1. Executive summary

Today's marketplace is becoming increasingly dynamic and volatile. As consumers become more sophisticated, they demand the right product at the right time, at the right price, and at the right place. Whereas quality was the competitive weapon of the 80s, customer responsiveness, or time-to-market is the differentiator today. In many industries, hyper-competition is forcing many enterprises to fundamentally change the way business is conducted in order to survive. Given these challenges, traditional paradigms for business management are ineffective. At the same time, businesses face tremendous pressure from their stakeholders to increase ROA, profit contribution and customer responsiveness.
Given the complexity of a typical supply chain, supply chain planning systems (also known as Advanced Planning Systems) enable companies to intelligently manage the activities of the supply chain. Every company must perform five basic activities or processes within a supply chain: buy, make, move, store and sell. Within each of these processes, there are short-term decisions (which product should be put on the truck?) and long-term decisions (do we need a new factory to meet demand?).

Through the intelligent application of constraint-based principles, we can reduce system inertia by reducing capacity on non-constrained resources without a corresponding increase in system nervousness or instability. Multi-enterprise planning capabilities of an intelligent system should include support for the various command and control structures as well as organizational aspects of the supply chain. The ability to model multiple authority domains and support autonomy with interdependence among the various business functions within a supply chain can provide a great deal of flexibility in managing system inertia. Ideally, the distributed architecture of a decision support system should provide global visibility to the various business units or functions to make decisions that meet both local business objectives as well as the global objective of the entire supply chain.

In this white paper we discuss the optimal allocation and utilisation of resources using mathematical optimisation techniques. We explain in non-technical terms the success and growing importance of optimisation techniques in efficiently processing complex supply chain problems in a cross-section of industry. We highlight the differences between strategic and tactical supply chain models. We set out the sequence of actions, the necessary system issues, the decision making issues and managerial aspects in Supply chain.
Through this paper the reader will:

1. appreciate the significance of using optimisation techniques in making decisions on industrial problems,
2. be aware of real-life case-studies highlighting the benefits of supply-chain optimisation,
3. have access to the relevant and the most recent articles and books on supply chain.

2. The business problem

A supply chain typically consists of the geographically distributed facilities and transportation links connecting these facilities. In manufacturing industry this supply chain is the linkage which defines the physical movement of raw materials (from suppliers), processing by the manufacturing units, their storage and final delivery as finished goods for the customers. In services such as retail stores or a delivery service like UPS or Federal Express, the supply chain reduces to problem if distribution logistics, where the start point is the finished product that has to be delivered to the client in a timely, manner. For a pure service operation, such as a financial services firm or a consulting operation, the supply chain is principally the information flow.

Consider a manufacturing firm: the facilities are the suppliers, the manufacturing and assembly sites, and the distribution centers. Major manufacturers have complex supply chains, comprising many thousands of linkages across many levels, and bringing together extensive bills of material.

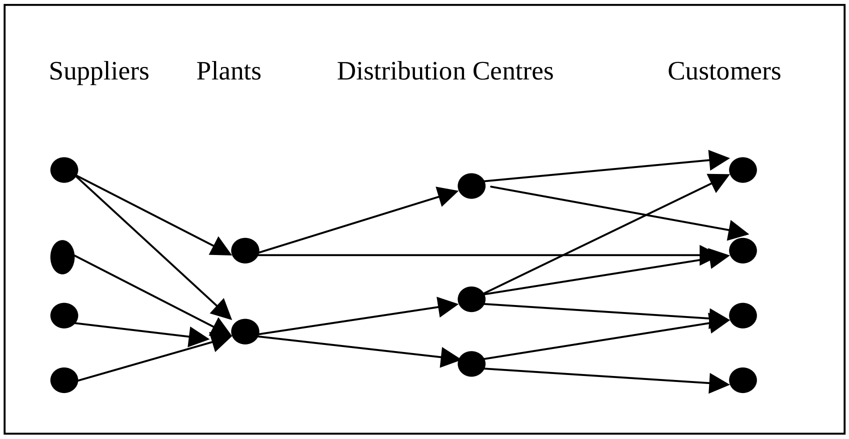

Figure 1. Supply chain network in manufacturing

The objectives in the supply chain are to satisfy some or all of the following:

1. Meet customer demand,
2. Reduce supply chain cost,
3. Improve product margins,
4. Lower inventories,
5. Increase manufacturing throughput,
6. Better return on asset.

During the 1990's, a small number of the best global multinationals broke away from the rest by creating a distinct competitive advantage through the optimisation of their supply chains and product technology. The next goal is to create supply chain networks that incorporate the "best with the best".

2.1 The supply chain network

Our work in SCHUMANN (Schumann, 2000,) provides a recent example of a prototype supply chain optimisation-based DSS. The software tool was built to aid supply chain planning and management in the automobile sector as well as in the pharmaceutical sector. Two models establish the core of the system, a strategic model, which focuses on the optimisation of the network design over a long-term, and a tactical model, which assists in the optimisation of resources across the supply chain network. Moreover, these two models were developed to represent supply chain capacity and inventory decisions taking into account the uncertainty inherent in the production costs, procurement costs, and demand.

Strategic	**Tactical**
What is it?	
The Schumann strategic model is a powerful software tool that focuses on the optimisation of network design over a long-term time frame, typically in excess of five years. It is able to consider both inbound (supply base) and outward (distribution) flows in determining the best supply chain configuration. Moreover, and uniquely among supply chain modelling tools, it takes into account a wealth of different scenarios relating to the future realisations of uncertain parameters, such as demand patterns and trade tariffs. The model allows users to explore strategic supply chain issues such as plant opening, relocation and closure, the development of product outsourcing with suppliers and distribution channel capacity. The model is an invaluable aid in analysing large, and usually irreversible, investments.	The Schumann tactical modelling package is a software system that assists in the optimisation of resources across a supply network. It perfectly compliments the strategic model by focusing on immediate and short-term planning horizons and is primarily aimed at bringing logistical improvements by optimising scheduling, inventory control and distribution channels. By simulating all elements of a complex supply chain in an environment of uncertainty, it can help to identify poorly utilised resources, waste, bottlenecks and other areas of risk, to reduce costs and to improve response times.

Where is it used?	
The most common application for the strategic model is in the arena of corporate planning and strategic supply chain management. The model is especially useful in developing capital budgeting plans. It may be used to analyse the current state of a supply network, and generate information on robustness to meet a series of scenarios - the introduction of new products, the development of new markets, and the utilisation of new or different suppliers. It may be applied to specific issues, such as new product flows driven by legislative changes.	The Schumann tactical optimisation system has been developed for application in any industrial manufacturing, assembly and distribution environment. At this prototype stage, it has proven effective in improving the logistical operations of automotive supply chains but there are no sectoral limitations. The model is equally applicable to a wide variety of supply chains and activities, such as central planning, scheduling, network development and cost control.
How is it used?	
Once an initial analysis and assessment has been performed, the model need only be run when a significant change to an input has occurred. This may be a new market entrant, a new type of production technology, or a fiscal change. The model would be typically used several times a year to allow the scenario generator to reflect any major opportunities or risks.	The first stage in the optimisation process is to introduce the physical elements of the supply network, such as products, channels, suppliers and customers, to the Schumann system. Next, an array of logistical attributes are added, including costs, demand profiles and cycle times, and any constraints that may be apparent. These elements combine to provide a map of the current supply chain; the user is then able to select a series of outputs based on their specific requirements. Running the model identifies the key opportunities and stress points in the chain. For example, Schumann will highlight risky resource limitations, opportunities to reduce inventory and alternative distribution channels.

