2 Production planning and steel industry

2.1 Supply chain management and production planning

2.1.1 The concept of supply chain management

Various definitions for the concept of a supply chain and the corresponding SCM exist. Common themes in all of these definitions are that a supply chain usually spans companies or organizational units of a single company (i.e., from the raw material supplier to the manufacturer to retailers) and the overarching aim of each supply chain is customer satisfaction (Chandra and Grabis 2007: 20, Govil and Proth 2002: 7, Christopher 2005: 5, Chopra and Meindl 2007: 3). Stadtler (2005, P.576) defined SCM as “the task of integrating organizational units along a supply chain and coordinating materials, information, and financial flows in order to fulfill customer demands with the aim of improving competitiveness of the supply chain as a whole. Most authors define the organizational units of an inter-company supply chain as the suppliers, manufacturers, warehouses, distributors, and retailers (Chandra and Grabis 2007: 18, Chopra and Meindl 2007: 3). However, in today’s large international companies, which face such issues as multi-site production planning, intra-company supply chains can bear the same amount of challenges (Günther 2005: 5). Other scholars (e.g., Werner 2010: 6) also include the disposal and recycling of the resulting waste after production in the supply chain. An example of an inter-company supply chain is illustrated in figure 2. Note that a supply chain is often actually considered a supply chain network (Christopher 2005: 5) due to the number of entities at each step that leads to diverging product and information flows.

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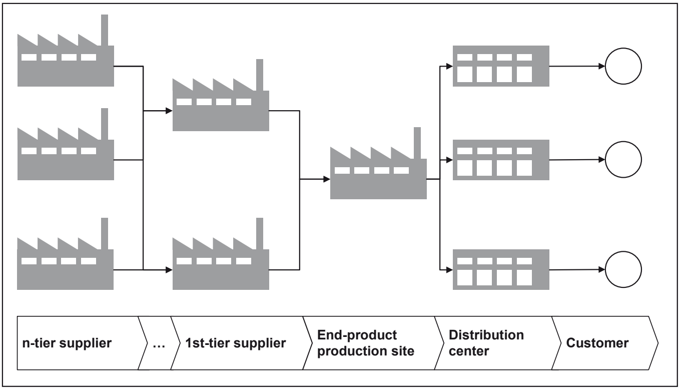

Figure 2: Inter-company supply chain

A company's supply chain can be a source of competitive advantage since individual businesses often do not compete against each other as standalone entities but rather as supply chains (Christopher 2005: 284). Additionally, a world where production and demand becomes increasingly globally fueled by factor cost differences, high growth in emerging markets, lower transaction costs, less trade barriers (Jacob and Strube 2008: 6), and increasing product variety and complexity, the task of SCM becomes increasingly important and complex. According to Chopra and Meindl (2007: 9), the decisions of SCM can be delineated into the three following categories:

1. *Supply chain strategy and design:* In this phase, a company decides on the structure and setup of a supply chain for a specific product or a product family for the next several years or the product lifecycle. Moreover, decisions on what is carried out in-house and what is outsourced are made. If the decisions are made to outsource, the locations and capacities of production facilities are chosen, and the warehouses and distribution network are setup. Additionally, decisions about the information and planning systems are also made. Aim of cooperation is defined in this phase in that each partner benefits at least on most terms; therefore, transaction prices play a crucial role (Stadtler 2005: 577). Although all supply chain partners hope to benefit from the relationship, one player, i.e., often the most powerful or biggest company, typically dominates. Looking to the automotive industry as an example, the automotive original

equipment manufacturer (OEM) usually dominates the whole supply chain of raw material suppliers, component suppliers, and sales agencies (Govil and Proth 2002: 8).

2. *Supply chain planning:* This phase has a much shorter timeframe, i.e., usually up to a year, and considers the configuration decisions that are carried out in the strategic phase as fixed. This phase aims at maximizing the supply chain's profit over the planning horizon via the implementation of effective planning decisions. In this phase, the demand is forecasted to make decisions on which markets are supplied from which locations, if work needs to be subcontracted, and which inventory policies are necessary. The demand scenario is also the basis for marketing and prize promotions. This illustrates that the planning phase establishes the parameters within which the supply chain will function. The result of this phase is a set of operating policies that govern short-term operations.
3. *Supply chain operation:* This phase has a very short timeframe of a week or a day, and during this phase, companies make decisions regarding single customer orders. The aim of this phase is to handle customer orders using the most effective means, i.e., by effective production planning, scheduling of production, and timely distribution to the customer.

