Advanced Planning

4

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4.1 What is Planning?

Why planning? Along a supply chain hundreds and thousands of individual decisions have to be made and coordinated every minute. These decisions are of different importance. They comprise the rather simple question *"Which job has to be scheduled next on a respective machine?"* as well as the very serious task whether to open or close a factory. The more important a decision is, the better it has to be prepared.

This preparation is the job of *planning*. Planning supports decision-making by identifying alternatives of future activities and selecting some good ones or even the best one. Planning can be subdivided into the phases (see Domschke and Scholl 2008, p. 26)

- *Recognition* and *analysis* of a decision problem
- Definition of *objectives*
- *Forecasting* of future developments
- *Identification* and *evaluation* of feasible activities (*solutions*), and finally
- *Selection* of good solutions.

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Supply chains are very complex. Not every detail that has to be dealt with in reality can and should be respected in a plan and during the planning process. Therefore, it is always necessary to abstract from reality and to use a simplified copy of reality, a so-called *model*, as a basis for establishing a plan. The "art of model building" is to represent reality as simple as possible but as detailed as necessary, i.e. without ignoring any serious real world constraints.

Forecasting and *simulation models* try to predict future developments and to explain relationships between input and output of complex systems. However, they do not support the selection of one or a few solutions that are good in terms of predefined criteria from a large set of feasible activities. This is the purpose of *optimization models* which differ from the former ones by an additional *objective function* that is to be minimized or maximized.

Plans are not made for eternity. The validity of a plan is restricted to a predefined *planning horizon*. When reaching the planning horizon, at the latest, a new plan has to be made that reflects the current status of the supply chain. According to the length of the planning horizon and the importance of the decisions to be made, planning tasks are usually classified into three different planning levels (see Anthony 1965):

Long-term planning: Decisions of this level are called *strategic decisions* and should create the prerequisites for the development of an enterprise/supply chain in the future. They typically concern the design and structure of a supply chain and have long-term effects, noticeable over several years.

Mid-term planning: Within the scope of the strategic decisions, mid-term planning determines an outline of the regular operations, in particular rough quantities and times for the flows and resources in the given supply chain. The planning horizon ranges from 6 to 24 months, enabling the consideration of seasonal developments, e.g. of demand.

Short-term planning: The lowest planning level has to specify all activities as detailed instructions for immediate execution and control. Therefore, short-term planning models require the highest degree of detail and accuracy. The planning horizon is between a few days and 3 months. Short-term planning is restricted by the decisions on structure and quantitative scope from the upper levels. Nevertheless, it is an important factor for the actual performance of the supply chain, e.g. concerning lead-times, delays, customer service and other strategic issues.

The last two planning levels are called *operational*. Some authors call the second level *tactical* (e.g. Silver et al. 1998, Chap. 13.2), but as this notion has several contradictory meanings in the literature, it is not used in this book.

A naive way of planning is to look at the alternatives, to compare them with respect to the given criteria, and to select the best one. Unfortunately, this simple procedure encounters, in most cases, three major difficulties:

First, there are often several criteria which imply conflicting objectives and ambiguous preferences between alternatives. For example, customer service ought to be as high as possible while—at the same time—inventories are to be minimized.

In this case no "optimal" solution (accomplishing both objectives to the highest possible degree) exists. A common way to deal with this *multi-objective decision problem* is to set a minimum or maximum satisfaction level for each objective except for one that will be optimized. In the above example one may try to minimize inventories while guaranteeing a minimum customer service level. Another useful way to handle multiple objectives consists in pricing all objectives monetarily by revenues or costs and maximizing the resulting *marginal profit*. However, not every objective can be expressed in monetary values, e.g. the customer service. A more general way is to define scale values or scores for every objective and to aggregate them into a weighted sum. A danger of this procedure is that it yields pretended "optimal" solutions which strongly depend on the arbitrary weights. An APS supports each of these procedures in principle. The case studies in Part IV give examples of some relevant modeling features of such systems.

The second difficulty is caused by the huge number of alternatives that are predominant in supply chain planning. In case of continuous decision variables, e.g. order sizes or starting times of a job, the set of alternatives is actually infinite. But also for discrete decisions, e.g. the sequence of several jobs on a machine, the number of alternatives may be combinatorially large (see Chap. 10). In these cases it is impossible to find an optimal solution by enumeration of all alternatives, and even a feasible solution may be difficult to find. In this situation, mathematical methods of *operations research (OR)* should support the planning process. Some methods are able to determine an exact optimal solution, e.g. Linear Programming (LP) or network flow algorithms, but for most combinatorial problems only near-optimal solutions can be computed by *heuristics*, e.g. local search. The success of these methods also depends on the way a problem is modeled. As examples, for some important types of optimization models the capabilities of OR methods are shown in the Supplement (Part VI).

The third and probably hardest difficulty is dealing with uncertainty. Planning anticipates future activities and is based on data about future developments. The data may be estimated by forecast models, but there will be a more or less important forecast error. This error reduces the availability of products and therefore reduces the customer service a company offers. For improvement of the service safety stocks can be utilized which buffer against demands exceeding the forecast. However, that is not the only way to tackle uncertainty.

Nearly always, reality will deviate from the plan. The deviation has to be controlled and the plan has to be revised if the discrepancy is too large. Planning on a *rolling horizon basis* is an implementation of this plan-control-revision interaction. The planning horizon (e.g. 1 year) is divided into periods (e.g. months). At the beginning of January a plan is made that covers January to December. But only the first period, the so-called *frozen period*, is actually put into practice. At the beginning of the second period (February) a new plan is made considering the actual developments during the first period and updated forecasts for the future periods. The new planning horizon overlaps with the previous one, but reaches one period further (until the end of January of the next year; see Fig. 4.1) and so on.

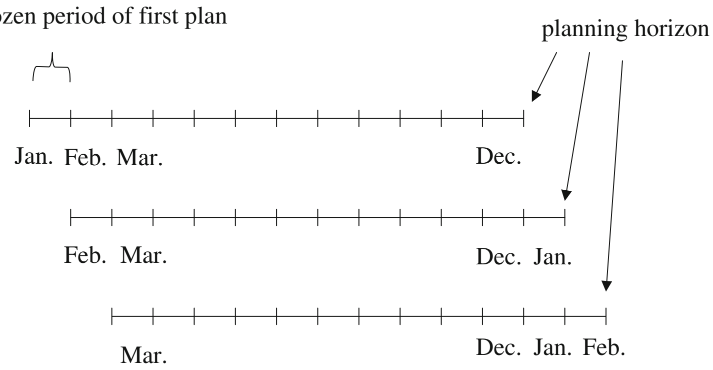

Fig. 4.1 Planning on a rolling horizon basis

This procedure is a common way of coping with uncertainty in operational planning both in classical planning systems and in APS. A more efficient way of updating the plans is *event-driven planning*: A new plan is not drawn up in regular intervals but in case of an important event, e.g. unexpected sales, major changes in customer orders, breakdown of a machine etc. This procedure requires that all data which are necessary for planning, e.g. stocks, progress of work etc., are updated continuously so that they are available at any arbitrary event time. This is the case for an APS which is based on data from an Enterprise Resource Planning (ERP) system.

