Logistic Optimization of Chemical Production Processes

Edited by
Sebastian Engell

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Contents

Preface

Lucky managers of chemical production units do not have to care much about logistics. Raw materials are always available at fixed low prices, the equipment produces the same (few) products day in day out, and the customers are eager to send more trucks, ships, etc. to be filled with products than can actually be loaded. The marketing department regularly makes auctions to determine which customer gets how much of the output of the plant. Such a situation may have existed in countries without competition and a free market, but while it makes the life of a plant manager easy on the one hand, we all know that there are most severe drawbacks for the economy as a whole, and as a plant manager you suffer from those on the other hand as well because, e.g., the vendors of the equipment that you need are in the same position and then you have to wait in line until you get a new valve, vessel, column, etc.

In a market-driven economy, demands are fluctuating, cost matters and customers want optimized products that are tailored to their specific needs. Most chemical plants can therefore produce a variety of different products or grades of products in parallel or sequentially, but the resources that are available in the production units are limited. Hence, a key question in the operation of a chemical plant is when to produce what and with which resources, and possibly also in which manner (according to which recipe). On a higher level, in a global company there are many different production sites that can deliver intermediates and products, so the production chain can be distributed over several sites of a production network. And there is the "make or buy decision", i.e. rather than producing intermediates in house they can also be bought from external sources. These questions have to be answered on different time scales, from the long-term planning of production capacities through setting yearly and monthly production targets to the daily decisions on product changeovers or the start of campaigns or individual batches and the immediate reaction to breakdowns, variability of yields and availability of personnel. All these operational decisions require logistic optimization that for the most part means to take the right *discrete* choices, i.e. choices among a finite set of alternatives. While such choices at first sight seem simpler than continuous optimization because in principle one can enumerate and grade all possible alternatives, as soon as there are several simultaneous options, the problem of the combinatorial explosion arises: the number of alternatives becomes too large to explore them all within a reasonable period of time. This type of problems is addressed by this book. Its topic can thus be described as "tools to solve combinatorial optimization problems that arise in chemical production management".

Logistic optimization is not only of importance in the operation of chemical plants and networks or chains of plants, but also in the planning of new plants or extensions and modifications of existing ones. For all multiproduct or multigrade plants, the quality of a concept for a new plant, a new unit or an addition to a unit can only be evaluated if the diversity and the temporal fluctuation of the demands and the ability of the plant to satisfy them are taken into account. And this, in turn, requires logistic optimization problems of the sort described above for a set of possible scenarios to be solved and the optimal operation of the different possible designs to be compared. As the pressure for immediate decisions in planning is not as high as in plant operation and fewer details have to be considered, in this area rigorous optimization is more likely to be an option than in real-time plant operation.

As stated above, the focus of this book is on *tools* for logistic optimization, including but not limited to optimization algorithms in the rigorous sense of the word. As the first of its kind, this book addresses the logistic optimization of chemical production processes both from a practical and from an academic point of view. From the review of the main problems in supply-chain optimization through the description of methods and tools that are currently used in industry, logistic simulation, campaign planning under uncertainty, heuristics- and optimization-based production planning and scheduling, the twelve chapters span the scope to recently proposed advanced optimization algorithms and to the embedding of such optimization algorithms into Enterprise Resource Planning (ERP) systems. All the chapters discuss real-world applications or case studies that are derived from real industrial problems. The authors represent the industrial users of tools for logistic optimization, the developers and vendors of such tools and software systems and academic researchers in a balanced fashion. It was my intention as the editor to provide an up-to-date survey of the field and at the same time a reference book than can be taken as the basis of courses on the operation of chemical and biochemical plants.

In the first chapter, Mario Stobbe (Evonik Degussa) sets the stage by giving an introduction into supply chains, supply-chain modeling and supply-chain management in the chemical industry. Chapters 2 and 3 deal with logistic simulation as a tool for logistic optimization, probably the tool that is most widely used in industry for this purpose (here optimization is understood in the practical and not in the rigorous sense of the word). Markus Schulz (Evonik Degussa) gives an overview of the potential applications of simulation and the organization of simulation projects. Andreas Liefeldt (Universität Dortmund, now with ABB Corporate Research) describes a simulator for a type of plant that has even more operational flexibility than traditional multiproduct batch plants, pipeless plants. The simulator includes a heuristic scheduling algorithm and supports both the planning and the operation of such plants.