What benefits does it bring?	
The major benefit of the model is its ability to make valid strategic judgements about the entirety of a supply chain, lending a hand in the planning of strategic investment programmes. It may determine the best mix of assets to support cost effective growth/contraction, assesses the impact of mergers and acquisitions, or identifies the lowest risk strategy in uncertain environments.	Tests have shown that Schumann is able simultaneously to generate double-figure improvements in capacity, reduction in lead-time and in total costs. The system brings users one-step closer to true supply chain integration.
Why use it?	
Few companies are able to translate the complexities of their business environment into an effective and flexible supply chain configuration. Capacity levels seem too high or too low, needless costs are incurred due to inefficiency and waste and, perhaps worst of all, opportunities are missed. The strategic model minimises these issues by determining the timing and extent of strategic network elements that govern operational activity.	Day-to-day activity in logistical management can be frustrating: stock outs and shortages, excess inventories, inefficient resource utilisation, failing customer service. These problems arise because normal planning tools fail to take adequate account of variation and uncertainty; Schumann is able to analyse supply chain issues to deliver optimised logistics and robustness.
What makes it different from other products?	
At present, although many other models are designed to achieve optimisation, none addresses uncertainty. True optimisation is only possible by introducing a stochastic approach to take account of ambiguities of the future.	Rather than having to function according to a series of rigid rules that do not relate to everyday life, as traditional MRP systems do, Schumann actually operates by taking account of conditions of uncertainty. It therefore allows users to understand the causes of inefficiency and risk, and to allocate resources to address problems at source. Schumann is also one of the first of a new breed of supply chain optimisation systems that is able to consider all elements across a complex supply network in an integrated fashion.

3. Issues and challenges

A supply chain must be efficient and effective. Efficiency minimizes resource use to accomplish specific outcomes, whereas effectiveness is the ability of channels to deliver products or services in a manner that is acceptable to end-users (Stern, El–Ansary, and Coughlan, 1996). Efficiency is measured by delivery time, product quality, number of short orders, and inventory levels. Whereas , effectiveness is measured by service quality and the service needs of the focal firm and the focal firm's customers (Mentzer, 1999).

3.1 Collaboration among the parties

A partnership is an interorganizational entity developed between two independent organizations in a vertical relationship within a supply chain. A supply chain consists of multiple partnerships (Gentry, 1996) and, therefore, partnering is important for successful retail supply chain relationships.

Strategic partnering is an on-going, long-term interfirm relationship for achieving strategic goals, which delivers value to customers and profitability to partners. For example there are many companies as Tommy Hilfiger and Ralph Lauren/Polo, and such stores as Federated Department Stores and May Department Stores that have developed their research in the field of retailing.

Operational partnering is an as-needed, shorter-term relationship for obtaining parity with competitors. Operational partnering is found in such apparel retailers as The Gap that exclusively sells its own brands. (Mentzer, Zacharias, Min).

Operational decisions involve shorter time spans (Ganesan, 1994; Lambert and Stock, 1993,17), fewer organizational resources, and are easier to implement and reverse (Hitt, Ireland, and Hoskisson, 1999) than strategic decisions. Thus, competitors are more able and likely to match operational actions than strategic actions (Grimm and Smith, 1997). Finally, each partner does not perceive the other as an extension of its own firm. Strategic and operational partnering is distinguished from transactional buyer-seller relationships by degree (Frazier, Spekman, and O'Neal, 1988). Strategic partnering includes an orientation to view the partner as an extension of their own firm, involving the partner in long term strategic initiatives. Operational partnering views the partner as a close associate in improving supply chains efficiency and effectiveness in the short term. Strategic initiatives are not shared with operational partners, but considerable operational coordination still occurs. Transactional relationships are treated on a purchase-by-purchase basis (Frazier, Spekman, and O'Neal, 1988). The relationship between the buyer and the seller does not look beyond the scope of the individual purchase and, thus, does not address the level of operational coordination of operational partnering or the strategic coordination of strategic partnering.

3.2 Advent of internet

With the development of technology, the electronic machines have a very important role in industries. Companies wish to exploit with the maximal profit the "electronic Supply chain management". The main techniques that now the companies are adopting is the web communication and Internet, this could imply a really drastic reduction of costs; the users, that now are pretending product in short time and small costs, can be satisfied with the Internet technique. Customers in fact are demanding "shorter lead-times, higher reliability, and real-time visibility into suppliers' systems".

Companies in the past had many problems with inventories; the products couldn't be always on time in the right place, but now with this Internet-based technique, the industries not only can satisfy the users but they can also improve and reduce their cost. The web-based research now is one of the main field in which a company is investing.

Supply Chain are becoming really complex. All the vendors are trying always to consider all the factors to be in competition with others. The products can be bought very easily on Internet, the deliver time is really short, and the production is optimised because most of products are produced just when the user request is received. For that reason all the factories now are trying to enter in the challenge, otherwise they would be cut off form the market.

Although many people have formulated several theories and integrated systems like ERP, the internet-based techniques are still on the market and are always one of the first aims to achieve. It is logic that a lot of constraints and solutions are totally wrong, but this can help the competition.

3.3 Responding to business needs

The main fields in which now the research is focused could be grouped in these three sectors: Demand planning; supply planning, and production planning/scheduling.

1. Demand Planning : Effective demand-planning solutions enable companies to anticipate and influence future customer demand. These solutions typically include collaborative forecasting tools that provide consistent demand data and information to all trading partners, so that supply-chain responsiveness is optimised. By implementing an effective demand-planning process, companies are often able to achieve significant improvements in supply-chain performance." (Kevin O'Brien)
2. Supply Planning : Effective supply-planning solutions enable companies to determine what products are required and when they are needed, as well as how to distribute available supply most profitably, by matching internal and external sources of supply with prioritised demand. In a complex multi-source, multi-distribution centre supply network, effective supply-planning solutions will typically determine which demands will be supplied by which trading partner and/or which distribution centre, as well as where to stock specific inventory quantities to support customer-service objectives. An effective supply-planning process supports global visibility and coordination among trading partners, rapid response to change, and reduced working capital requirements." (Kevin O'Brien)

3. Production Planning/Scheduling: Effective production planning/scheduling solutions enable companies to determine what to produce and when to produce it, based on finite capacity constraints and material availability. These plans are used to manage labour and equipment loads as well as determine time-phased future material requirements. Scheduling is typically short-term, perhaps at the hour- or even minute-level of detail for each key work centre. By implementing an effective production planning/scheduling process, companies are often able to significantly reduce inventories, increase throughput, and improve on-time delivery performance." (Kevin O'Brien)

The main advantages and improvements that these there types of research can give are:

- 15% to 25% reduction in finished goods inventories, resulting from improved forecasting, reduced lead times, and improved inventory planning.
- 7% to 15% increase in customer service levels, resulting from identification of realistic delivery commitments based on true capabilities and forward visibility of potential problems with sufficient time to respond.
- 3% to 7% increase in throughput, resulting from improved scheduling and material planning.
- 25% to 33% reduction in WIP inventories, resulting from improved coordination of materials and capacity.
- 20% to 30% reduction in raw materials inventories, resulting from reduced lead times, improved supply planning, and supply-chain integration.