This study focuses on creating effective scheduling models for steel production, and it clearly falls into the category of supply chain operation. Although the decisions made in this phase have a short time horizon, they are crucial to the success of the supply chain. Without a high level of operational excellence, a supply chain cannot be competitive.

2.1.2 Hierarchical structures in production planning

Considering the plurality of topics that can be subsumed under production planning activities (e.g., investment/divestments of plants, clustering of product families, allocation of products to plants, and detailed scheduling), we can readily see why companies usually deconstruct the overall production planning problem into different groups or organizational units. While companies can adopt many deconstruction approaches, the production planning is often categorized based on their time horizon and their importance to the company. In 1975, Hax and Meal introduced a production planning approach that split up the planning problem of a company into four hierarchical levels of decision making. Their *first* hierarchical level comprises the assignment of products to multiple plants and long term investment decisions to increase capacity. At the *second* hierarchical level, the capacity of each plant is allocated to product families, and the accumulation of seasonal stock is planned based on a monthly demand forecast. The *third* hierarchical level comprises the determination of monthly schedules for each product type considering stock levels. At the *fourth* and last level, the time allocation per product family is shared among the individual products of the family with a planning horizon of one month (Hax and Meal 1975: 59f).

Although Hax and Meal (1975) developed one of the first approaches, many other approaches for the deconstruction of the production planning problem have since been developed (Schneeweiß 1995, Kletti 2007, Günther and Tempelmeier 2012, Dyckhoff and Spengler 2010). The deconstruction into hierarchical levels is driven by the problem's high level of complexity when solved as a single optimization question. Such a problem size is usually not manageable for an optimization model or a single person. With no other alternative, the potential risk of a developing a less than optimal solution when the problem is tackled in successive steps is irrelevant. Additionally, companies already have hierarchical structures; therefore, such an approach often fits well into existing organizational and decision making structures and triggers management involvement (Hax and Meal 1975: 59, Schneeweiß 1995: 9).

Nowadays, the framework that is most commonly applied to the deconstruction of planning activities is the use of three hierarchical levels that range from strategic to operational planning (Günther and Tempelmeier 2012: 26, Dyckhoff and Spengler 2010: 30). In the context of production planning, these planning levels can be defined as follows:

- *Strategic* planning focuses on creating a competitive position for the company and preserving that position in a changing market environment. The planning horizon of strategic planning is about 5 years. Part of strategic planning includes the development of a global production footprint, including investment and divestment decisions.

- *Tactical* planning focuses on developing strategic initiatives for implementation. The time horizon for tactical planning activities is about one to five years. Typical questions considered include the allocation of products to plants or capacity adjustments within the existing production network.
- *Operational* planning focuses on the efficient operation of the existing production system. Planning activities have a planning horizon of up to one year. Typically, these activities include the detailed production scheduling, inventory control, and lot sizing.

Lin and Moodie (1989) and Missbauer et al. (2009) developed hierarchical planning approaches for steel mills to optimize operational production planning. In contrast, Nickel et al. (2005) developed a mathematical model to aid in strategic decision making regarding the supply network design of a leading international steel company. Publications that focus on operational planning activities are classified in section 3.2.1. Since this work develops an approach to optimize scheduling in the steel industry, it clearly focuses on the operational level of production planning

2.1.3 Advanced planning systems

Advanced Planning Systems (APS) aid companies with SCM and production planning from the strategic to operational levels. The main characteristics of an APS, which are also the main differences from classic material requirements planning (MRP) systems, are as follows (Stadtler and Kilger 2008: 83):

- *Integral planning* signifies that the APS encompasses the supply chain as a whole.
- *True optimization* is carried out by defining objectives and constraints properly and applying either exact optimization techniques or heuristics.
- *A hierarchical planning system* (i.e., as described in section 2.1.2) of the APS is necessary to achieve true optimization for the whole supply chain. Therefore, the APS defines a number of modules along the supply chain and with varying planning horizons that are interdependent; i.e., they are linked by information flows.