There are three main characteristics of APS:

- *Integral planning* of the entire supply chain, at least from the suppliers up to the customers of a single enterprise, or even of a more comprehensive network of enterprises
- *True optimization* by properly defining alternatives, objectives, and constraints for the various planning problems and by using optimizing planning methods, either exact ones or heuristics (see Fleischmann and Meyr 2003, Chap. 9.4)
- *A hierarchical planning system* (see Schneeweiss 2003 and Chap. 1).

A hierarchical planning system is the only framework permitting the combination of the two preceding properties: Optimal planning of an entire supply chain is neither possible in form of a monolithic system that performs all planning tasks *simultaneously*—this would be completely impracticable—nor by performing the various planning tasks successively—this would miss optimality. Hierarchical planning is a compromise between practicability and the consideration of the interdependencies between the planning tasks.

Note that the traditional material requirements planning (MRP) concept (see Orlicky 1975) which is implemented in nearly all ERP systems does not have any of the above properties: It is restricted to the production and procurement area, does not optimize and in most cases even not consider an objective function, and it is a successive planning system.

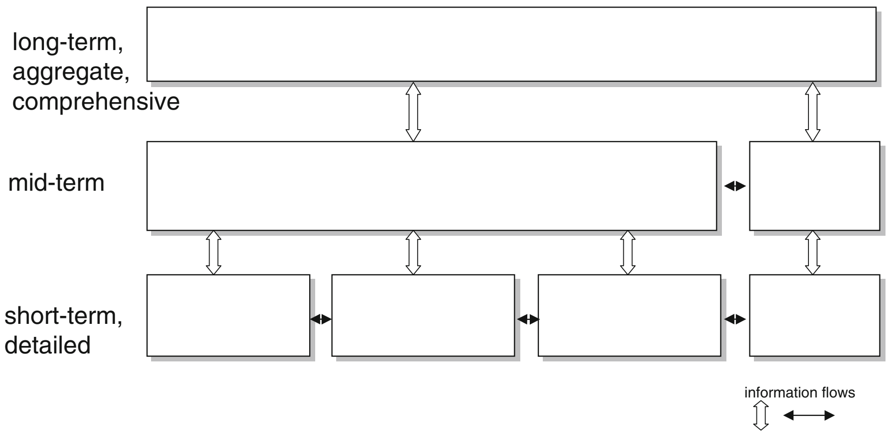

Fig. 4.2 Hierarchy of planning tasks

The main idea of hierarchical planning is to decompose the total planning task into *planning modules*, i.e. partial plans, assigned to different levels where every level covers the complete supply chain but the tasks differ from level to level (see e.g. Miller 2001): On the upmost level, there is only one module, the development of an enterprise-wide, long-term but very rough plan. The lower the levels are, the more restricted are the supply chain sections covered by one plan, the shorter is the horizon and the more detailed is the plan. Plans for different supply chain sections on one level are coordinated by a more comprehensive plan on the next upper level in a hierarchical structure (see Fig. 4.2).

The increasing (resp. decreasing) degree of detail is achieved by disaggregating (resp. aggregating) data and results when going down (resp. up) in the hierarchy. *Aggregation* concerns

- Products, aggregated into groups
- Resources, aggregated into capacity groups
- Time: periods, aggregated into longer ones.

The modules are linked by vertical and horizontal information flows. In particular, the result of a higher planning module sets restrictions for the subordinate plans, and the results of the latter yield feedback information on performance (e.g. costs, lead-times, utilization) to the higher level. The design of a *hierarchical planning system* (HPS) requires a careful definition of the modular structure, the assignment of planning tasks to the modules, and the specification of the information flows between them. Usually, an HPS works with a rolling horizon, where sophisticated coordination of the planning intervals and horizons on the different levels has been suggested in literature (e.g. Hax and Meal 1975; Stadtler 1986).

Planning takes into account future developments, identifies alternatives for future activities and provides directives for their implementation. However, the decisions themselves usually are put into practice outside of the planning system. Because of this separation and because of the above mentioned planning intervals, a time gap between planning and the final implementation has to be bridged which leaves room for unforeseen events. For this reason and in order to keep planning systems manageable, usually not all decisions are prepared in the planning system itself, but there is still some degree of freedom left open (to more precisely specify or revise a plan) until the final *execution* takes place. For the remainder of the book "execution" is defined as the starting and subsequent controlling of activities that have to be carried out immediately. Thus, in contrast to instructions prepared by a planning system, decisions for execution cannot be revised.

An *"execution system"* receives the decisions of a higher–ranked planning system, checks whether the assumptions underlying the plan are still valid, puts in further details when necessary (like assigning transport activities to production orders) and—in case no unexpected events have occurred—brings the overall decisions to final execution. However, if unforeseen events like machine breakdowns etc. have happened, it is up to the execution system to recognize this status and to react immediately. Minor problems may be solved by the execution system directly. If serious problems occur, an "alert" has to be sent back to the planning system, thus initiating an extraordinary re-planning. This event-driven planning simplifies the use of an HPS and makes it more flexible. A prerequisite is a communication system that guides alerts (see Chap. 13) on "events" to the relevant planning levels and tasks. Moreover, the result of one planning task can also generate alerts for other plans.

APS try to "computerize" planning. This might incur some problems for many human planners because they are afraid of being substituted by machines. This fear is based upon three major advantages of APS: they visualize information, reduce planning time, and allow an easy application of optimization methods. However, modeling is always a relaxation of reality. Therefore, human knowledge, experience, and skill is yet required to bridge the gap between model and reality. Planning systems, no matter how *advanced* they might be, remain decision support systems, i.e. they support human decision-makers. Also, in event-driven planning it is usually the human planner (at the interface between the execution and planning system) who decides whether a plan is to be revised. Finally, each planning module requires a human "owner" who is responsible for its function, data, and results.

4.2 Planning Tasks Along the Supply Chain

The whole Supply Chain Network can be split into internal supply chains for every partner in the network, each consisting of four main supply chain processes with substantially different planning tasks. *Procurement* includes all subprocesses which provide resources (e.g. materials, personnel etc.) necessary for production. The limited capacity of resources is the input to the *production* process which may consist of various subprocesses. The *distribution* bridges the distance between the production site and the customers, either retailers or other enterprises processing the products further. All of the above logistical processes are driven by demand forecasts and/or order figures determined by the *sales* process.