The third part of the book is devoted to industrial solutions for complex scheduling and supply-chain management problems. Christoph Plapp, Dirk Surholt and Dietmar Syring (Axxom AG) present a tool for the solution of large supply-chain optimization problems that combines optimization and heuristics to successfully solve problems that are currently beyond the scope of rigorous optimization. Iiro Harjunkoski, Marco Fahl and Hans Werner Borchers (ABB Corporate Research) discuss the application of state-of-the art optimization technology to a copper production process that can serve as an example of how adaptation to the needs of the real problem and careful engineering can bridge the gap between academic algorithms and practical applications and give benefits in real industrial applications. Rudolf Metz (Bayer Technology Services) focuses on stochastic tools for handling the randomness of demands in the planning of production campaigns.

Part IV of the book deals with optimization methods and is intended to provide an introduction to the state-of-the-art in optimization technology from an academic point of view. The authors of this section have invested a lot of effort to make these chapters easier to follow and more pleasant to read than most journal papers on scheduling and discrete optimization. First, Guido Sand (Universität Dortmund, now with ABB Corporate Research) describes the engineering of mixed-integer programming (i.e. the rigorous solution of decision problems with real and discrete degrees of freedom as they arise in the solution of production planning and scheduling) for the solution of real batch-production problems. Carlos A. Mendes, Ignacio Grossmann, Iiro Harunkowski and Marco Fahl (Carnegie Mellon University and ABB Corporate Research) discuss the choice of linear mixed-integer optimization models for the same task, in particular the key issue of the modeling of time that has been the focus of scientific discussion for many years now. The contribution by Jochen Till, Guido Sand and Sebastian Engell (Universität Dortmund) addresses the issue of how to include uncertainty about the future evolution of demands, production capacities, etc. into the solution of scheduling problems and present an alternative algorithmic approach to the solution of scheduling problems, evolutionary algorithms. The last chapter in this section by Sebastian Panek, Olaf Stursberg and Sebastian Engell (Universität Dortmund) introduces a completely different approach to the modeling and solution of scheduling problems, based upon timed automata that were introduced in computer science in the past decade. The formulation of the models can be done in a modular, intuitive fashion, and the problems are solved using tools from computer science for reachability analysis.

In the last part of the book, the embedding of the solution of operational planning and scheduling problems into the mid- and long-term material and resource planning performed by ERP (enterprise resource planning) systems is discussed. Mathias Göbelt, Thomas Kasper and Christopher Sürie (SAP) describe a concept for the integration of short- and midterm scheduling and demonstrate it for the solution of a case study. Winfried Jaenicke and Robert Seeger (OR Soft) discuss the integration of scheduling algorithms with ERP systems and stress the role of humans and organizations in the planning and scheduling process.

In the collection of the contributions I tried to achieve a balance between the end users of tools and methods in the chemical industry, the tool developers, whose main concern is to develop and to market tools that are user friendly and efficient, possibly for a limited class of problems and without full regard for rigorous optimality, and academic researchers who have to venture into new areas, to try new ideas and to be concerned with optimality in the rigorous sense of the word. In my view, the book demonstrates that the inevitable differences and occasional tensions between these views in this area have led to a productive "supply chain" from academia to industry, as demonstrated by several applications and case studies where state-of-the-art optimization methods have been brought to use for challenging industrial problems. My special thanks go the industrial contributors, because for them, in contrast to the academic authors, writing chapters of a book is a low-priority activity at least in the view of their superiors. It is my sad duty to mention that one of the authors, Thomas Kasper from SAP, passed away this year, caused by a severe illness. I hope that this book will contribute to keeping his memory alive among his colleagues and friends. For the collection of the chapters, the activity of the section Produktionslogistik (logistics of chemical production processes) within the German VDI-GVC Fachausschuss Prozess- und Anlagentechnik (Working Group on Process and Plant Technology, now ProcessNet Fachausschuss PAT) was very helpful and is gratefully acknowledged. Finally, it is my pleasure to thank the publisher, Wiley-VCH, and in particular Waltraud Wüst, for encouraging me in this endeavor and for their continuous support and the right combination of patience and pressure.

Wetter (Ruhr), January 2008 *Sebastian Engell*

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Part I
Introduction

1 Supply Chain and Supply Chain Management*

Mario Stobbe

1.1 Introduction

The design, planning and controlling of networks of business processes with multiple stages in order to improve competitiveness has been a theme of operations research since the 1950s [1]. In practice, international operating companies with large supply and distribution networks especially applied the research results. Since the 1980s, the interest in the theme of networks in general as a competitive means has increased for the following reasons:

- globalization of the markets for distributing and procuring materials;
- internationalization of site structures;
- emerging customer expectations regarding quality, time of delivery and price;
- significant improvements of information technology as a means of dealing with increasing complexity.

The increased interest led to new terms such as supply chain and supply chain management and – at least in the US – an abundance of new research. In this introductory article, we discuss the characteristics of a supply chain and supply chain management.