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(Kevin O'Brien)

An important are of research are the techniques for analyzing the role of intangible resources has three stages. The collaborating parties carry out the first three independently:

- The determination of the nature, strength and sustainability of the current advantage in terms of product and/or delivery system features.
- The determination of the intangible resources, which produce each key feature and their categorization in terms of a framework of four capabilities.
- The generation of scenarios for each of the key intangible resources by considering the issues of protection, maintenance, enhancement and leverage.
- The sharing of perceptions in a Perceptual Synthesis.

The technique for analyzing the role of intangible resources gave managers a new 'resource based strategy' perspective and a language with which to communicate that perspective to colleagues and collaborators. The "Perceptual Synthesis" enables managers to achieve a better mutual under-standing of issues, which, by virtue of their subjective and qualitative nature, were difficult to communicate." (Hall, Andriani)

3.4 Outsourced supply chain: third party and fourth party logistics

The fast development within logistics and its significance to industrial companies has lead to the development towards Third Party Logistics. The essay definition of Third Party Logistics is that a third part is involved in the relationship between a supplier and a customer, and handles not only the transport function, but also other logistical functions, such as warehousing. Close and long term relationships are catchwords for Third Party Logistics.

The connection between logistics and supply chain management

To distinguish more clearly between logistics and supply chain management practices, take the example of a large firm that has managed to vertically integrate all of its activities. That is, the firm controls everything from the point of sourcing raw materials to delivery of the final product to the customer. For this firm, the most important logistics practice would be that of logistics management. Such a firm would need to have strong internal controls to coordinate information flows, and have close integration with suppliers and customers. The supply chain management skills the firm needs are managing structured supply chain partnerships and relationships with the final customer.

However, most firms are not as large as in this example. The typical firm relies on other firms for inputs and/or a connection to the final customer and the success of their business is directly related to the performance of others along the chain. This is particularly so for SMEs. Consequently, the ability of these firms to manage their logistics activities depends on their ability to manage the multitude of relationships they have with suppliers and customers. This requires a special set of skills.

Throughout this report the phrase logistics will be used in its common sense (that is, the activities involved in moving, storing and handling freight), while logistics chains or chain management will be used to describe the inter-connectivity or inter-dependence characteristic of logistics.

LOGISTICS ACTIVITIES

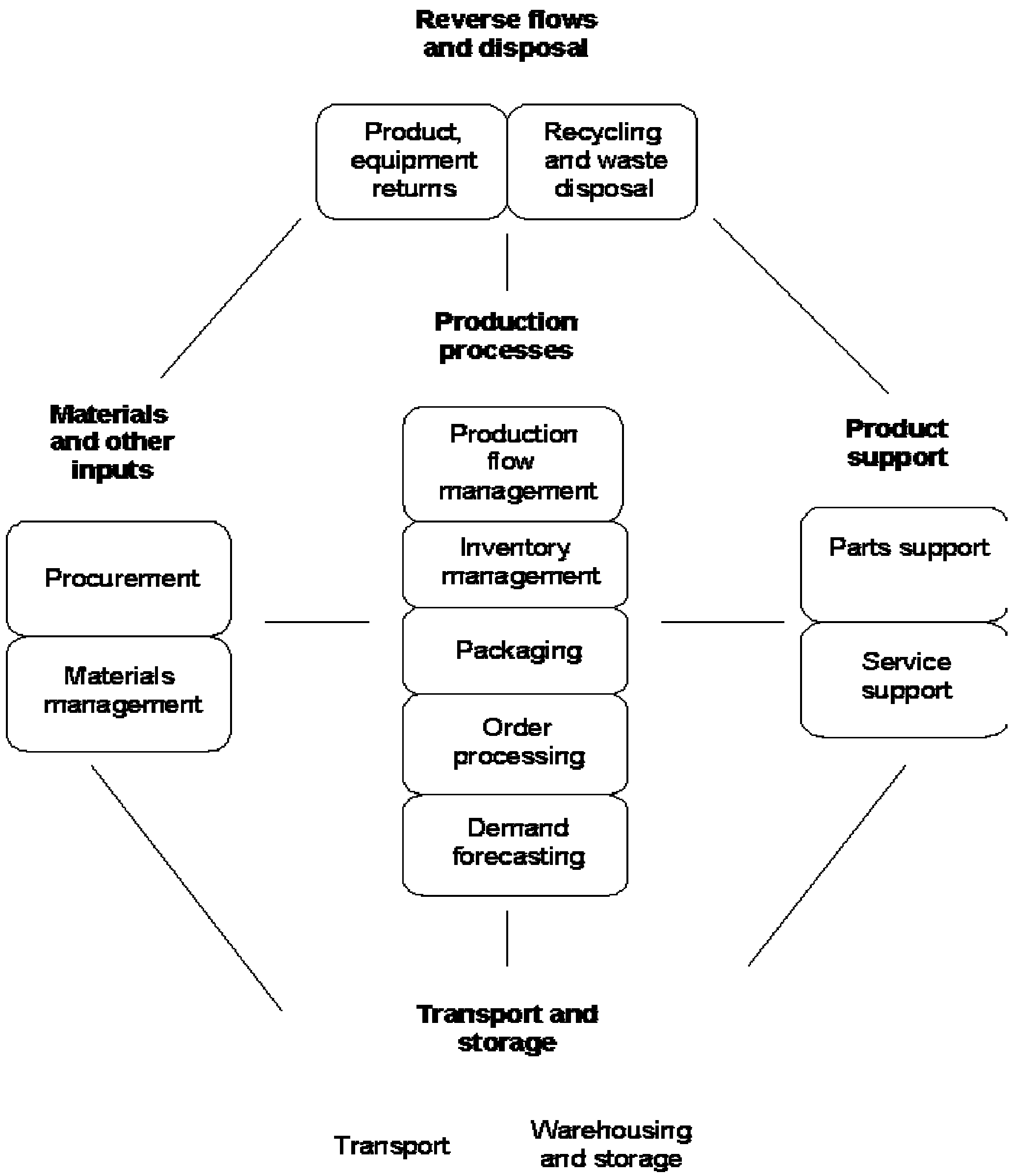


Figure 2

Freight logistics as an industry

The logistics activities presented in Figure 2 are either performed 'in-house' or are performed as services to a given firm by a service provider. Historically, transport operators have been providers of services to other firms and most firms have organised the majority of their 'non-transport' activities internally.

