP/MIP knowledge. Of course, this entails a loss of flexibility in the models that can be formulated. But the resulting models are easy to understand and can be explained quickly to the decision makers. An SND module provides the following main functions within the framework of the strategic planning process explained in Section 6.3 and Figure 6.2:

- Generating alternatives,
- Evaluating alternatives,
- Administrating alternatives and scenarios,
- Reporting, visualizing and comparing results.

The last two functions are particularly important in the iterative strategic planning process which involves large series of design alternatives and scenarios. These functions, the modeling aids and special algorithms for network design make up the essential advantages over a general LP/MIP software system. Chapter 16.1 gives an overview on the APS that contain an SND module as well as some providers of specific stand-alone tools.

6.6 Conclusions

The tradeoff between model solvability and model realism will always remain. The more realistic the model is the more resources have to be allocated for model development and validation, data collection and validation, model maintenance, and model solving. Since all models involve some level of abstraction, approximations, and assumptions, the results of the models should always be interpreted carefully with common (engineering) sense. Different models with different levels of detail and realism are appropriate and useful at different stages of the design process. Systematically increasing the level of model complexity for the same problem and evaluating their solutions and their consistency provides a way to, at least partially, validate the models. The common thread among successful applications of model-based strategic supply chain design is the sustained effort of a group of highly specialized designers, who exploited the structure of the problem to generate a formulation of acceptable size and degree of realism and a solution algorithm that had an acceptable computation time. This model then became a strategic asset for the corporation that greatly increased the performance of the designed supply chain and speed of the design. To remain competitive global corporations need a methodology to evaluate and efficiently configure robust global logistics systems in a short amount of time. The network design modules in the current generation of APS provide only limited modeling features. The research trend is towards an integration and combination of the features of the domestic and global models as well as towards the development of the supply chain based on investment decisions. Another trend is towards the design of flexible and robust supply chains that are based on possible scenarios. Case studies have provided ample evidence that the use of such a model and solution methodology can yield significant savings for a corporation interested in expanding globally. A drawback of the newer models and solution algorithms is the significant level of technical expertise required to achieve the fast solution times. A very important area of future research is the standardization and technology transfer process of these solution methodologies so that they can be more widely applied. Global corporations implement ERP systems and Business Data Warehouses at ever increasing rates, providing APS and decision-makers with the basic data and information necessary for Strategic Network Design. It can be expected that models and methodologies currently available in APS will become more versatile in the near future and incorporate some of the features currently only discussed in the academic literature.

This will allow these global corporations to use this information in a timely fashion to significantly increase their profits and to remain competitive.

References

Arntzen, B. C.; Brown, G. G.; Harrison, T. P.; Trafton, L. L. (1995) *Global Supply Chain Management at Digital Equipment Corporation.*, Interfaces, vol. 25, no. 1, 69–93

Choi, F. (1997) *International Accounting and Finance Handbook*, John Wiley, Somerset, New Jersey, 2nd ed.

Dogan, K.; Goetschalckx, M. (1999) *A Primal Decomposition Method for the Integrated Design of Multi-Period Production-Distribution Systems*, IIE Transactions, vol. 31, no. 11, 1027–1036

Fleischmann, B.; Ferber, S.; Henrich, P. (2006) *Strategic planning of BMW's global production network*, Interfaces, vol. 36, no. 3, 194–208

Geoffrion, A.; Powers, R. (1995) *20 Years of Strategic Distribution System Design: an Evolutionary Perspective*, Interfaces, vol. 25, no. 5, 105–127

Laval, C.; Feyhl, M.; Kakouros, S. (2005) *Hewlett-Packard Combined OR and Expert Knowledge to Design Its Supply Chains.*, Interfaces, vol. 35, no. 3, 238–247

Papageorgiou, L.; Rotstein, G.; Shah, N. (2001) *Strategic supply chain optimization for the pharmaceutical industries*, Industrial & Engineering Chemistry Research, vol. 40, no. 1, 275–286

Popp, W. (1983) *Strategische Planung für eine multinationale Unternehmung mit gemischt-ganzzahliger Programmierung*, OR Spektrum, vol. 5, no. 1, 45–57

Ratliff, H.; Nulty, W. (1997) *Logistics composite modeling*, in: A. Artiba; S. Elmaghraby (Eds.) *The Planning and Scheduling of Production Systems*, chap. 2, Chapman & Hall, London

Santoso, T.; Ahmed, S.; Goetschalckx, M.; Shapiro, A. (2005) *A stochastic programming approach for supply chain network design under uncertainty*, European Journal of Operational Research, vol. 167, no. 1, 96–115

Schmidt, G.; Wilhelm, W. (2000) *Strategic, tactical and operational decisions in multi-national logistics networks: a review and discussion of modeling issues*, International Journal of Production Research, vol. 38, no. 7, 1501–1523

Shapiro, J. (2007) *Modeling the Supply Chain*, Duxbury Thomson Learning, 2nd ed.

Simchi-Levi, E.; Kaminsky, P.; Simchi-Levi, E. (2004) *Managing the Supply Chain: The Definitive Guide for the Business Professional*, McGraw-Hill, New York

Ulstein, N. L.; Christiansen, M.; Grønhaug, R.; Magnussen, N.; Solomon, M. M. (2006) *Elkem Uses Optimization in Redesigning Its Supply Chain.*, Interfaces, vol. 36, no. 4, 314–325

Vidal, C.; Goetschalckx, M. (1997) *Strategic production-distribution models: A critical review with emphasis on global supply chain models*, European Journal of Operational Research, vol. 98, 1–18

Vidal, C.; Goetschalckx, M. (2001) *A Global supply chain model with transfer pricing and transportation cost allocation*, European Journal of Operational Research, vol. 129, no. 1, 134–158