1.2 Terms and Definitions

1.2.1 Supply Chain

1.2.1.1 Structure

The word chain in supply chain is misleading as it implies a linear structure. However, the structure of a supply chain is usually a network structure and only in

* A list of abbreviations is given at the end of this chapter.

rather seldom cases a linear chain. The supply chain can be described in different levels of detail as will be outlined below when discussing the Supply Chain Organizations Reference Model (SCOR-model). For a first characterization, a supply chain will be considered here as a network of organizations exchanging materials, service and information in order to fulfill customers' demands. In a broad sense, the organizations are companies (legal entities). In a narrow sense, this definition applies to large companies with numerous sites in different countries providing a variety of materials and services as well. Some authors term the latter an intra-company supply chain and the former an inter-company supply chain. The setting of a complex intra-company supply chain is typical for large chemical companies.

The structure of a supply chain in the broader sense is comparable to a virtual corporation. A virtual corporation is a network of legally independent companies which cooperate for a limited time in order to achieve a given objective.

1.2.1.2 **Function**

Defining a supply chain solely by its structure and its components will be inadequate. From a functional point of view, the supply chain is comparable with logistics networks. A closer look at the characteristics of logistics networks and at supply chains will show some significant differences even when applying a modern characterization of logistics. In a classical sense, logistics only comprises storage and transportation of materials. Nowadays, logistics is treated as an enabling function including tasks such as procurement, production, distribution and disposal of materials. Both definitions have in common that logistics are seen from the point of view of a single company. A holistic definition of logistics includes suppliers and consumers as participants. Some authors equate this holistic concept with supply chain management as both concepts share some essential characteristics regarding organization and tasks. These characteristics are process orientation, co-ordination of information and material flow.

Process orientation means that the organizational structure corresponds to the key processes. This is in strong contrast to the functional organization where (parts of) processes are assigned to departments and, thus, processes are organized according to the structure of the departments. Besides the typical logistic processes, order acquisition, order processing and product development are typical key processes. These processes may cross the legal boundaries between companies in order to serve the needs of the customer which leads to the necessity of co-ordination of material and information flow.

However, the players in a logistics network are participants whereas in the supply chain they are (or should be) partners. This becomes apparent when looking at planning processes. Participants make decisions on their own trying to improve some variable – usually the profit – related to their own company. In contrast, partners in a supply chain make their decisions based on a collaborative and holistic consideration of effects along the supply chain in order to achieve a competitive advantage for the supply chain as a whole. The decisions include not only operational/short-term decisions but also tactical and strategic decisions regarding the design of the supply chain. Eventually, the intended purpose of a supply chain is to fulfill the customers' demands in a most efficient manner and to outperform other supply chains.

1.2.2 Supply Chain Management

Based on the characterization of a supply chain, supply chain management (SCM) can be defined as "a process oriented approach to procuring, producing, and delivering end products and services to customers." It includes sub-suppliers, suppliers, internal operations, trade customers, retail customers and end users. It covers the management of materials, information, and fund flows [2].

A large variety of definitions of SCM exist which cannot be discussed in detail here. A look at the origins of the term will partly explain how different and sometimes misleading definitions evolved. The term SCM was established by consultants in 1982 [3]. They were the first to treat logistics as a top management concern. They argued that only the top management can balance the conflicting objectives of different functional units, e.g., long production runs (production) vs low inventories (finance). From this fact it becomes apparent that SCM is a management concept (!) and that it has evolved from practice. Theoretic considerations and interpretations followed some years later and often reflect the theoretical background of the author.

Managing the supply chain generally comprises three elements of activity:
- supply chain analysis
- supply chain planning
- supply chain execution

Before starting an improvement process, a clear picture of the supply chain has to be obtained. Therefore, Supply Chain Analysis is a critical success factor. Usually, this analysis will describe the "as-is" status and the desired "to-be" status. As a supply chain is built up of different companies for a limited time, it is essential that all partners speak the same "language" to describe and measure the as-is-status as well as to evaluate the to-be-status. For this purpose, usually a widely accepted model called the SCOR-model is used.

Supply Chain Planning (SCP) comprises all planning activities at the operational, tactical and strategic levels. Well known activities at the operational level are demand forecasting, network planning and scheduling. In order to ease these complex activities, so-called Advanced Planning Systems (APS) are used. At a strategic level, SCP includes supply chain design. Supply Chain Design comprises the selection of partners, the definition of the core business of each partner, selection of outsourcing strategies, supplier management and the selection of enabling technologies such as e-commerce and e-procurement.

Finally, Supply Chain Execution means putting agreed operational plans into practice with minimum effort.

1.3 Network Dynamics and Management of the Supply Chain

Although the term SCM first appeared in 1982, several effects connected with SCM were investigated long before then. From systems theory it is well known that the behavior of complex systems is more than the sum of its components and therefore cannot be understood solely by the analysis of its parts.