However, a feature of the modern economy is the scale of out-sourcing that firms are prepared to undertake. For example, a number of overseas studies have suggested that the overall out-sourcing market is growing at a rate greater than 20 per cent per year.**(**Martin Christopher 25**)**Christopher suggests, "for most companies today, 'out-sourcing' has grown to represent 50 per cent or more of their costs…"(Browne and Allen 3**)**

Logistics activities are targets for those firms choosing to out-source. Table 3 lists the type of logistics activities being offered by logistics service providers, as described by the Holland International Distribution Council.

Table 3: Out-Sourced Logistics Services

Classic Out-Sourcing	**Advanced Services**
Warehousing Transport Goods Dispatch Delivery documentation Customs documentation	Pick and pack Assembly/packaging Returns Labelling Stock count
Full Services	
Order Processing Systems/IT Payments Collection Shipment Tracking	Order Planning Invoicing Consulting Materials

Source: Browne and Allen 2001, p.257

There have been many studies of logistics out-sourcing overseas. The following is one example:

"A survey conducted in 1996 estimated that the third-party logistics market in the European Union was worth approximately $32 billion, which represented just less than a quarter of total logistics expenditure. This study found that out-sourcing varied significantly between countries." **(**Browne and Allen)

Europe is seen as having one of the most mature third party logistics markets, with 76 per cent of European companies using third party logistics providers compared to 58 per cent in the United States. (Browne and Allen)

Fourth party logistic

As the third party logistics markets have matured, a new type of logistics service provider has emerged - 4PLtm**(**Rushton **)** (see Figure 3). A fourth party logistics service provider is defined as "an integrator that assembles the resources, capabilities, and technology of its own organization and other organizations to design, build and run comprehensive supply chain solutions". **(**Rushton **)**

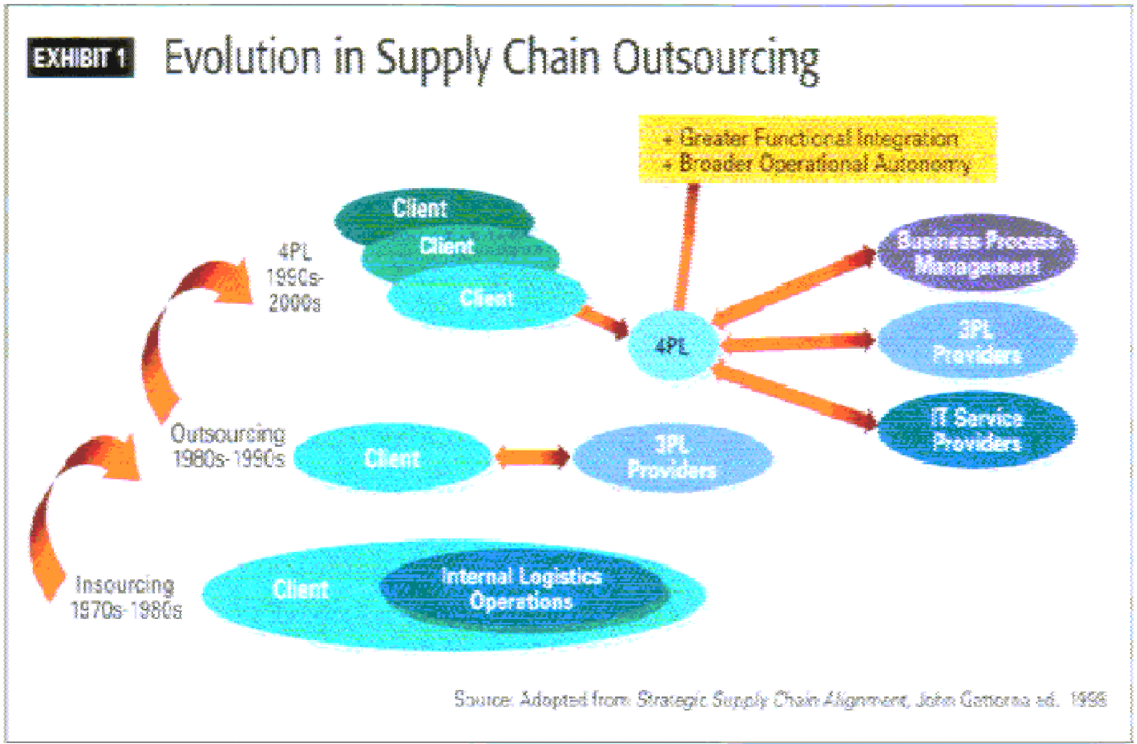


Figure 3: Evolution in Supply Chain Outsourcing(14)

The emergence of fourth party logistics providers reflects the benefits of good supply chain management practices, but also demonstrates the now blurring boundaries between logistics management and supply chain management.

The 3PL provider challenges

By definition, Third Party Logistics (3PL) providers are independent companies that design, implement, and/or manage a client's supply chain logistics needs. While many of the logistics service capabilities required in a 3PL environment are shared by companies that perform their own logistics functions, there are unique "multi-client" capabilities that are often required if 3PL providers are to be successful. For example, providers must apply optimisation to logistics functions across multiple clients, while maintaining key data elements for reporting and billing on an individual client basis. For a provider to take advantage of all the possible leverage points that exists by combining multiple clients into a single distribution model, it must take advantage of shared facility, systems, systems support, human resources, and material handling equipment. In simple terms, the 3PL provider should optimise multiple clients' logistics services as if a group of clients were a single logistics organization.

business challenge
The 3PL market is relatively new, growing at a healthy rate, and remains highly fragmented, the combination of which makes the environment extremely competitive. A 3PL provider that intends to stay in this market must grow by not only increasing its customer base, but also by increasing its breadth of services. This means providers that were comfortable with providing only transportation services, for example, must now consider offering warehouse / distribution center services. In the long term, a Lead Logistics Management service model that comprehends full supply chain management, source through consumption, will be required to stay competitive.

4. Current technology

4.1 Activity based costing

The role of financial accounting is to report historical results to external audiences. This is inadequate for supply chain decision-making for it employs allocation of indirect and fixed costs based on historical volumes that will change in the future. The management accounting community developed a new method called activity based costing, which seeks to allocate indirect costs, otherwise called activities, to cost objects, such as product and customer costs. This allocation is based on cost drivers that determine how the activities contribute to the total costs of the cost objects. Indirect cost drivers may be volumetric such as cost driver for the receiving department that equals the number of parts handled by the department during the planning period and may also be non-volumetric, such as a cost driver for machine set-up costs that equals the number of times a machine is set-up during the planning period. The allocation of direct costs involves natural and obvious drivers, such as machine hours for machine cost, and is much more straightforward.

For the purpose of decision-making, the managerial accounting or modelling practitioner must develop cost relationships of direct and indirect cost, rather than mere point estimates of them. These are functions that describe how costs will vary in the future as a function of the values of their cost drivers. Nonlinear and discontinuous functions of a single cost driver may be approximated by linear and mixed integer programming constructions. If a cost relationship involves multiple cost drivers with cross-product terms, nonlinear programming modelling techniques may be required.