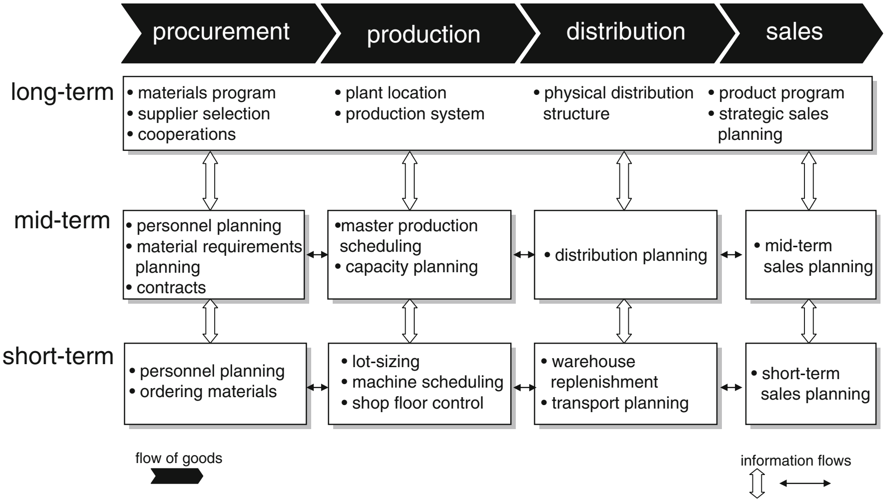

Fig. 4.3 The Supply Chain Planning Matrix

4.2.1 Supply Chain Planning Matrix

The *Supply Chain Planning Matrix* (SCP-Matrix, see Rohde et al. 2000) classifies the planning tasks in the two dimensions "planning horizon" and "supply chain process". Figure 4.3 shows typical tasks which occur in most supply chain types, but with various contents in the particular businesses. In Fig. 4.3 the long-term tasks are shown in a single box to illustrate the comprehensive character of strategic planning. The other boxes represent the matrix entries, but do not correspond exactly to the planning modules of an HPS. The latter may contain only parts of a box—e.g. on the short-term level the planning tasks can be decomposed according to further dimensions like factory sites or product groups—or combine tasks of several boxes. This is a question of the design of the HPS as mentioned in Sect. 4.1. The SCP-Matrix can also be used to position the *software modules* of most APS vendors (see Chap. 5). The construction of an HPS from the software modules of an APS is discussed in Part IV.

4.2.2 Long-Term Planning Tasks

Product Program and Strategic Sales Planning. The decision about the product program a firm wants to offer should be based on a long-range forecast which shows the possible sales of the whole product range. Such a forecast includes dependencies between existing product lines and future product developments and also the potential of new sales regions. It is often necessary to create different scenarios depending on the product program decision. Long-range forecasts consider information on product-life-cycles and economical, political, and competitive factors. As it is not possible to estimate long-range sales figures for each item, the products need to be aggregated into groups of items sharing common sales and production characteristics. Marginal profits of potential sales and fixed costs for assets have to be considered in the objective function of the product program optimization problem.

When a manufacturing member of a supply chain thinks about introducing a new product (group), it has to determine the location of the decoupling points with respect to the specific customers or markets considered. The location of the decoupling point is predefined by the (strategic) decision on the order lead-times (time between order entry and planned delivery) that probably will be accepted by the customers and therefore should be assigned to a respective product/market combination (see Hoekstra and Romme 1992, Chap. 1.5). The shorter the order lead-time is, the better customers will be satisfied, but—on the other hand—the more downstream the decoupling point has to be settled. As we have seen in the previous chapter (p. 68), this entails some increased demand uncertainty for higher-value products.

Physical Distribution Structure. As more and more companies concentrate their production capacities because of high investments in machining, the distance between the production facility and customers and the respective distribution costs increase. Such trends and a changing environment require a reorganization of the distribution system. The physical structure comprises the number and sizes of warehouses and cross docking points including the necessary transportation links.

Typical inputs for the decision are the product program and the sales forecast, the planned production capacity in each plant, and the underlying cost structure. The objective is to minimize the long-term costs for transportation, inventory, handling, and investments in assets (e.g. warehouses, handling facilities etc.). The question, whether the transports are performed by one's own fleet of vehicles or a third-party carrier, is very closely related to the decision on the physical distribution system. For this reason, the two decision types should be integrated into one model.

Plant Location and Production System. Long-term changes in product programs or sales figures require to review the existing production capacities and locations. Furthermore, the continuous improvement of production technologies leads to new prerequisites. Therefore, the production and decision systems need to be verified. Usually, decisions on plant locations and the distribution structure are made together. They are based on long-term forecasts and production capacities available (without consideration of single machines). Planning the production system means organizing a single production plant, i.e. designing the layout of the plant and the resulting material flows between the machines.

Materials Program and Supplier Selection. The materials program is often directly connected to the product program because the final products consist of some predefined components and raw materials. Sometimes different materials could be used alternatively for the same purpose. In order to select one of them for the materials program, one should consider price (including possible quantity discounts), quality, and availability.

As A-class materials (see e.g. Silver et al. 1998 for an introduction to the ABC-analysis) cause the biggest part of procurement costs, it is reasonable to source those parts through special supply channels. Therefore, the suppliers should be rated according to quality, service, and procurement costs.

Cooperations. Further reduction of procurement costs is often achieved by strategic cooperations with suppliers of A-class items. Planning and evaluation of collaboration concepts gain importance because no longer companies but whole supply chains compete against each other. These concepts include simultaneous reduction of inventories and backorders using ideas like *VMI (vendor managed inventory)*, *EDLP (every-day-low-price strategies)*, and *JIT (just-in-time)* supply. While the above cooperation concepts concern day-to-day operations, *simultaneous engineering* and *consolidation centers* set strategic frames for the daily procurement processes.

4.2.3 Mid-Term Planning Tasks

Mid-Term Sales Planning. The main task in mid-term sales planning is forecasting the potential sales for product groups in specific regions. As the forecasts are input to master production scheduling, the products are grouped according to their production characteristics (e.g. preferred resources, changeover times etc.). The forecast is usually calculated on a weekly or monthly basis for 1 year or less. It includes the effects of mid-term marketing events and promotions on sales. For example, if a temporary price discount is offered, demand will usually peak during the discount period, but reach a low immediately afterward. The necessary safety stocks for finished products are mainly determined by the quality of the forecast. Therefore, it is reasonable to set them on the basis of the forecast error which has to be calculated in the forecasting procedure.

Distribution Planning. Mid-term distribution planning comprises the planning of transports between the warehouses and determination of the necessary stock levels. A feasible plan fulfills the estimated demand (forecasts) and considers the available transportation and storage capacities while minimizing the relevant costs. Inventory holding and transportation costs are elements of the objective function. The planning horizon consists of weekly or monthly buckets. Therefore, the underlying model only considers aggregated capacities (e.g. available truck capacity and not single trucks). The distribution plan could also state the usage of the own fleet and the necessary capacity which must be bought from a third-party carrier.

Master Production Scheduling and Capacity Planning. The result of this planning task shows how to use the available production capacity of one or more facilities in a cost efficient manner. Master production scheduling (MPS) has to deal with seasonal fluctuations of demand and to calculate a frame for necessary amounts of overtime. As the plan is based on families of products and weekly or monthly time buckets, it does not consider single production processes. The objective is to balance the cost of capacity against the cost of (seasonal) inventories. If more than one production facility is considered, the transportation costs between the locations have to be included in the objective function.

Personnel Planning. Capacity planning provides a rough cut overview of the necessary working time for finished products. Personnel planning has to calculate the personnel capacity for components and other production stages which have to be passed before the final assembly of the products. This planning step considers the specific know how of personnel groups and their availability according to labor contracts. If not enough employees are available to fulfill the work load, personnel planning shows the necessary amount of additional part time employees.