In contrast to the modern APS, traditional MRP systems do not have any of the above properties. They are in most cases restricted to the production and procurement area, are not focused on optimization, and are uncapacitated based on lead times and production lots that neglect the workload and plan successively from the level of the master production schedule to detailed scheduling (Stadtler and Kilger 2008: 84, Günther et al. 2006: 3720). Furthermore, unlike APSs, MRP systems usually neglect industry specific characteristics, such as shelf life or batching restrictions (Fleischmann 2012: 18, Knolmayer et al. 2009: 105). Figure 3 illustrates the planning modules that are usually found in an APS.

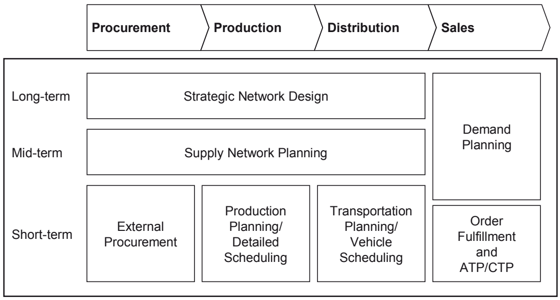

Figure 3: Software modules of Advanced Planning Systems (Günther et al. 2005: 10)

This work focuses on planning activities that relate to the module of production planning/detailed scheduling (PP/DS); therefore, this module is explained in more detail. The module's main objective is to determine feasible production plans; thus, it focuses on operative planning and is restricted to an individual plant in most cases. The module determines the lot sizes if they were not addressed in mid-term planning, followed by the determination of the exact sequences and timing (Knolmayer et al. 2009: 100, Stadtler and Sürie 2012: 149) using a finite and thus capacity restricted scheduling policy (Günther et al. 2006: 3721).

Günther et al. (2006) applied the block planning approach using the APS system from SAP, SAP APO©. Their investigation focused on a make-and-pack problem from the consumer goods industry. They showed that the PP/DS module of SAP APO© is well-suited to support the block planning approach, but their additionally presented MILP optimization was computationally even more efficient (Günther et al. 2006).

Additionally, there are reports about successful implementations of APSs in the steel industry. The company Deutsche Edelstahlwerke, a mid-size producer of stainless steel with a yearly production of about 700,000 tons in 2010 (DEW 2012), implemented the factory planner and supply chain planner by JDA (i.e., formerly known as i2 technologies) and observed benefits regarding a reduction in the order processing time by 80%, reduction in work-in-progress inventories and raw materials by 20%, improvement of on-time deliveries from 60% to 85%, and improvement in the lead time by 20% (JDA 2012).

2.2 Production planning and detailed scheduling

2.2.1 Production planning and scheduling process

Within the scope of operational planning, production planning and scheduling is concerned with the planning and control of production processes related to the timely production of products in the appropriate quantities within capacity restrictions (Schuh 2006: 28, Günther and Tempelmeier 2012: 147). To illustrate the tasks of production planning, the RWTH Aachen used extensive experience with consulting projects to develop a production planning and scheduling framework intended to illustrate relevant interdependencies (Schuh 2006: 11). Figure 4 illustrates this framework, which divides production planning and scheduling into core and cross-sectional tasks.

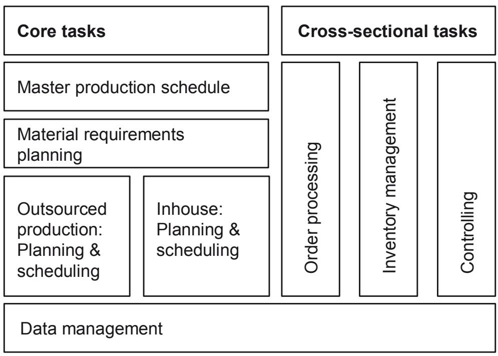

Figure 4: Production planning and scheduling tasks (Based on Schuh (2006: 29) and Lödding (2008: 5)

According to this framework, the core tasks include the master production schedule, the material requirements planning, and the planning and scheduling of outsourced and in-house production. *Master production schedule* determines which products in what quantity need to be produced during the upcoming planning periods. *Material requirements planning* calculates the material and resources required for production, including the secondary requirements of components and parts, based on the output of the master production schedule and current inventories. It plans the production orders and determines the capacity need. The next step, production planning and scheduling, is divided into outsourced and in-house production. The planning and scheduling tasks for outsourced production usually consist of determining the order quantities and supplier selection. Planning and scheduling for in-house production usually involves the determination of lot sizes and production sequences with detailed start and end times depending on the production characteristics (Lödding 2008: 6, Schuh 2006: 37f, Slack et al. 2010: 422f).