The connection between activity-based costing and supply chain optimisation models is important, but complicated. For our purposes here, the key construction needed to create costs for the supply chain decision database is a mapping of indirect costs in the company's general ledger into natural categories of supply chain costs with associated cost relationships, drivers and resources. A cost driver corresponds to a resource if its availability is limited. Otherwise, the cost driver is merely an accounting device for tracking costs.

Activity-based costing and optimisation modelling play complementary roles in identifying costs and cost relationships for supply chain decision making. A supply chain optimisation model provided a template for costs and cost relationships in terms of generic planning elements such as processes resources, facility costs, and transformation recipes. Activity-based costing analyses of general ledger and other raw cost data determines, the specific nature of these generic elements, an parameter defining their cost relationship.

4.2 Mathematical models

Questions asked by a decision maker in a supply chain typically are:

- When and how much of a raw material to order from a supplier,
- When to manufacture an order ,
- When and how much of the product to ship to a customer or distribution center,
- Constraints are limitations placed upon the supply plan,
- A supplier's capacity to produce raw materials or components,
- A production line that can only run for a specified number of hours per day and a worker that must only work so much overtime,
- A customer's or distribution centre’s capacity to handle and process receipts.

(Larry Lapide)

The constraints imposed on him in answering these questions can either be *hard* or *soft*. Hard constraints could be for example the number of working hours in a shift or the maximum capacity of a truck and they have to be satisfied. Soft constraints instead can be relaxed or violated. Examples of soft constraints include customer due dates or warehouse space limitations. In practical situations penalties are imposed if a soft constraint is not met. The penalties allow constraints to be weighted by importance. For example, missing a customer due date is a more important concern than cluttering a warehouse aisle.

The objective of the decision-maker could be one or a combination of the following:

- Maximizing profits or margins
- Minimizing supply chain costs or cycle times
- Maximizing customer service
- Minimizing lateness
- Maximizing production throughput
- Satisfying all customer demand

“ (Larry Lapide)

Mathematical models describe the relationships among decisions, constraints, and objectives. These are expressed by mathematical formulas. To express these models in mathematical formulas involves translating physical problems in algebraic formulas.

Good quality models that capture the essence of the underlying system are required in order to obtain maximum result of the supply chain. These models can become very complex as well as detailed. Due to the plethora of models in the market it is not uncommon to make the wrong choice. There fore attention must be paid in
selecting the model that is suitable for the needs of the business.

4.3 Computational techniques

Supply chain planning optimisation techniques and solutions attempt to accomplish the following tasks:

- Determine a feasible plan that meets all demand needs and supply limitations
- Optimise the plan in relation to corporate goals such as low cost and profitability " (Larry Lapide)

A solver is an algorithm that has been automated to process models. The time taken by the solver to process the model can vary significantly with e the dimension and the complexity of the model.

A solver can provide three types of solutions:

1. Feasible Solutions that satisfies all the constraints of the problem.

2. Optimum Solution that the best feasible solution that achieves the objective of the optimisation problem. Although some problems may yield more than one feasible solution, there is usually only one optimum.

3. Optimised Solution that partially achieves the objective of the optimisation problem. It is not the optimum or best solution, but it is a satisfying or reasonable one. This is usually one of the best feasible solutions. However, for optimisation problems that have no feasible solutions, it may be one of the best *infeasible* solutions. For example, in a resource-constrained environment, it may be a solution that is infeasible because it does not meet all customer due dates, but it may minimize operating costs. (Larry Lapide)

4.4 Case studies showing the use of optimisation technology

Optimisation based techniques provide significant improvement in the performance and insight into the system, without the investment of much money.

Optimisation can :

- benefit the business and profitability in many ways,
- generate solutions faster than any other software,
- automates the solution process and verifies that the solution adheres to your business rules,
- dramatically improves business flexibility, responsiveness to changing circumstances, and ability to test "what if" scenarios,
- focuses decisions and resources on business priorities .

Here there are some examples of companies that increased a lot their goods because of optimisation (See 50) :

Chrysler Motors Engineering

(Sheet-Molded Compound Process Improvement)
The objective was to identify controllable and significant material and process variables that could minimize the effect of Sheet-Molded Compound (SMC) formulation. First-time-through capability of the finished product improved from 77% to 96%. Supplier scrap was reduced from 16% to 1.7%. Reduced inspection cost repair and costs due to optimisation are estimated at $900,000 per year.

Eastman Kodak Company

(Pinch Roller System of Optimisation: A Comparison Between Traditional DOE and Taguchi Methods)
The time required to perform the data analysis for both the Taguchi and traditional analysis is comparable, and is insignificant compared to the time required for data gathering. For this study, the time required to gather data was approximately one hour per experiment. Twenty-seven experiments were required to generate the Taguchi data, and 60 experiments were required to perform the traditional analysis. The time required for the Taguchi experiments was only 45% of the time required for traditional experimentation.

Flex Technologies, Inc.

(Factors Affecting Solvent-Bonded Connector Durability: Optimisation of the Strength of an Emission Control Harness Assembly)
This study investigated the improvement of automotive emission control harnesses. This product must conduct vacuum signals to various devices that alter the combustion engine's performance to minimize emissions. A low but noticeable number of solvent-bonded harnesses were found separated in finished assemblies. Application of Taguchi's methods resulted in a reduction in parts failure from 17% to 1.1%. As a result, an inspection cost savings of $200 per 1,000 pieces was realized on monthly production of 500,000. ($1.2 million annually).

Ford Motor Company

(Fuel Pump Flow)
The variability range in fuel pump flow was reduced by 65%. Development of a new fuel pump with severe requirements was completed eight months prior to plan as a result of this study.

Hy-Lift Division, SPX Corporation

(Cold-Start Noise Reduction for Hydraulic Roller Tappets)
The objective was to reduce cold-start noise in a 5.2 litre V-8 gasoline engine. As a result of this study, tappet noise was reduced by 75%, and an estimated annual savings of $4,900,000 was achieved.

ITT Suprenant

(High Voltage, High Temperature Wire Strip Force Optimisation)
This study examined strip-force problems associated with one type of high-voltage, high-temperature wire used in the electronic OEM marketplace. Variability of strip-force was the primary cause of rejection. The objective was to minimize strip-force variation around a target value. As a result of bringing the process under control, an annual savings in material and production cost of $100,000 was achieved.

Lucas Girling Ltd.

(Optimisation of the Strength of Diesel Injection)
The objective was to reduce the rework rate of a diesel injector on the assembly and test operation. After the first stage of Taguchi Methods implementation, a 17% reduction in rework was realized and another 4% after a second stage of implementation. This equates to an annual cost savings of 14,880 pounds sterling.

North American Reiss, Kenkor Division

(Optimisation of a Hot-Stamping Process)
Taguchi Methods, specifically Parameter Design, was used to assist design engineers in developing a product that both meets their needs and is manufacturability. In less than one month, a hot-stamping process was both established and optimised. The results not only yielded 100% conformance, but enabled the design engineers to develop realistic product requirements in less than half the normal time.