Material Requirements Planning. As MPS plans only finished products and critical materials (concentration on bottlenecks), material requirements planning (MRP) has to calculate the production and order quantities for all remaining items. This could be done by the traditional MRP-concept (see Orlicky 1975) which is available in most ERP-systems or by stochastic inventory control systems. Whereas the MRP-concept is suitable for rather important (but non-bottleneck) materials and A-class components, stochastic inventory systems are adequate for C-class items. The calculation of material requirements should support lot-sizing decisions for every item in the bill of materials (BOM) and consider the dependencies between the lots on different levels of the BOM. Mid-term planning sets frames for weekly or monthly order quantities and safety stock levels which ensure the desired service level for production.

Contracts. On basis of the weekly or monthly requirements obtained from MRP, basic agreements with A-class suppliers can be made. Such contracts set the price, the total amount, and other conditions for the materials to be delivered during the next planning horizon.

4.2.4 Short-Term Planning Tasks

Short-Term Sales Planning. In make-to-stock environments the short-term sales planning comprises the fulfillment of customer orders from stocks. Therefore, the stock on hand can be partitioned in committed stocks and the *available-to-promise* (ATP) quantity. If a customer requests a product, the sales person checks on-line whether the quantity could be fulfilled from ATP and turns the requested amount in committed stock. For customer inquiries on the availability of products in future periods the ATP quantity is calculated by adding stock on hand and planned production quantities. The *capable-to-promise* (CTP) functionality is an extension of the traditional ATP task which has the additional option of creating new production orders.

Warehouse Replenishment, Transport Planning. While the mid-term distribution planning suggests weekly or monthly transportation quantities for product families, the short-term warehouse replenishment particularizes this plan in daily quantities for single products. This time-phased deployment schedule considers detailed transportation capacities (e.g. available trucks) and actual customer orders or short-term forecasts. Planned or actual production quantities set the frame for the transportation plan and also restrict the possible degree of customer service. Every day the planned truck loads have to be deployed to customer locations according to a cost-minimizing routing.

Transports occur not only in the distribution process, but also as part of the procurement and may be controlled by either the supplier or the receiver. In the latter case, transport planning is necessary on the procurement side as well, and the transport processes have to be considered also in the mid-term and long-term levels of procurement planning.

Lot-Sizing and Machine Scheduling, Shop Floor Control. Short-term production planning comprises the determination of lot-sizes and the sequences of the lots on the machines. Lot-sizing has to balance the costs of changeovers and stock holding with respect to dependencies between different products. These lots are scheduled according to their due dates and the available capacity with minutely accuracy. Both tasks can independently be executed if the changeovers are not dependent on the sequence of the products. As interruptions or delays are common in complex production environments, the shop floor has to be controlled actively and orders have to be rescheduled appropriately.

Short-Term Personnel Planning, Ordering Materials. The short-term production schedule determines the appropriate personnel of the shop floor with respect to the knowledge and capability. Short-term personnel planning determines the detailed schedule of the staff with consideration of employment agreements and labor costs. As some amount of material might already have been committed by mid-term contracting, the short-term task of filling the commitments in a cost efficient manner still remains.

4.2.5 Coordination and Integration

As already mentioned the planning modules in an HPS need to be connected by information flows. Typical contents of these flows are discussed in the following.

Horizontal Information Flows. The main horizontal flows go upstream, consisting of customer orders, sales forecasts, internal orders for warehouse replenishment and for production in the various departments, as well as of purchasing orders to the suppliers. This way, the whole supply chain is driven by the customers. However, the exchange of additional information in both directions and not only between neighbored modules, can improve the supply chain performance significantly (see bullwhip effect, Chap. 1). This concerns in particular actual stocks, available capacity lead-times, and point-of-sales data.

Basically since Ling and Goddard (1988), the term *Sales & Operations Planning* (S&OP) stands for a quite intensive, mainly horizontal, possibly bi-directional information exchange between sales-oriented (like marketing, promotions' planning, pricing, forecasting) and operations-oriented (like procurement, production, distribution) functional departments of a company on a mid-term, aggregate level, which is, e.g., executed at predefined dates in monthly planning rounds.

A good example for its usefulness are promotional activities in form of temporary price discounts: "Sales" determines a potential price discount and estimates its dynamic effects on demand. Sales price and its corresponding forecasts of demand are given to "Operations" which simulates their effects on the goods flow in the supply chain and on financial KPIs like the profit. Because of the supply chain's complexity (multiple stages, limited capacities etc.) this may be a very challenging task. If the results are not satisfying, sales will rethink the discount and the whole process might be repeated, for example, with a lower discount in mind. Since different organizational units—even though belonging to the same company, often following individual, misaligned incentives—are involved, a consensus may be hard to find. Thus, a planning round usually ends in a joint meeting where the different parties negotiate a final plan they can agree with. The above example shows that S&OP is generally also concerned with financial planning and might be linked to or constrained by business planning and budgeting. As Miller (2001, Chap. 6.5) points out, S&OP is very much in line with hierarchical planning. For instance, the above mentioned capacity check requires sufficient interaction with the short-term, detailed production planning and scheduling departments at the various production sites and thus also necessitates some vertical information flows.

Vertical Information Flows. Downwards flows coordinate subordinate plans by means of the results of a higher level plan. Typical information are aggregate quantities, allocated to production sites, departments, or processes. The timing of quantities is better expressed in form of projected final stocks at the end of the lower level planning horizon because this includes the information about the longer planning horizon on the upper level and provides more flexibility on the lower level. Coordination is also achieved by allocation of capacities and by setting due dates.

Upwards flows provide the upper level with more detailed data on the performance of the supply chain, e.g. actual costs, production rates, utilization of the equipment, lead-times etc. This information can be used in the upper level planning for anticipating the consequences for the more detailed processes on the lower level.

Table 4.1 Specific planning tasks of the SC-type "consumer goods industry"

Attributes and Contents	Impact on Planning
Multiple sourcing of material	Short- and mid-term supplier allocation
Flow line organization	Simultaneous . . .
Batch production	. . . lot-sizing and . . .
Sequence dependent changeovers	. . . scheduling necessary
Known, stationary bottlenecks	Focus on bottlenecks possible
Low working time flexibility	Mid-term planning of working time
Three-stage distribution system	Choice of distribution channels, allocation of safety stocks
Seasonal demand	Building up seasonal stock
Long life cycle	Forecasts based on historical data
Hundreds of product types	Aggregation . . .
Standard products	. . . of final items . . .
Divergent BOM	. . . necessary and possible
Alternative sites	Integrated mid-term production and distribution planning
Deliver-to-order	Forecasts and safety stocks of final items, deployment, shortage planning
Capacity constrained	High utilization aspired, master planning w. r. t. capacity
Intra-organizational	Central coordination by means . . .
Coordination of mixture type	. . . of mid-term "master . . .
Unlimited information	. . . planning" possible
Customer oriented	High service levels aspired

4.3 Examples of Type-Specific Planning Tasks and Planning Concepts

Up to now quite general planning tasks—to some extent appearing for every member of a supply chain—have been described. For example, Hübner et al. (2013) have shown that the SCP-Matrix of Fig. 4.3 is not only appropriate for the manufacturing stage of an SC, but can also be adapted for (grocery) retailers. However, the importance of a specific planning task may vary with respect to the type of supply chain considered. While some tasks, e.g. *lot-sizing* or *ordering materials*, may be extremely difficult (and thus relevant) in one type of SC, they may be quite simple (and therefore negligible in terms of planning) in another type of SC. In order to illustrate this, the two exemplary "SC-types" of the last chapter, *consumer goods manufacturing* and *computer assembly*, will be picked up, again.