In 1958, Forrester started studies on an effect which is nowadays often referred to as the bullwhip effect. The bullwhip effect describes the amplification of temporal variations of the orders in a supply chain the more one moves away from the retail customer. Forrester showed that small changes in consumer demand result in large variations of orders placed upstream [4, 5]. It is interesting that this effect occurs even if the demand of final products is almost stable. For his studies, he assumed that some time delay exists between placing an order and the realization of this order (production). Furthermore, he assumed that each part of the supply chain plans its production and places its orders upstream taking into account only the information about the demands of its direct customer.

One may argue that Forrester investigated this effect theoretically; however, several authors were able to prove that this effect also occurs in reality [6–9]. This shows that an unmanaged supply chain is not inherently stable.

Nowadays, the bullwhip effect is best known from the so-called beer game. The Beer Game is a simulation developed at MIT in the 1960s to clarify the advantages of taking an integrated approach to managing the supply chain. A detailed description of the beer game and a playable version can be accessed via the internet (http://beergame.mit.edu/). In the beer game, the human players take the role of a part of a linear supply chain, e.g., a retailer, a wholesaler, a distributor or a manufacturer. The objective of the game is to minimize the total costs of the supply chain by maintaining low stocks but nevertheless managing to deliver all orders. There exists only one product called Lovers's Beer which is manufactured in units of one crate of beer. Two different costs have to be taken into account: inventory costs and backlog costs. Orders can be placed each week and it takes another two weeks before the supplier receives the order and two weeks before the orders reach the next part of the supply chain. If a part of the supply chain is unable to deliver in time, the orders are backlogged and the units have to be delivered the next week. The game is started in week one and each player has to decide how many units he wants to order from his supplier. The first round is finished by checking how many orders are delivered in time and how many orders are backlogged. The next round is started by placing the orders for the next week.

Usually, the game is started assuming that the only information a player gets are the orders of the player he supplies with beer. This is referred to as placing orders on local information. In this setting, human actors provided with local information usually tend to overact by an amplification of orders placed. Together with the inherent dynamics of the system, a slight variation of the end user demand in the beginning of the game is sufficient to introduce a persistent oscillation of demands resulting in boosting stocks and number of orders and high costs for operating the supply chain.

In another setting, the human players are provided with global information about the system. This means that all players are informed about inventory levels and orders placed for each of the components of the supply chain. Furthermore, they are encouraged to work out co-operative strategies to deal with the dynamics of the system. Compared to the local information structure, this usually results in lower inventory levels and less out-of-stock-situations for all participants. Typically, the stocks and the number of orders in this setting are much lower, resulting in much lower costs for operating the supply chain and lower costs for each player as well.

The beer game demonstrates the value of sharing information across the various supply chain components. In practice, supply chains are usually more complex and much harder to manage. Current research has investigated that in practice the bullwhip effect is due to the following reasons:

- overreaction to backlogs;
- neglecting to order in an attempt to reduce inventory;
- no communication up and down the supply chain;
- no coordination up and down the supply chain;
- delay times for information and material flow;
- shortage gaming: customers order more than they need during a period of short supply, hoping that the partial shipments they receive will be sufficient;
- demand forecast inaccuracies: everybody in the chain adds a certain percentage to the demand estimates. The result is invisibility of true customer demand.

The identification of these reasons led to recommendations how to avoid the bullwhip effect. Some of these recommendations are:

- ordering decisions should be based on the demand of the ultimate customer instead of upstream forecast updates;
- eliminate gaming in shortage situations;
- stabilize prices in order to avoid large variations of demands;
- avoid order batching.

Many of these recommendations can be achieved using modern means of information technology. Standardized order procedures based on widely accepted information protocols will help to reduce the delay of information and current systems for advanced planning and scheduling (APS) provide means to support humans in decision making in complex networks. Building blocks of APS systems are:

- strategic planning
- forecasting
- global network planning
- distribution planning
- transportation planning
- production planning
- scheduling

Electronic data exchange is the enabler for these building blocks as manual data administration is error-prone, time-consuming and costly.

1.4 Design Criteria/Integration Concepts

Operating the supply chain has a major impact on its efficiency. Efficiency in this sense means that the operating expense in terms of time and money for a given design of the supply chain is as low as possible. However, the operating expenses are influenced by the design of the supply chain as well and the design varies according to the company's business and strategy. This is usually referred to as effectiveness. Effectiveness in this sense means that the design of the supply chain enables low operating expenses for a given business.

The design of the supply chain has different levels of interest. The driver of the supply chain design is the strategy the supply chain has agreed to follow. On this level, the partners agree on a strategy (e.g., prioritization of products and customers) and controlling issues (e.g., common performance indicators). These decisions are the drivers of the design of the other levels.