Nissan Motor

(Brake Pad Study)
Using dynamic characteristics, Nissan improved the efficiency of the energy transformation to the brake pad. Overall weight of the brake system was reduced and squeals rate was reduced to 4% of the original condition. Nissan Technical Centre conducts 70 projects annually, all using dynamic characteristics.

Rockwell International

(Space Shuttle Main Engine Nozzle Brazing Improvement)
Improvement of the furnace brazing process resulted in a reduction in variation of 82%. Cycle time was reduced to 1/3 of the original process.

Sanpo Chemical

(Bean Sprout growing process)
This company broke the traditional bean sprout-growing paradigm "Beans that grow fast do not have a good shelf life, and beans that grow slowly do not become large enough." The time to grow a bean sprout was reduced from 7 days to 4 days without affecting taste or shelf life, a 40% improvement in productivity.

Xerox
(Copy machine paper arrival time)
Xerox reduced the variability in arrival time and paper orientation by 66%. Xerox is probably the most advanced user of Taguchi Methods in the U.S. They started implementation of Robust Design in 1982, and today the Robust Design approach is fully integrated into their product development process.

5 Future trends

5.1 Real options and risk

Today's uncertain and dynamic business environment creates opportunity and risk. Supply chain optimisation is most useful in situations where a company or a product has a complex supply base, a complex manufacturing process, a complex distribution system, and volatile demand. Essentially, whenever there is uncertainty in the behavior of supply chain operations or in market demand, Supply chain optimisation could benefit the company.
However, the real challenge of supply chain management stems from the uncertainty that is inherent in everyday events at every point in the chain, for example

1. Forecasts of customer demand are seldom accurate and often misleading,
2. Manufacturing is vulnerable to technical problems, and
3. Distribution can suffer from freight delays.

It is paramount to develop models for supply chain that take into account the uncertainty and complexity.

At virtually all levels of planning, the supply chain decision database will contain data describing options not currently included in the company's operations. Strategic options might include potential acquisitions or mergers, the construction of new facilities, the development of new technologies, or supply contracts with new vendors, or manufacturing exchange agreements with other firms. Preparing data to evaluate such options is not simply a matter of forecasting or extrapolation. For example, evaluation of a potential acquisition requires integrating its supply chain decision database with the decision database of the company to create combined inputs for an optimisation model of the merged supply chains. Similarly, a model to evaluate the re-design of a distribution network needs data describing the locations of potential distribution centers, along with costs for constructing or renting facilities in these locations, and transportation rates from these locations to the company's markets. In summary, the decision database often requires data about supply chain options for which the firm has no historical data.
Supply chain analysis at all levels of planning requires data and structural inputs reflecting company policies and managerial judgments about risk. The decision database must be extended to include these data, and optimisation models require decision variables and constraints that mechanise them. For example

1. For a global corporation planning its strategy for next year, the CEO may wish to impose a constraint limiting the manufacture of any product family at any single facility to no more than 75% of total forecasted volume for the year.

2. For a distribution company developing its tactical plans for the coming quarter, the VP for Marketing and Sales may wish to limit the maximal distance between any distribution center and any market it serves to 300 miles, which roughly equals the limit of one day deliveries.
3. For a manufacturing firm, the Manufacturing VP may wish to limit the dollar volume of out-sourced production for next year in a particular department to no more than 25% of the department's annual budget.
4. For a company making local deliveries of products, the general manager may wish to limit the number of part-time drivers scheduled each week.

In performing strategic and tactical analyses, model structures reflecting management policy such as these may be soft implying the need to make several model runs to measure the tradeoffs of cost or revenue against the other criteria. Such multi-objective analysis requires the mangers to specify a range of permissible values for the non-monetary criteria. On the other hand, for scheduling applications, the tradeoffs among criteria must be hard-wired to ensure rapid computation of a final plan for execution.

5.2 Balance between modelling flexibility and built-in functionality

Optimisation depends heavily on the ability of the application to model real world issues. This can be done with built-in modelling functionality, such as predefined safety stock, rather than built-in functionality. An application may provide flexibility with general purpose modelling capability that allows users to create models, for example defining the safety stock. Applications need to provide users with a balance between built-in capability and flexibility.

Some vendors provide general purpose modelling applications that allow users the flexibility to optimise across a broad range of decisions. These products allow users to tailor the optimisation to their own environment, letting them optimise decisions uniquely important to them. Chesapeake Decision Sciences *MIMI Planning and Scheduling* is a general purpose modelling application. Other companies providing these types of applications include CAPS Logistics, i2 Technologies, and Numetrix.

Other vendors offer built-in capabilities rather than general purpose modelling application functionality. While these applications limit the ability to optimise unique decisions environments, they minimize the implementation configuration efforts for specific supply chain problems. For example, Manugistics has recently added optimisation capability to its product suite tailored for consumer products and the distribution- intensive companies. While this provides less flexibility to optimise, it reduces configuration efforts. Logility is developing similar optimisation capability.

In order to provide some level of built in functionality, many of the general purpose modelling application vendors are developing or offering templates. These are semi-custom applications, created using their general purpose modelling applications. Templates reduce implementation configuration efforts. For example, i2 Technologies is building templates that are specific to industries such as Semiconductor, High-Tech, and Metals. In addition, CAPS Logistics now markets Supply Chain Designer and Supply Chain Coordinator; strategic and tactical supply chain-planning application.

5.3 Customised solutions

The software vendors provide the Decision Support system and not Decision making system. Optimised solutions are frequently not reasonable or executable and need to be controlled by the planner.

To ensure that optimisation applications provide reasonable, executable solutions, most vendors provide graphical user interface (GUIs) to facilitate manipulating data and modifying solutions. This functionality includes the following:

- Graphical drag-and-drop planning boards,
- user–defined constraints and rules,

- Controlling the optimisation procedures.

  Many graphical planning boards allow users to change a variable, say a date or order, and immediately see the impact on the objective and asses new constraints violations.

  Vendors also give users control over the solution by allowing them to incorporate unique constraints or rules into the model. For example, a planning application might allow a user to specify that customer due dates can be relaxed by one or two days or the user may approve the maximum level of overtime. While this is useful functionality, some users are tempted to abuse it by changing the objective.

  Some vendors allow the users to control the progress and performance of the solver method, allowing the planner to set a time limit on the solver and then pause. This lets the planner evaluate the solution so far.

For strategic and tactical supply chain planning, it is important that an optimisation model system provide graphical displays of data, including graphical mapping of inputs and outputs

Geographical information system (GIS) do not add to the system's inherent analytical capabilities. Still, they are very useful for communication data, problems and solutions, especially to managers who may be too busy to study detailed, tabular data.

For a company doing business in Europe, a GIS would be used to display the results of a logistics network design analysis. For example, the GIS could produce a map of the Europe for each product showing

- The optimal location of distribution centers supplying the product,
- Color-coded data indicating which markets are served by each distribution center,
- Links of variable thickness indicating the relative flows of product between distribution center and markets.