Their most important planning tasks are derived from the characteristics of the respective SC-type. To admit a better differentiation, type-specific names will be introduced for some particularly characteristic tasks. Tables 4.1 (p. 83) and 4.2 (p. 84) try to emphasize the causal linkage between the typology of Chap. 3

Table 4.2 Specific planning tasks of the SC-type "computer assembly"

Attributes and Contents	Impact on Planning
Large number of products procured	Mid-term master plan coordinates ...
Long supplier lead-times	... purchasing and order promising
Unreliable supplier lead-times	Safety stocks of components
Short materials' life cycle	High risk of obsolescence, mark down, phase-in, phase-out
No bottlenecks in production	Only rough capacity planning necessary
Two-stage distribution system	Merge-on-the-fly
Forecasts and orders available	Forecast netting
Short life cycles	No sales history available
Customized BOM	Configuration check
Convergent BOM	Demand-supply matching, component substitution
Assemble-to-order	Forecasts and safety stocks of components, order promising, allocation planning
Material-constrained	Master planning synchronizes materials
Supplier oriented	Long- and mid-term contracts
Customer oriented	Short delivery times, high delivery reliability aspired

(Tables 3.3 and 3.4) and the impact on planning that the respective attributes of an SC-type have. Additionally, hierarchical planning concepts—especially designed to link these respective tasks—will be shown as an example. For sake of briefness, we concentrate on mid- and short-term operational planning tasks, only.

4.3.1 Consumer Goods Industry

Master Production Scheduling, Capacity Planning and Mid-Term Distribution Planning. As consumer goods manufacturers often face seasonal or strongly fluctuating demand and because the supply chain is capacity-constrained, it is necessary to smooth those effects by pre-production in periods with less customer demand. Here, master production scheduling has to trade off the costs for seasonal stocks due to pre-production and the costs for capacity, especially the additional expenditure for working overtime in periods with peak demand. Up to now, most consumer goods manufacturers had a quite low working time flexibility and therefore changes in the working time pattern already had to be announced on the mid-term. Because of this and because of the scarce capacity, mid-term planning of working time is a crucial task in consumer goods industry. But in the meantime, more and more labor agreements are going to provide flexible working times. Thus, further sophisticated planning methods could lead to lower costs by effectively taking advantage of the additional freedom.

Furthermore, quite a lot of consumer goods companies use more than one site for producing the same product. Thus, the above planning task is getting more complex as capacity problems could be balanced by shifting production quantities from one site to another. Therefore, the costs for transports to the demand point are relevant and have to be considered, too, during the decision process. This extension of master production scheduling leads to a planning model (in general: *capacity-constrained master planning*) which includes both the tasks of mid-term production planning and mid-term distribution planning. If alternative sites producing the same products are sourcing their material from multiple suppliers with substantially different purchasing prices, the master planning model has to integrate the procurement side, too.

Usually, the main result of master planning in the consumer goods area is *not* the production quantity because the demand or forecast might change in the short run. Therefore, short-term scheduling needs to plan with updated demand data. So, the necessary capacity (especially working time, shift pattern, and overtime), the quantity which has to be pre-built (seasonal stock), and the transport capacity on each link are the decisions aided by master planning.

Mid-Term and Short-Term Sales Planning. Since a deliver-to-order decoupling point is given, all production and most of the planning processes are driven by forecasts, more precisely, by forecasts for final items. Forecasting is often the crucial point in consumer goods industries because inventory of finished products is quite expensive and lost sales or backlogs reduce the customer's trust in the company. These effects are sometimes amplified by depreciations which arise because of the low shelf-lives of the products. Therefore, it is necessary to include the seasonal influences and the additional demand which is caused by promotions and marketing activities.

The high number of product types forbids the forecasting of individual final items for a mid-term planning horizon. However, since standard products are considered and since a divergent BOM is given, aggregation of final items to product groups quite often is straightforward. Thus, in mid-term forecasting usually aggregated product groups are considered and the time buckets comprise 1 week or more. As a general rule, the total planning horizon should at least include a complete seasonal cycle. Usually, the planning task consists of two steps. The first involves statistical forecasting under consideration of trends and seasonal effects. For that purpose, the time series of past demand are analyzed and extrapolated into the future. This can easily be done because the long life cycles of products give access to a long history of sales data. In a second step, the additional demand which is caused by planned marketing activities is added to the base forecast.

The short-term forecasting procedure then considers all products and a more detailed time grid (usually daily buckets). As the sales personnel has exact information on promotions for each time bucket (day), the short-term forecast figures should be composed from the statistical base forecast, supplementary demand resulting from promotions, and the change in demand caused by seasonal fluctuations. The information on seasonal effects (calculated in mid-term sales planning) has to be considered as add-on to the base forecast because the short horizon comprises not a complete cycle which is necessary for a seasonal planning model.

Lot-Sizing and Machine Scheduling. Production planning in consumer goods industries seems simple as the production process only consists of one or two stages. But in practice one of the hardest planning problems occurs because of high sequence dependent setup costs and times. This dependence enforces the simultaneous determination of lot-sizes and sequences: changes in the sequence of lots cause alterations in setup costs and setup times (i.e. in the net capacity actually remaining for production) which influence the lot-sizing decision. But the sequencing decision in turn is based on known lot-sizes. This problem is the more crucial, the tighter capacities are. However, since often bottlenecks are stationary and known, it is possible to concentrate on a single bottleneck stage comprising several parallel flow lines.

Transport Planning, Warehouse Replenishment. A further crucial task in consumer goods industries is to balance the inventories in the multi-stage distribution network. Two major types of stocks are affected on the short-term, namely the lot-size and the safety stock.

In a deliver-to-order (= make-to-stock) environment final items have to be produced on forecast, i.e. without knowing customer orders. These production quantities, the so-called *lot-size stock*, have to be distributed among the various stocking points of the 3-stage distribution system at which customer orders arrive. The task of *deployment* is to plan the short-term transportation activities such that customer orders can best possibly be fulfilled.

The deliver-to-order decoupling point also enforces *safety stocks* of final items to be placed at the most downstream stage (i.e. before customer delivery) in order to avoid stock-outs. In a 3-stage distribution system it seems—for risk pooling purposes—often reasonable to hold a part of the safety stocks at upstream warehouses (e.g. central warehouses etc.). Thus, not only the determination of the total amount of safety stock, but also the allocation of safety stocks within the distribution system are important planning tasks, seriously influencing customer service.