The cross-sectional tasks include order processing, inventory management, and controlling of planning and scheduling. *Order processing* coordinates and monitors the customer orders across different business units, e.g., production, distribution, and accounts payable, until they are sent to the customers. *Inventory management* tracks products and components in stock and ensures that stock levels are in line with company requirements, e.g., seasonal demand. *Controlling* monitors the target achievement with a set of key performance indicators. Core and cross-sectional activities depend on effective and efficient *data management,* which includes planning systems (Lödding 2008: 6, Schuh 2006: 58ff).

The objectives of production planning and scheduling may vary along the triangle of quality, time, and costs, but some criteria are common to many production entities, including the following (Dickersbach 2006: 238, Schuh 2006: 28):

- meeting demands within production deadlines,
- high and balanced resource utilization,
- short lead times with low setup efforts,
- low stock and work in progress levels, and

- high flexibility.

Obviously, the values of performance indicators and objectives may vary depending on the characteristics of the production system in question. A short lead time for one production system, e.g., the production of silicon wafers with a lead time of 35 days, may be extensively long as compared to another, e.g., the production of cars within 3 to 5 days. Therefore, the characteristics of a production system obviously need to be clearly considered in order to be able to understand the associated production planning and scheduling challenges.

2.2.2 Relevant planning characteristics

In order to meet the production planning objectives discussed in the previous section, numerous characteristics of the production planning problem must be considered. Hence, no one production planning solution works for all kinds of production environments. The criteria that must be considered can be grouped into product specific characteristics, production specific characteristics, and demand specific characteristics (Günther and Tempelmeier 2012: 10f, Lödding 2008: 98ff, Dickersbach 2006: 239).

Product specific characteristics focus on the specification of the product, i.e., whether it consists of multiple parts or just one, if it is mobile or not, and the shape of the product (e.g., fluids or parts). These characteristics significantly influence the structure of the production system and also the applicability of chosen production planning methods.

Production specific characteristics are concerned with the type of production system used in the manufacture of the product. The following aspects determine the chosen production system and influence the planning methods:

- The number of variants that are produced in the same production run. This impacts production planning, particularly if the setup times are long and/or sequence dependent.

- The production quantity of each variant. Generally, as the production quantity increase and the number of variants decrease, the production system in place is increasingly more automated, e.g., the mass production of razor blades versus the production of prototypes in a job shop environment.

- The complexity of the materials or parts flow for the product system. On a mass or serial production line, the production steps are usually connected to allow for continuous production flow, whereas in a job shop environment, various production facilities are grouped into workshops (e.g. stamping and painting), and the product needs to be transported from one workshop to the next; therefore, each product may have a different flow rate. The materials for the parts flow significantly influence the inventory levels and lead times of a production process. Transport modes may range from one-piece flow in an automated serial production process to lot by lot transport in a job shop environment.

- Time constraints between production steps (e.g., necessary waiting times from one step to the next) where production is not allowed to stop in between the steps.

Demand specific characteristics describe how the production system relates to the customer. With the help of the customer order decoupling point, different types of customer relationships are classified. The customer order decoupling point splits the upstream processes, which are forecast-driven, from the downstream processes, which react to the customer orders (Stadtler and Fleischmann 2012: 31) as illustrated in figure 5. If the customer orders goods from stock, the production system is called “make-to-stock” because the production is completely forecast-based and customer orders are fulfilled from stock. If products are assembled to order, parts are pre-produced based on demand forecasts and assembled based on customer orders. If a product is made to order, production starts after the customer order arrives, and if a product is engineered to order, the product is designed based on a customer order, e.g., ship building.

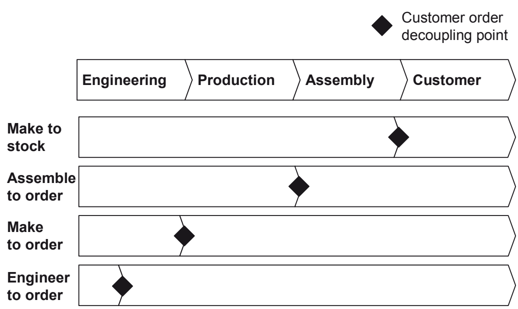

Figure 5: Customer order decoupling points

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