For scheduling applications, graphical displays allow human verification and manipulation of plans computed by an optimisation model. An open issue is the appropriate level of human interaction with the scheduling system. The present style of many systems relies too heavily on such interaction. As a result, scheduling plans are inferior to those that could be found by rigorous optimisation models and solution methods. Moreover, the human scheduler may spend excessive time manipulating trial solutions to find one that is acceptable. A related difficulty is that off-the-shelf scheduling systems rely too heavily on the human scheduler to customize solutions to the company's scheduling environment. In many cases, the company would benefit significantly by investing in a more expensive scheduling system with customized analytic methods.

On-line analytical processing (OLAP) refers to the application of data management and data mining tools to organize, analyse and display complex input and output database. A key feature is Multidimensional Data Viewing (MDV), which allows an analyst to develop graphical display of complex data in a relational database. This capability is also valuable for comparing and contrasting plans for multiple scenarios.

5.4 E-commerce and supply chain

E-commerce requires intelligent supply chain, which must provide instant access to the right data anywhere. Sophisticated optimisation engines cannot only make possible real-time collaborative decision-making among all partners in the supply chain with the web as the medium, but can greatly increase responsiveness to customers.

This is the emerging world of e-collaboration, which takes supply chain management to the next level. Companies will move beyond the singular mentality of intra-company optimistaion to focus on how inter-company e-collaboration can transform consumer demand into consumer satisfaction. For example, a company can do forecasts collaboratively across its virtual organization, using optimised planning applications within its manufacturing, distribution and transportation resources to meet demand and actual customers orders. E-collaboration addresses volume planning scheduling, sequencing, distributional management, and procurement planning.

The internet is already changing how companies deal with customers via quickly emerging Customer Relationship Management (CRM) applications such as those that include product configuration software. The best configurators offer intelligent support to help customers select online the parts or features that want to include in their product to meet their specification.

eCHAIN Logistics combines the operational experience of an international logistics service provider with the IT and methodological competences of a leading consulting firm. This combination enables to offer integrated concepts tailored to the individual requirements of the clients´ businesses.

6 Appendix

A. An internet based tool for supply chain optimisation

Software for building, solving, and analysing optimisation problems has seen a surge of development over the past decade. The attractiveness of the optimisation models addressed by this software can be explained in part by the obvious appeal of minimizing costs or maximizing profits in operations research and management science applications. More broadly, the concept of an objective function has proved to be a valuable modelling tool in describing the desired solutions for a range of planning and operational problems. It can be a lot easier to say that a certain combination of costs must be minimized than to formulate constraints that rule out every possibility for uneconomical behaviour.

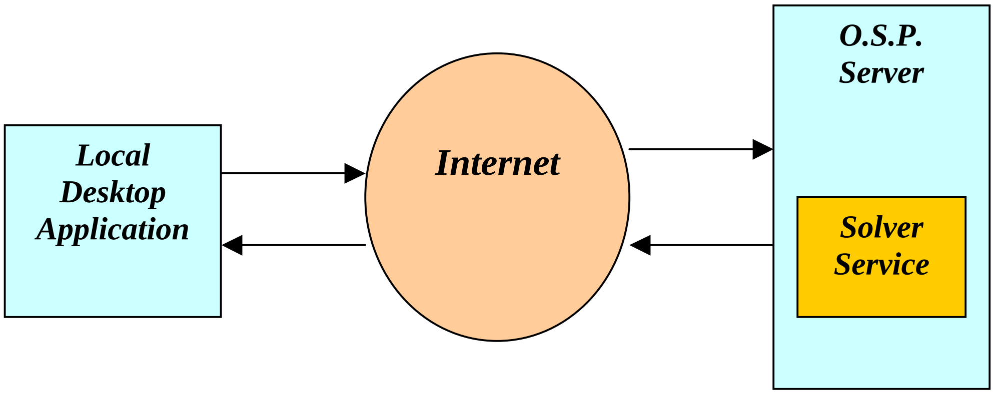
Software for optimisation does tend to be more complicated to buy and configure than comparable packages for simulation, statistics or decision analysis. The market for optimisation software encompasses two distinct kinds of products: solvers that implement various optimising algorithms, and *modelling systems* that support the development and application of mathematical programs. A product of either kind is typically available for use with a number of products of the other, through separate purchase or various package deals. This arrangement has given modellers a valuable degree of flexibility in combining methods and interfaces to meet their needs, but at the cost of some additional complexity in connecting software from different sources." (Fourer)

A typical evidence of the main role of optimisation in the industrial market could be the EU craft project titled Optimisation Service Provider (OSP). This is an internet-based application, which gives to companies the comfortable advantage to use many optimisation tools via web. This application:

1. allows the use of optimisation tools without the significant cost of an in-house optimisation solution,
2. provides training through an Application service provision techniques,
3. provides vertical, generic and customisable end-user solutions for a number of industrial sectors.

OSP contributes to the community in two distinct ways. First, it extends the concept of ASP to include decision support applications. Second it includes training, which is a critical factor for the use of optimisation by a wide user-base that may not have the key expertise and/or resources to adopt optimisation for competitive advantage.

This is a sample scheme of the O.S.P. project. On the web site (www.osp-craft.com) you will be able to find more details.



B. A strategic and tactical planning

The different levels of planning in the supply chain can be classified in a hierarchical structure as follows(see Dominguez-Ballesteros, 2001):

(i) **Strategic activities***: decisions about major resource acquisitions and investments and the manufacture and distribution of new and existing products over the coming years. These decisions determine the most effective long-term organisation of the company's supply chain network, and aim at maximising return on investment or net revenues.*

(ii) **Tactical activities***: decisions about how the facilities will be used, and how market demands will be met over the next few time period(s). These decisions, which have a medium-term scope, aim at minimising manufacturing, transportation, and inventory holding costs while meeting the demand.*

(iii) **Operational activities***: decisions about the production, schedule and distribution of the products manufactured. These decisions, which typically affect activities over a short-term planning horizon, determine the most effective resource utilisation within the supply chain network, and aim at minimising short-term production cost while meeting demand, and generating the best goods delivery schedule. These activities do not usually involve large capital investments.*

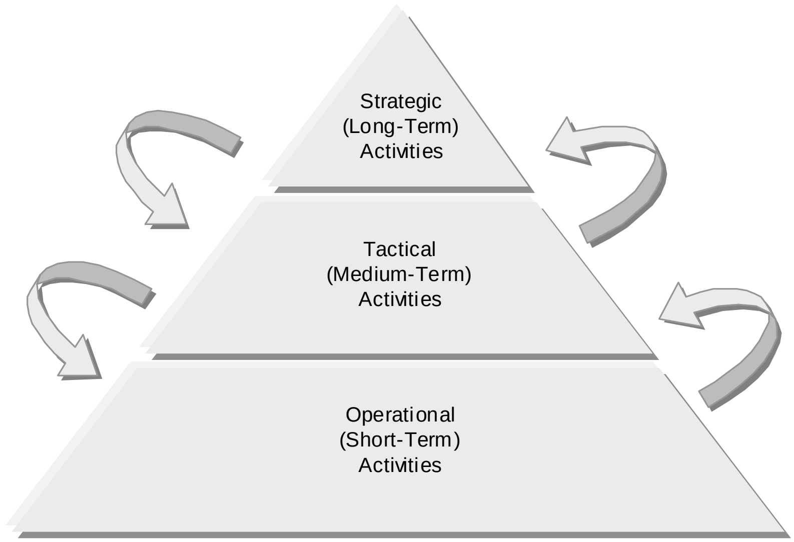


Figure 1 Hierarchy of the Supply Chain Activities

Optimisation models set out to make best use of available and (limited) resources. This makes optimisation an attractive tool for decision support, often proposed by economists and operational research practitioners.