On the level of material flow, physical properties of the network are designed, i.e., decisions upon the existence of plant sites, warehouses and distribution centers, the transportation links between these components and their capacities are made. The decision upon the customer order decoupling point is a good example of how strategic decisions may influence the level of material flow.

The decoupling point is the boundary between the order-driven and the forecast-driven operations within a supply chain. Operations upstream of the decoupling point are forecast-driven, i.e., production for a certain time period is started before all customer orders are known. Operations downstream of the decoupling point are order-driven, i.e., production for a certain period of time starts after all customer orders are known. Furthermore, the decoupling point dictates the form in which inventory is held. Upstream, it is usually held as semi-finished goods while downstream it is held as finished goods. The semi-finished goods are generic in the sense that they allow for customization. Customization is related to the product (viscosity, color, water content, etc.) as well as to the choice of some other attributes such as packaging material, packaging size and pallet size. In order to gain flexibility, several authors recommend to design a supply chain such that it carries inventory in a generic form awaiting final processing or treatment so as to postpone product customization. Besides flexibility, postponement leads to lower inventories as it enables the production of materials according to customer orders and prevents building stocks resulting from inaccurate forecasts.

Many of the problems exhibited on the level of material flow are the result of the distortion of marketplace sales information as it is transferred upstream through the supply chain. Therefore, the design of the information flow is as important for the effectiveness and efficiency of supply chains as the design of the material flow. The information flow is obviously influenced by the level of material flow. However, the information flow is not necessarily dependent on the material flow.

Introducing new information links or improving existing ones may have no causes in material or process flow while having an impact on the efficiency of the supply chain, e.g., exchanging information regarding the sales planning between suppliers and distributors enhances planning quality enabling lower response times and lower storage costs.

The level of the information flow boils down to a purely technical level where the partners agree on common protocols for transferring data. For the chemical industry, an initiative to set uniform standards is CIDX. CIDX (http://www.cidx.org) is a trade association and standards body whose mission is to improve the ease, speed and cost of conducting business electronically between chemical companies and their trading partners. It provides the Chem eStandards, a collection of defined messages and related business process guidance that companies use to understand the requests and fulfill electronic business orders and related transactions.

At the process level, the flow of material and the flow of information are linked together by describing the transformation of information and material. Hence, it reflects the workflow of a supply chain.

1.5 SCOR: Modeling the Supply Chain

In this chapter, we want to switch from the components of a supply chain to its processes. For simplification, we focus on intra-company supply chains.

Companies have been creating processes and workflows for decades and these processes and workflows were subject to local optimization many times. As discussed above, these local optimizations usually do not lead to a global optimum. In the worst case, the objectives of local optimizations are inconsistent and contradictory. For example, operations usually aim at simplifying the product portfolio to achieve long production runs and low cleaning times while marketing in contrast assumes diversification as a means to gain some competitive advantage. Aiming at a global optimum means to weigh these different objectives according to the strategy of the company. This objective can be achieved best with a team made of expert members of all departments along the supply chain including marketing, sales, procurement and production which are able to draw the whole picture. The main problem of such a team are the different viewpoints and the different vocabularies which are used to describe the same processes. For such a team, a common language is urgently needed allowing for efficient communication and a common view of the supply chain. A widely accepted approach to provide such a common language is the SCOR-model.

1.5.1 The SCOR-Model

The Supply Chain Operations Reference-model [12] has been developed and endorsed by the Supply-Chain Council (SCC), an independent non-profit-making corporation, as the cross-industry standard for supply-chain management.

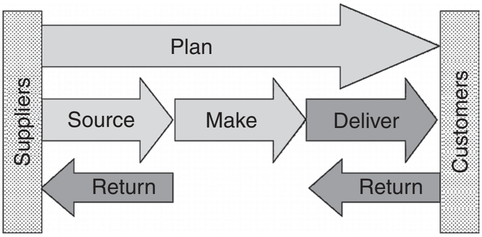

Fig. 1.1 The first level of the SCOR-model [12].

The SCOR-model is used to describe, measure and evaluate the configuration of a supply chain. It supports:

- Business Process Reengineering: capture the "as-is" state of a process and derive the desired "to-be" future status.
- Benchmarking: quantify the operational performance of similar companies and establish internal targets based on "best-in-class" results.
- Best Practice Analysis: characterize the management practices and software solutions that result in "best-in-class" performance.

The SCOR-model is a process reference model which is defined at different process levels. Besides the definition of the process, for each level indicators are proposed to allow to assess the performance of the process. In order to improve the process, best practices for the process elements are described which are based on the experience of the council members.