Because of the intense competition in consumer goods supply chains and because of the high power of customers (wholesalers, retailers) very high service levels are aspired. However, usually not all incoming customer orders can immediately be served from stock. The crucial task of selecting the minor important orders that can best be postponed (but nevertheless may get lost because customers become annoyed) is called "*shortage planning*".

Coordination and Integration. Since an intra-organizational supply chain is given, information could centrally be made available and central coordination should basically be possible. This coordination task should be settled on the mid-term master planning level because—as we have seen above—here an integration of procurement, production, and distribution is necessary, anyway.

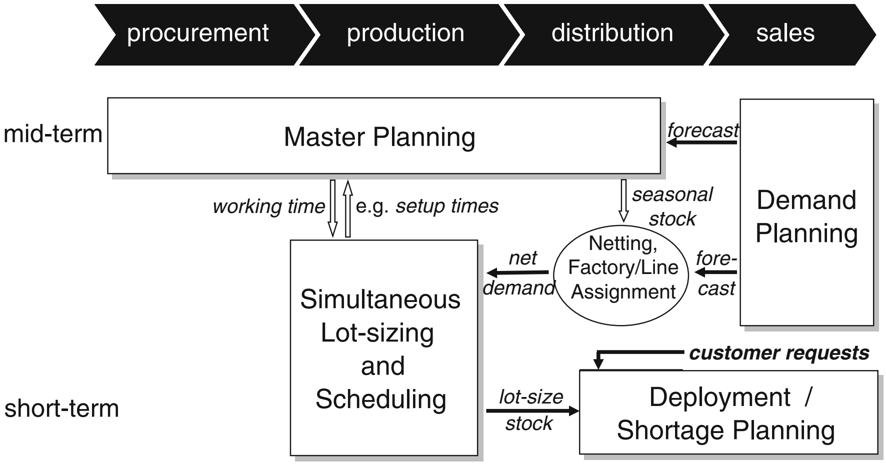

Fig. 4.4 Exemplary operational planning concept for the consumer goods manufacturing SC-type

After deriving these specific planning tasks of the consumer goods SC-type the question is how to link them together to get an integrated planning concept covering the whole (intra-company) supply chain best possibly. As we have seen in Sect. 4.1, *hierarchical planning* is a proper way to allow such a coordination. Of course, only a rough and very general draft of such a planning concept can be shown here. Details concerning aggregation of products or resources, time buckets of planning modules, and planning frequencies have to be skipped over. Thus, Fig. 4.4 only presents a "skeleton" of planning modules and the basic information flows between them. A planning concept for a real world supply chain has to be adjusted appropriately. A more complex consumer goods supply chain may comprise further planning tasks and require additional modules with the respective information flows in between. However, we hope to give some idea how the specific planning requirements of a consumer goods SC-type have to be reflected in a "fitting" planning concept.

Because of the higher degree of uncertainty only such decisions that cannot be postponed to later, shorter-term planning should be predetermined at the (capacity-constrained) *Master Planning* level. Just this information should be passed on the short-term level by means of instructions. As we have already seen, in consumer goods supply chains such decisions usually comprise the determination of working time like shift patterns (because of its low flexibility) and the build up of seasonal stock (because of the long planning horizon being necessary). In order to take sound decisions, all influencing factors should be considered. For mid-term master planning in consumer goods supply chains this means that constraints like

- Dynamic forecasts of customer demand (in order to reflect seasonality)
- Limited capacity of resources and capabilities of extension
- Minimum stocking levels (safety stock and anticipated lot-size stock).

and further decisions like

- Transport flows from factories to central warehouses (CWs) and customers (because stocks can be balanced between CWs)
- Production quantities of factories
  (in order to evaluate the amount of overtime being necessary).

altogether have to be integrated in a single, holistic view of the supply chain.

This can (for reasons of complexity) and should (because of uncertainty) only be done in an aggregate manner, e.g. by means of product types, aggregate resources and monthly time buckets. Demand information has to be available at the same aggregation level. Such mid-term forecasts often are made in a further *Demand Planning* task by a central Sales department by consolidating the (more accurate) decentral forecasts of their regional dependencies and upgrading this aggregate forecast with additional, centrally available information like planned TV advertisements etc.

Because of seasonality the planning horizon usually should include at least one seasonal cycle—quite often a year. To make mid-term planning more realistic, decisions of the short-term level, to be taken at later moments, have to be anticipated. In consumer goods supply chains average setup times (also reducing mid-term capacity, but not being considered in detail in mid-term planning) or the average level of lot-size stock are of relevance. These essentially are a result of the shorter-term lot-sizing and scheduling module.

Short-term planning has to respect the instructions of the mid-term planning level. However, short-term planning has a more detailed view of the supply chain. For example, since *Simultaneous Lot-sizing and Scheduling* (SLS) has to decide about changeovers, now "setup families" have to be considered which have the property that setup costs and setup times only occur for changeovers between items of different families (see Sect. 3.4, p. 64). Usually, a product type consists of several setup families. Thus, there is a higher level of detail than it was at mid-term master planning.

Also a shorter planning horizon suffices (e.g. 2 months) and capacities of production lines instead of aggregate resources are the limiting factor. Consequently, the aggregate instructions of the mid-term planning level have to be disaggregated into more detailed instructions for the short-term level. That means that working time commitments have to be refined at the decentral factories (maybe within an additional master production scheduling task) and that seasonal stocks of product types have to be assigned to setup families.

On the short-term, usually more accurate forecasts of customer demand are available. These short-term forecasts, the disaggregated seasonal stock, and the planned safety stocks are balanced with the initial stocks that are currently available at the central warehouses to compute the net demand that has to be satisfied by SLS. This net demand furthermore has to be *assigned* to (the production lines of) the factories. Note, if initial inventories have fallen below the safety stock levels, a part of the net demand is used to "refill" safety stocks. Also note that this *Netting* procedure has the character of a disaggregation step and that due to the better demand information the mid-term (virtual) transportation flows between factories, central warehouses, and customers normally have to be revised on the short-term.

At each factory, the decentral SLS is responsible for production line planning, i.e. determining the sizes and sequences of production lots of setup families. The lot-size stock of final items, resulting from a further disaggregation of setup families into final items (within SLS), has to be *deployed* to the CWs at which customer requests arrive. As the deliver-to-order decoupling point indicates, the final *Shortage Planning* at the CWs matches the incoming customer orders against the forecast-based stocks and determines whether and when a certain order will be delivered.

Finally note that—for sake of clarity—only two dimensions are printed in Fig. 4.4, but actually three dimensions would be necessary. This is due to the fact that there may be several factories and CWs where planning tasks like SLS or demand planning have to be tackled decentrally. Furthermore, additional planning levels and modules may be required, e.g. in order to plan the movement of machines or tools between factories (see e.g. Sect. 21.1.2). This has to be done if total customer demand is stable but regional customer behavior changes over time. Then, it may be advantageous to serve customer demand always from the nearest factory in order to save transportation costs of finished products, but this also depends on the costs for the movement of machines. Such a planning task would have a lower planning frequency than the ordinary master planning described above.