Mathematical programming models have been used to represent the different activities that are involved in a manufacturing supply chain, such as for facilities location, for production capacity, for production scheduling, for inventory levels, and so on.

SCHUMANN (Schumann, 2000,see 40) puts into practice the integrated planning of the strategic and tactical decisions of an automobile manufacturing, and a pharmaceutical goods distribution networks. It is normal practice to re-examine a supply chain planning network after a significant change has occurred in the operational environment. Typical examples are changes in regulation requirements (emission levels), a new market entrant, or the introduction of a new production technology type. The strategic model is used to determine the best strategy for asset (plant capacity, technology type) allocation. The tactical model complements the strategic model by focusing on the logistics, optimising scheduling, inventory control, and distribution of goods, which make best use of the allocated assets (see Belen's thesis).

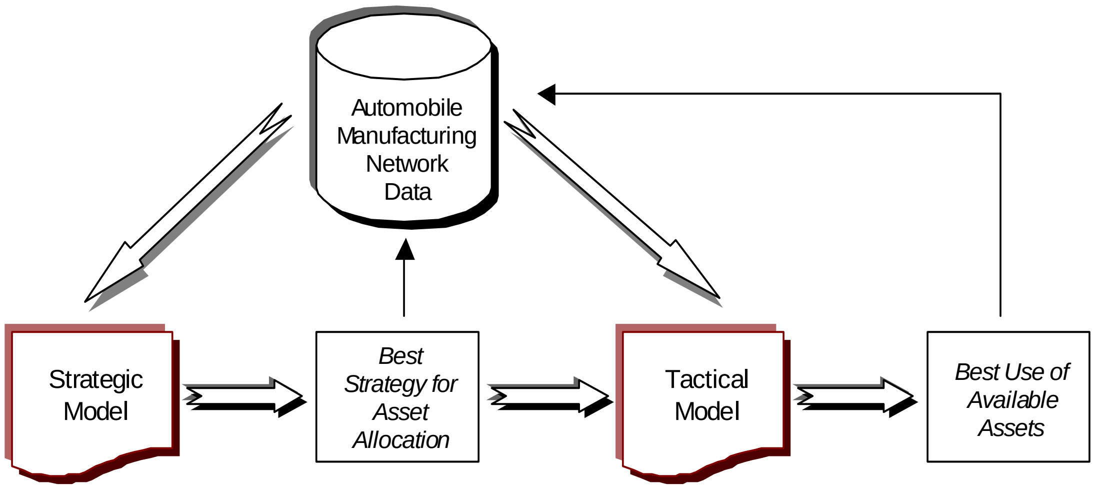


Figure 2 SCHUMANN Models/Data Flow

A single model, which combines both the strategic and tactical decisions, is clearly desirable (Bradley & Artzen, 1999; Shapiro, 2001). An important aspect of creating such an integrated model is either the availability or the implementation of a supporting data mart. The various model parameters used in this integrated model must first reside in such an analytic database (data mart, or decision database). The results are also stored as decision data, and the database is explored using suitable (R)OLAP tools.

C. Other sources of information

www.combination.com
Advanced Process Combinatorics Inc. provides complete solutions to complex operations management problems in process scheduling, supply chain optimization, project and portfolio management, warehouse management and dispatch systems. Advanced Process Combinatorics delivers highly sophisticated optimization algorithms unmatched by any other vendor to bear on complex industrial problems, in a way that is practical, useable and fast.

http://www.echainlogistics.com/.
eCHAIN Logistics combines the operational experience of an international logistics service provider with the IT and methodological competences of a leading consulting firm. This combination enables to offer integrated concepts tailored to the individual requirements of the clients´ businesses.

www.e-optimisation.com
e-Optimization.com is designed as an informational meeting place for anyone interested in optimization software - from expert algorithm developers to business people who wish to learn more about this important technology.

www.eudoxus.com
Exodus Systems Ltd is a group of mathematicians who enjoy helping businesses to make better decisions and run their operations more efficiently. They do this by analyzing business problems and building mathematical models of them. They then apply mathematical techniques such as optimization to the models and translate the resulting solutions back into the real world.

www.i2.com
i2 recognizes the vast potential waiting to be unleashed in the value chain through Dynamic Value Chain Management, allowing collaboration across functions in a company as well as across companies in the value chain. This is the next frontier for increasing productivity, and the philosophy to which i2 is applying its expertise, passion, and technology.

http://www.lcp-ashlyns.com/schumann/lcp_page.htm
LCP was established in 1985 with a vision to help companies realise the benefits of supply chain management; at the time it was barely recognised in terms of its potential. The company has acquired international recognition and has a blue chip client list. It can claim with confidence to be the leading independent consultancy specialising in supply chain management and logistics. LCP has maintained its focus exclusively on the Supply Chain. The emphasis is on maximising return on assets through the design and application of appropriate supply chain strategies.

www.lytegroup.com
The Lyte Group, Inc. is a team of consulting and software specialists dedicated to navigating your business towards total supply chain optimization. Using their flagship software product, SPOTLYTE 2000©, they help you dramatically improve the profitability and competitive impact of your company.

www.manu.com
Manugistics solutions are used by more than 1,100 clients around the world, including more than half of the Fortune 50® to lower operating costs, improve customer service, enhance profitability, and accelerate growth by optimizing the supply-demand network from design and procurement through pricing and delivery

www.psiplanner.com
They are a Supply Chain software and consulting business offering affordable, easy-to implement solutions to complex planning problems. Their Managing Partners have over 40 years of combined Supply Chain and Information Systems experience.

www.sas.com/solutions/supplychain/index.html
SAS provides targeted solutions for problems arising at several key points in your supply chain. Each solution improves supply chain performance independently, but all can work together to share

information and create integrated solutions. Solutions also can be customized extensively to match your particular needs and goals.

www.schneiderlogistics.com
They do this by leveraging our 60 years of transportation experience every time they tackle a tough logistics problem. They use our deep operating knowledge to create solutions as unique as your needs. They employ the brightest minds in the industry. We draw on our strong network of transportation providers. And they develop leading-edge technology to save you money and improve your customer service.

www.sct.com
SCT is a global information technology solutions company, serving nearly 1,700 clients worldwide. Find out more about SCT's solutions, business alliances, investor relations, and more right here on this Web site.

www.thesupplychain.com
theSupplyChain.com provides the services around scCommunity including bringing multi-company data into the system via integration with disparate systems as well as developing new, and implementing off-the-shelf, application modules.

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