At the first level (Figure 1.1), the scope and the contents of the model are described using five types of management processes:

- Plan: processes that balance aggregate demand and supply to develop a course of action which best meets sourcing, production and delivery requirements.
- Source: processes that procure goods and services to meet planned or actual demand.
- Make: processes that transform product to a finished state to meet planned or actual demand.
- Deliver: processes that provide finished goods and services to meet planned or actual demand, typically including order management, transportation management, and distribution management.
- Return: processes associated with returning or receiving products returned for some reason.

At the second level (configuration level) (Figure 1.2), to each basic process a process type is assigned which is one of the following:

- Plan: a process that aligns expected resources to meet expected demand requirements.
- Execution: a process triggered by planned or actual demand that changes the state of material. The process types Source, Make and Deliver are detailed with regard

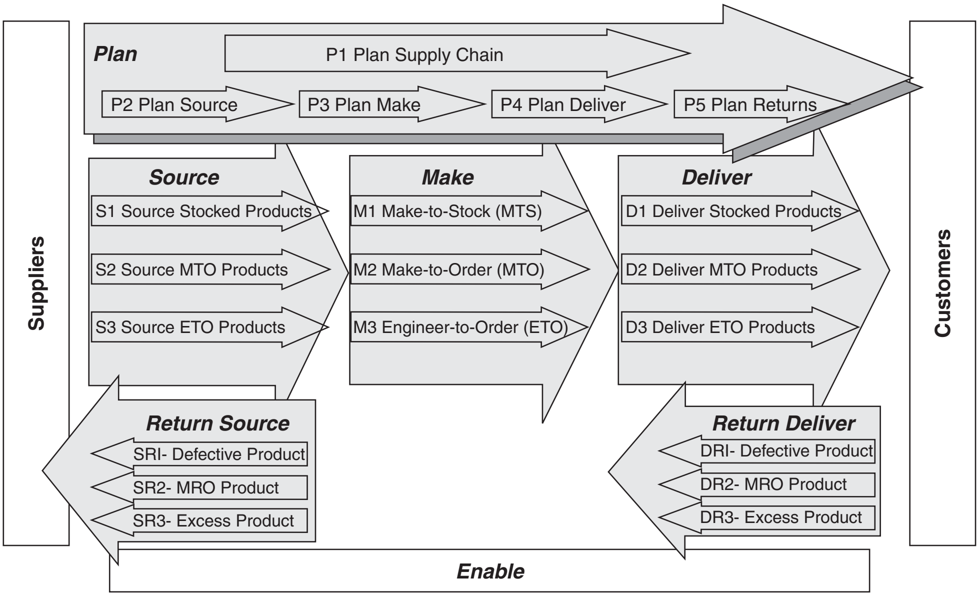

Fig. 1.2 The configuration level of the SCOR-model [12].

to the type of customer order. For the Make-process this may be make-to-order, make-to-stock or engineer-to-order.

- Enable: a process that prepares, maintains or manages information or relationships on which planning and execution processes rely. These process category comprises support processes of the Execute- and the Planning-processes which maintain information flow.

On level three, each process can be further detailed. In Figure 1.3, level 3 is depicted for the process configuration deliver-stocked-product.

Further levels can be added to take into account the supply chain management practice of the companies involved.

Beside the definitions, each level of the SCOR-model includes key performance indicators to measure performance and recommendations regarding best practice.

1.5.2
Quick Checks Using the SCOR-Model

Several projects applying the SCOR principles were already carried out within Evonik Degussa. Evonik Degussa, a wholly owned subsidary of Evonik Industries AG, is a multinational corporation consistently aligned to high-margin specialty chemistry. It is organized on a decentralized basis. Business operations are in the hand of twelve Business Units.

Up to now, several projects were accomplished which are termed Quick Checks but are better known within the company as SCOR-projects. The objective of a

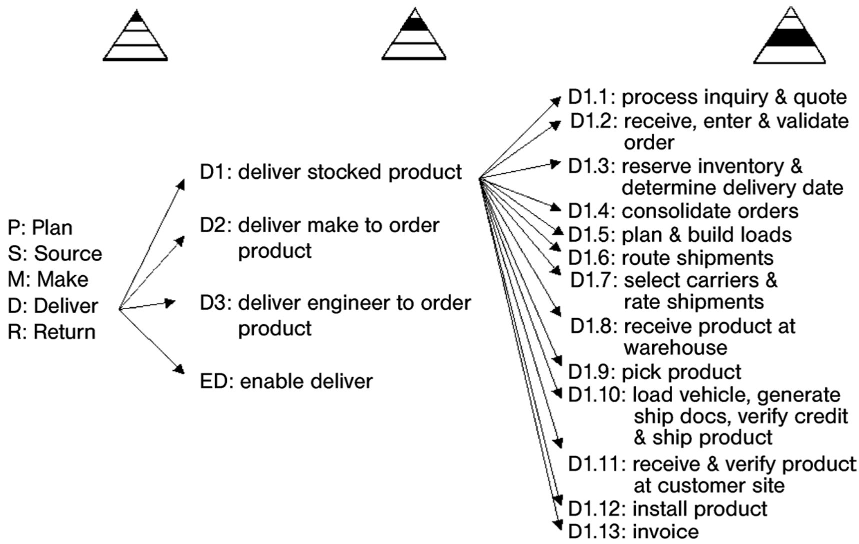

Fig. 1.3 Level 3 of the SCOR-model [12].