This example already shows that our typology is by far not (and cannot be) comprehensive. Even a small change in the assumptions being made may have significant impact on planning tasks and planning concepts. As a second example, in our consumer goods supply chain we (implicitly) restricted ourselves to products with a rather long shelf life. If this is not the case (e.g. for fresh food), holding stocks is only possible for a very short time. Then excess capacity instead of inventory has to balance seasonal demand and the lot-size stock has to be restricted, too. So the planning concept of Fig. 4.4 is not appropriate any more and has to be adjusted accordingly. However, we think that quite a lot of supply chains fit the consumer goods SC-type introduced above. Nevertheless, the fresh food example shows that it is very important to document *how* a planning concept has been derived from the specific characteristics of an SC-type. Because only then it is possible to check whether the own supply chain fits the type and where adjustments in the planning concept have to be made.

As a second and quite contrary example of type-specific planning tasks and corresponding planning concepts we now come back to the computer assembly type introduced in Sect. 3.5.

4.3.2 Computer Assembly

As pointed out below and summarized in Table 4.2, the specific characteristics of the computer assembly SC-type necessitate special emphasis on quite different planning tasks.

Master Production Scheduling, Capacity Planning and Mid-Term Distribution Planning. As opposite to the consumer goods type, less a capacity-constrained, but rather a material-constrained supply chain can be found. Because of the high working time flexibility, capacity of production is only a minor focus of mid-term planning. The limited availability of some important components, however, is a serious problem. If critical suppliers have a high power within the supply chain, mid- to long-term contracts (comprising both maximum supply and minimal purchasing quantities) ought to ensure the desired flow of components. These commitments limit the material supply (upper and lower bounds) that can be utilized. Due to their long lead-times quite a lot of components have to be ordered in good time on basis of demand forecasts.

Both material constraints and long lead-times enforce a mid-term balancing of demand against possible component supply. In so doing backlogs may arise. As will be shown below, *order promising* needs to know component availability in order to set reliable delivery dates as soon as customer requests arrive. The information about availability (the so-called ATP quantities) is a result of this *material-constrained master planning*. Thus master planning has to synchronize the purchasing of a vast number of different components (planned component inflow) and to provide this information about planned component availability for *order promising* in form of ATP.

Mid-term distribution planning is only a relevant topic if an order can be satisfied from alternative sources such that one needs to choose between different distribution channels. Only in this (rather seldom) case, the distribution system has to be incorporated in master planning.

Mid-Term Sales Planning. In configure-to-order and assemble-to-order environments all assembly processes are kicked off by a specific customer order. Processes upstream from the decoupling point—and especially the *purchasing*—have to be based on forecasts, either directly on forecasts for components or indirectly on forecasts for final items.

In the first case, component demand could be estimated *directly* on basis of the sales histories and the assembly histories, respectively. In case of short life cycles, there is only a very poor history available. Sometimes, knowledge about life cycles of related components with similar functionality (e.g. of the discontinued predecessor) can be utilized as a surrogate. However, such a direct approach is mostly useful for C-components and -materials with minor value and rather long life cycles.

For high tech A-components with rather short life cycles the risk of obsolescence is very high and not only understocking, but also overstocking should be avoided. Then, one may try to *indirectly* derive a (hopefully) more accurate component demand from the production program. Thus final item demand has to be estimated on basis of aggregate product types. Component demand (= planned component inflow) has to be derived from the planned production quantities in a sort of BOM explosion (as integral part of the master planning process). This task can quite easily be implemented in assemble-to-order environments where standard variants are predominant. In case of a configure-to-order decoupling point, however, also the structure of the BOM, i.e. the share of components within product types (e.g. the share of 1 TB and 500 GB hard disks within consumer PCs) has to be estimated which is an extremely difficult problem. Note that the component demand considered here corresponds to the planned component inflow stated above as a result of master planning. But the master planning process has to simultaneously respect supplier lead-times and material constraints. Thus master planning is more than a simple forecasting procedure.

Short-Term Sales Planning. On the short-term more accurate demand information is available, i.e. the already known customer orders' share of actual demand is higher. So one has to wonder how to integrate this information into the forecasting process and how to match "old" forecasts with incoming customer orders ("forecast netting"). The latter problem actually comprises the tasks of controlling forecast accuracy and reacting to forecast errors. Since forecast errors should be hedged against by safety stocks, here refilling of safety stocks (in case of too pessimistic forecasts) or reduction of the currently available stock (in case of too optimistic forecasts) are addressed. In consumer goods supply chains this netting procedure is still a relatively simple task because just stocks of final items have to be considered. In computer assembly supply chains, however, stocks of components have to be netted. This implies that forecast accuracy can also be measured on the component level.

Besides the danger of understocking, there is a high risk of overstocking of components because of their short life cycles. Thus, at the end of the life cycle one possibly has to take care about promotions or discounts in order to get rid of obsolete component stocks. In any case, older components have frequently to be replaced with their more modern successors (phase-in, phase-out). Thus, quite often forecasts for both predecessor and successor have to be aligned (see Chap. 7).

An upstream decoupling point entails rather long order lead-times. Thus—as compared to consumer goods manufacturing—there is a noticeable time span between a customer request and the delivery of the complete order to the customer in computer assembly supply chains. If a customer has to wait anyway, he at least wants to get a reliable promise at which point in time his order will be delivered (a so-called "due date" or "promised date"). So the *order promising* and all subsequent further *demand fulfillment* processes are very important tasks within such a type of supply chain. Whereas short delivery times and early due dates are aspired by order promising, the compliance with that due date has highest priority throughout the demand fulfillment afterward.

Quite often *order promising* is an on-line task. A customer wants his due date to be assigned very soon after his request (e.g. within a few minutes). Then order promising has to be executed on a first-come-first-served basis. Thus, there is a high chance that a less lucrative order books components that later on could be assigned to a more lucrative order. In order to realize higher profits, it may be useful to allocate quota of components to specific customer classes (as it is well known from yield management and flight ticketing). Such a "refinement" of ATP is sometimes called *allocation planning*. Note that allocation planning is only required in shortage situations.

Lot-Sizing and Machine Scheduling. As we have seen, in computer assembly supply chains setup costs and times are negligible. There are no serious bottlenecks in production and working time is quite flexible, even on the short-term. Thus lot-sizing is irrelevant and scheduling the *released* customer orders ("*production orders*", "*jobs*") with the objective of meeting the promised due dates also is not a very critical task.

However, in order to select the orders to be released next, the currently available, anonymously purchased stocks of components ("supply") have to be assigned to the already promised customer orders ("demand"). This *demand-supply matching* is only important in shortage situations. If supply of components is not sufficient to satisfy all customer orders in time, i.e. with respect to the promised due dates, one has to decide which demand should be backlogged and which supply should be accelerated. In the first case, the Order Management department has to contact some carefully selected customers and to inform them about delaying their orders. Of course, simultaneously new second or even third promised dates have to be set ("*re-promising*"). In the second case, the Procurement department has to negotiate with some critical suppliers in order to (hopefully) speed up the delivery of their components. Since hundreds of components and thousands of customer orders might be concerned and thus should be considered, this obviously is a very difficult task. Note that there can be further degrees of freedom, e.g. due to component substitution, because customers might be satisfied by similar components of alternative suppliers not originally agreed on.