SCOR-project is to identify, evaluate and prioritize actions using shortcut methods. SCOR-projects are usually executed by teams made up of members of different departments including customer service, sales, controlling, operations, procurement and logistics. The teams are supported by internal consultants, who provide knowledge about the SCOR-model and preside over the team meetings.

1.5.2.1 **Describing the As-Is Status**

A SCOR-project comprises a sequence of workshops which last between one and three days. The sequence of workshops starts with teaching principles of supply chain management, the SCOR-terminology and key performance indicators in order to set up a common vocabulary and view. The next step is to describe the flow of materials running from the suppliers of raw materials to the main customers of the final products. In order to reduce complexity, products and customers are usually grouped according to substantial similarities. For customers, usually some geographic attribute is used. For products, similarity is decided on a case-to-case basis. In some cases, similarity is defined according to similar ways of production, e.g., a group of products are made by applying a make-to-stock-strategy and another by applying a make-to-order-strategy, in some other cases according to similar packaging, e.g., returnable and non-returnable containers. The depiction in a geographical map supports this process indicating suppliers, plant sites, distribution centers and final customers (Figure 1.4). Once the map is finished, it can be used to add some further details about the sourcing, making and distribution of the product groups, i.e., adding the process types of level 2 of the SCOR-model. In the geographical map, the process types are simply represented as letters and numbers, e.g., m1 for make-to-stock and m2 for make-to-order. From the geographical map,

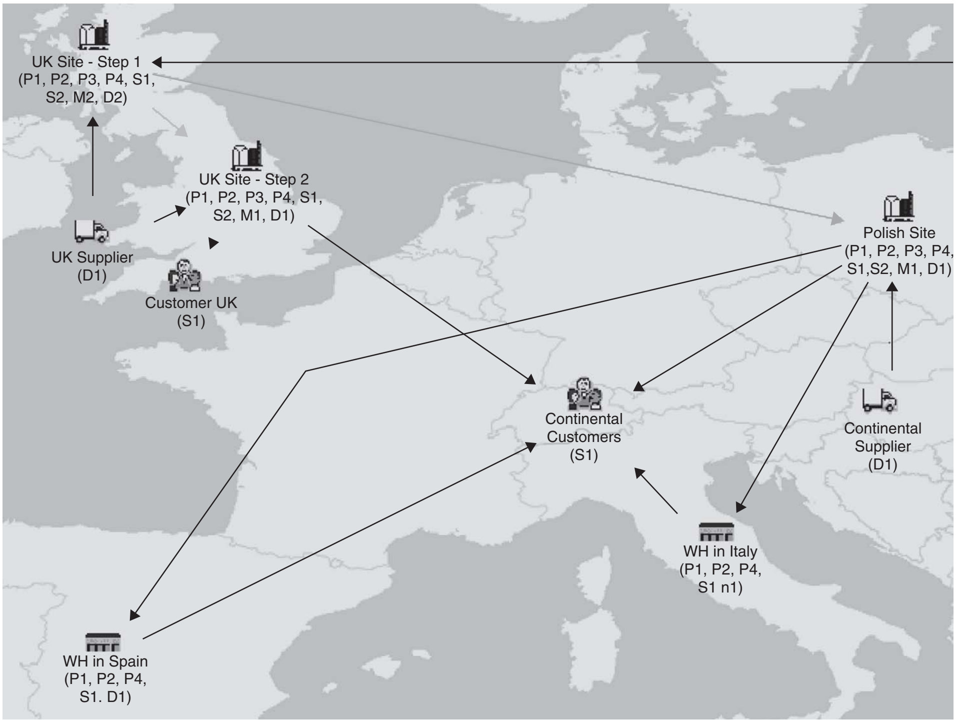

Fig. 1.4 Geographical map depicting suppliers, plant sites, distributors and customers.

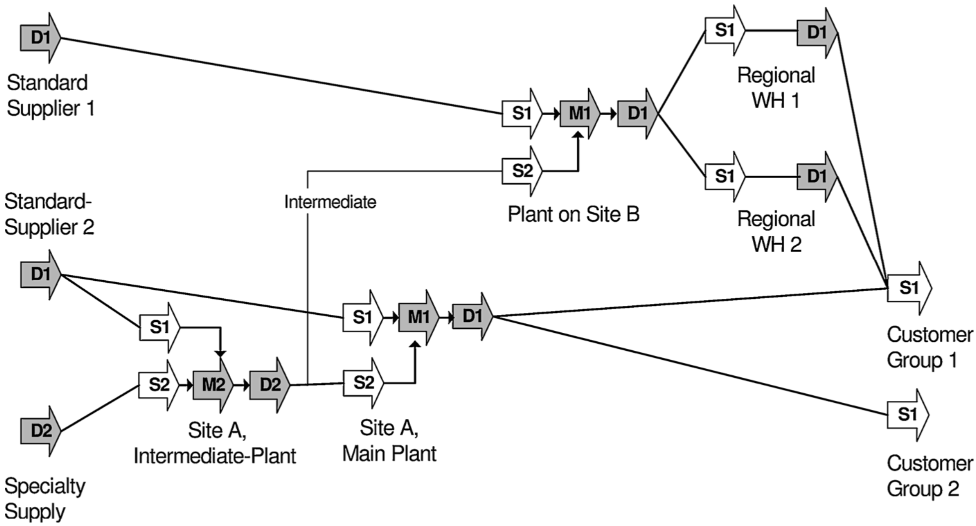

Fig. 1.5 Thread diagram with material flows and process types.

potential defects become apparent by reviewing the as-is-state of the supply chain and the corporate strategy, e.g., small trading units are filled at the plant site and delivered to the customers although a distributor is contracted to fulfill this task.

Accordingly, the process types are refined by using a so-called thread diagram which links the process types together. From the thread diagram it becomes apparent whether the process types fit together. For example, the only customer of a certain product places his orders such that it is possible to start production after he places the order while being sure to deliver in time. In this case, the thread diagram will show a process type for the deliver process which is deliver-make-to-order-product (Figure 1.5). On the other hand, operations produces this product as stock which will be depicted as the process make-to-stock. These process types do not fit as it is obviously not necessary to build up stock to satisfy the customer. The stock leads to additional net working capital and, thus, additional costs which either prevent additional profit or will lead to competitive disadvantages.

After the material flow, the information flow in the organization is described in a matrix where on the left side the functional units are represented. The process elements of level 3 are assigned to the functional units as depicted in Figure 1.6. From this figure it can be seen which departments are responsible for processes and where the responsibility is unclear.

The figures mentioned in this section are sufficient to describe the as-is state of the supply chain. Establishing and discussing these figures lead to first ideas of potential enhancements of the supply chain regarding the structure of the supply chain and the process flow.

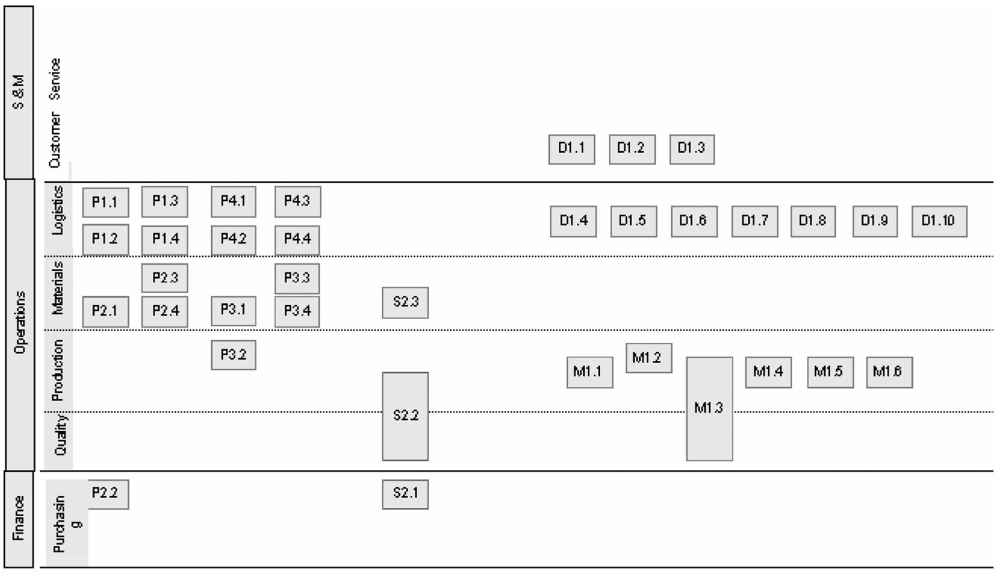

Fig. 1.6 Assignment of elements of level 3 to departments.