Transport Planning, Warehouse Replenishment. Like it was the case for mid-term distribution planning, shorter-term transport planning is not a critical task. Sometimes, there may be a choice between alternative transportation modes, e.g. between "normal" delivery by a carrier and "express" delivery by a parcel service.

It is interesting to note that—because of the convergent BOM—an assignment of currently available stock to customer orders, similarly to the demand-supply matching, may be required at several stages downstream from the decoupling point. The latest possible stage in a 2-stage distribution system are the distribution centers where different order lines (e.g. monitors and computers) have to be "matched" to a complete order. Such matching tasks are necessary whenever a customer order initiates the release of material (or the execution of some processes), but the material released (or the output of the process) will not durably remain assigned to this specific order. For example, customer order 1 may initiate the assembly of a system unit, but order 2, having a higher priority, will finally catch this unit. Such a procedure increases flexibility, yet also decreases the stability of a system. The earliest possible "marriage" between an order and its components—as the other extremal—would be the *durable* assignment of ATP on hand at the order promising stage. Then, very reliable due dates can be promised (because the necessary components are already on stock and cannot be caught by other orders) and a complete tracking and tracing of this order is possible. Obviously, such a procedure necessitates a high stock level due to high WIP.

However, the major focus of short-term planning is on the supply side. As introduced above, safety stocks have to be held on component level. This is the more important, the longer and the less reliable supplier lead-times are. As compared to the consumer goods supply chain, determination of correct safety stock levels is more complicated since service levels are usually defined and measured for finished products, whereas safety stocks have to be set for components. Because of the short material life cycles, there is a high risk of obsolescence, too. So at the end of the life cycles, short-term safety stock planning has the character of a newsboy problem (see Nahmias 2005, Chap. 5).

Coordination and Integration. Due to the high power of some suppliers and customers, intensive collaboration should be established, e.g. in order to exchange capacity (material availability) or demand information. For the intra-company part of planning, also central coordination by means of a (material-constrained) master plan is useful which synchronizes the activities of the Sales, Production, Procurement, and Order Management departments. The outcome of master planning should be the planned inflow of components. As can be seen in Fig. 4.5, this information is used to synchronize the purchasing (by means of the aggregate inflow) and order promising (by means of ATP). The input of master planning may be mid-term forecasts for final item demand (aggregated to product types) and attach rates, i.e. forecasts for the share of components within these product types. Both are results of a *Demand Planning* task which usually is in the responsibility of the Sales department. As for consumer goods supply chains, also decentral forecasts of several sales regions have to be consolidated and upgraded to an aggregate forecast for the company.

Thus, the task of *Master Planning* is to link the planned component inflow with final item demand. This task would be straightforward if there weren't any constraints. While production capacity is a rather loose limitation, the problem is to respect upper and lower bounds for the procurement of some critical components and to respect the varying, partly long lead-times. The objective should be to balance inventory holding costs for components against profit that might be obtained by different product types in several regional markets. Note, however, that purchasing and order promising not necessarily have to be synchronized by taking monetary objectives into account because just a *unique* master plan—no matter whether cheap or expensive—is required.

Purchasing needs to know about the aggregate component inflow master planning calculates with, e.g. about the weekly or monthly inflow of hard disks of a specific size or class of sizes. Concrete purchasing orders to each supplier (which entail a higher level of detail) have to meet this aggregate component inflow best possibly. Thereby, multiple sourcing, supplier contracts, economic lot-sizes, and safety stock targets (including forecast netting) have to be taken into consideration. The master plan can only take care of the most critical A-components. Thus, the

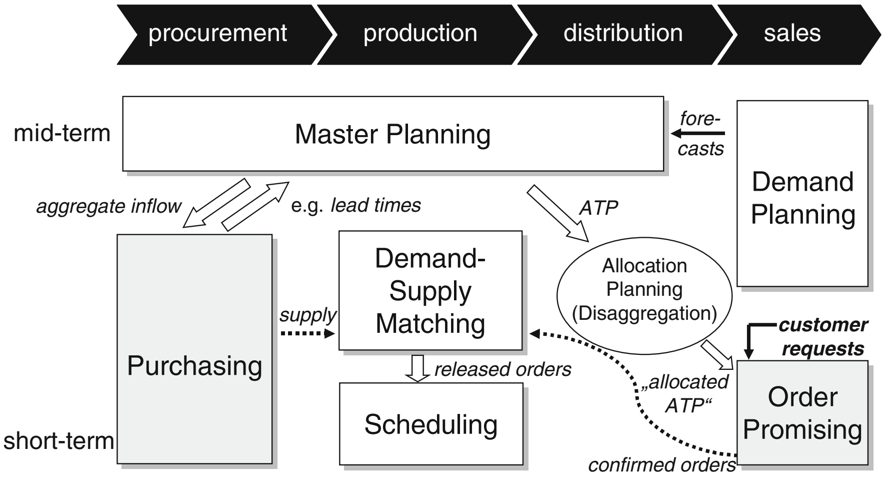

Fig. 4.5 Exemplary operational planning concept for the computer assembly SC-type

remaining B- and C-components have to be forecasted and ordered, directly. The result of purchasing is the component inflow (component supply) that arrives at the inbound warehouses and becomes available for assembly. In order to feed master planning with up-to-date data, purchasing has to provide realistic information about lead-times and minimum or maximum purchasing quantities of critical components.

On the other hand, order promising requires information about ATP quantities, i.e. the part of the component stock on hand and the expected component inflow (already in transit or planned by master planning) that has not yet been allocated to specific orders and thus can be promised to customers in the future.

Since final item demand has driven the master plan, there already has been some rough assignment of component stock—and thus ATP—to different markets. However, if detailed quotas for smaller sales regions are required to permit an on-line order promising, the output of the master plan has to be refined into "allocated ATP" in a further *Allocation Planning* step. Similar to the netting procedure in consumer goods supply chains, this task primarily is a disaggregation step because the major (material-constrained) decisions about assignment of component stock to markets have to be taken on the master planning level. *Order Promising* then suggests a due date for an incoming customer order by searching within allocated ATP for all requested components of the order. In case of customer compliance with the date, the confirmed order finally books the corresponding components within allocated ATP (but usually not within physical stock) so that they cannot be promised a second time.

The coupling to short-term production planning is rather loose. *Demand-Supply Matching* has to balance the available stock of components—which is the actual supply resulting from short-term purchasing activities—with the confirmed orders. Note that actual and planned supply may deviate considerably because of unreliable lead-times. But this discrepancy should be buffered by safety stock (within master planning and purchasing as well). Besides supply acceleration activities and re-promising of orders, the confirmed orders, to be released to the shop floor next, are the results of Demand-Supply Matching. These assembly jobs afterward have to be *scheduled* on the shop floor. As mentioned above, if there is only a temporary assignment of components to customer orders, planning tasks similar to this demand-supply matching may also occur at further downstream stages, the last of them being settled at a distribution center.

Of course, there may exist other useful ways to hierarchically link the planning tasks and planning modules of a computer assembly supply chain. However, a planning concept for computer assembly has to take into account the specific requirements of such a type of supply chain.

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