Chapter 3
Production Planning and Control Frameworks

The work described in this volume lies at the intersection of two streams of literature. The first of these addresses the structuring of the planning problem as a sequence of decisions made at different levels of the organization with different levels of information and different time frames. The second is related to the mathematical modeling techniques used to describe and solve planning problems formulated at different levels of the organization. We begin by reviewing the different ways in which the problem of planning and coordinating production in complex organizations has been addressed by presenting the two most widely used decision frameworks for designing and implementing PPC systems in this chapter.

3.1 Material Requirements Planning (MRP) and the Manufacturing Planning and Control (MPC) Framework

The steady increase in the scale of industrial operations over the course of the nineteenth and twentieth centuries brought the need for more sophisticated organizational structures and management tools to support the effective coordination of complex activities over wide geographical areas (Chandler 1962, 1980). These developments, together with the increasing complexity and technical sophistication of industrial products, rapidly rendered it impossible for any individual, or body of individuals, to have complete command of all the information needed to manage the entire organization effectively. The unsuccessful attempts at centralized planning in the totalitarian economies, despite the very high levels of resources dedicated to these exercises, serve only to underscore the difficulty of this undertaking. As a result, most firms decompose the planning function into a sequence of steps carried out by different groups, with each group's decisions defining the range of possibilities for those made by the next and successively adding detail until a workable

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solution has been obtained. Initially such systems were almost completely manual, but various computational and informational aids were developed over time. An overview of the early development of such systems, which has been centered on the widely used Material Requirements Planning (MRP) approach systematized by Orlicky (1975), is given by McKay (2010). The resulting Manufacturing Planning and Control (MPC) framework, although subject to variation, has been widely adopted and represents the state of industrial practice across a wide range of industries. Hence we begin by discussing this framework in detail, which will allow us to identify potential improvements that may be obtained using the more elaborate approaches discussed in this volume.

In many discrete manufacturing industries, final products are assembled from a large number of components, each of which is itself manufactured using a multistage process. For example, in the mechanical engineering industries, the production of complex products such as construction machines or machine tools requires the coordination of tens of thousands of purchased, manufactured, and intermediate items, referred to as stock-keeping units (SKUs). In these environments, the PPC system has to coordinate thousands of parallel material flows for the components in order to guarantee the availability of *all* required components at the time of assembly. Demand for components is mostly a *dependent* demand required to meet the build schedule stated in the Master Production Schedule (MPS). The computation of this dependent demand through the well-known *bill of material (BOM) explosion* logic of Material Requirements Planning (MRP) (Vollmann et al. 2005) requires substantial computational power and, not surprisingly, was one of the first planning tasks to be automated when computers became available for business applications in the early 1960s.

Combining the current inventory levels and planned lead times of the production units (which are, of course, estimates of cycle times) with the BOM explosion yields time-phased net requirements for each SKU in the BOM. Since the gross requirements of each SKU are calculated from the lot sizes of the SKUs for whose production the SKU under consideration is required, lot sizing is an integral part of this calculation. Once time-phased net requirements and lot sizes for both production and purchase orders are calculated, the planned lead times of the production orders can be decomposed into planned lead times for the individual manufacturing operations at the workcenters performing them. This process also assigns the capacity requirements of these operations to the planning periods in which their performance is planned, permitting the calculation of time-phased capacity requirements using the Capacity Requirements Planning (CRP) procedure (Vollmann et al. 2005). Software systems performing these functions, termed MRP systems, represented the state of the art in the mid-1970s and constituted a tremendous advance over the independent demand inventory control systems or, in some cases, manual calculations of material requirements (Wight 1983: 44) used previously. We do not describe the MRP computations in detail here; a concise description with illustrative examples is given by Hopp and Spearman (2008). More extensive descriptions are presented by Baker (1993) and Vollmann et al. (2005), while Tardif and Spearman

(1997) and Voss and Woodruff (2003) describe MRP in terms of mathematical programming. The original book by Orlicky (1975) remains an interesting and useful reference.

Several characteristics of MRP are of interest to the discussion in this volume:

1. The procedure uses fixed, exogenous planned lead times, usually derived from historical observations of realized cycle times. This facilitates both lead time setting and coordination of the material flow through multiple production stages.
2. MRP is uncapacitated. The capacity requirements over time result directly from the MPS, the lot-sizing rules, the planned lead times, and the current inventory levels of SKUs at the various levels of the BOM. Hence substantial imbalances between required and available capacity can occur.
3. The Master Production Schedule (MPS), which determines the medium-term capacity requirements, is an exogenous input to the system.

MRP does largely what its name implies—material requirements planning with very limited support for capacity planning. The lack of support for Master Production Scheduling is particularly critical; the MPS is treated as a fixed, exogenous input that may be infeasible with respect to capacities. Any infeasibility must first be identified, often a challenging task in itself, and then "repaired" by adjusting either the available or required capacity in the planning periods. The latter can be accomplished by adjusting the MPS, modifying the lot-sizing rules after the CRP process has been completed, or by detailed scheduling at the order or operation level within the production units, which requires a fairly high amount of released work and WIP to be effective. In order to overcome these limitations, a PPC system should support integrated planning of both material and capacities for all resources, as well as the creation of the build schedule (the MPS) that determines the resource requirements.

The serious nature of these limitations raises the question of why a production planning approach with such deficiencies is so widely employed. A confluence of several factors has led to this situation. Firstly, in environments where production capacity is relatively cheap, plentifully available, or both, it is relatively easy to address delays in production plans by adding capacity through overtime, subcontracting, or additional machines. In production environments that maintain relatively constant capacity utilization, cycle times will also remain relatively stable, allowing suitable planned lead times to be learned over time. We have observed several cases of firms deliberately maintaining a constant utilization level, to the extent of temporarily deactivating production equipment in periods of low demand. Another factor in favor of MRP is the transparency of its logic to the end users, in contrast to optimization models that frequently produce solutions that are difficult to explain. Historically, MRP was a tremendous advance over independent demand inventory control systems since it derives the material requirements from the MPS, which is a statement of *future* production as opposed to a forecast. Finally, the wide adoption of MRP in industry has provided an extensive ecosystem of software, consultants, and corporate knowledge supporting its use.

3.1.1 Role of the Master Production Schedule

Master production scheduling has proven more difficult to standardize than the MRP calculation itself. A reference structure for a master production scheduling system derived mainly from empirical observations that covers many practical cases in discrete manufacturing was proposed by Berry et al. (1979) and is described in Vollmann et al. (2005). This MPS reference structure considers the general case where the production and purchasing activities upstream of a specified *customer order decoupling point* (CODP) are based on demand forecasts and the completion of final products downstream of the CODP on customer orders. The CODP is located at the point in the supply chain where material is committed to a particular order and cannot be used to fill any other. A CODP located at the assembly stage results in assemble-to-order (ATO) production, as is common with PCs, and allows short delivery times for complex products, e.g., in mechanical engineering. Make to stock and make to order are special cases with the CODP at the final product or at the raw material level, respectively.

In this MPC structure, the MPS incorporates information from both demand forecasts and confirmed customer orders to provide a time-phased build schedule for all independent demand items, usually based on weekly time buckets. This build schedule provides the input to the MRP system that generates the orders for the production units that are forecast driven (e.g., purchasing and component production). The time-phased capacity requirements that result from an MPS can be calculated by estimating the capacity requirements induced at all relevant workcenters by each unit of the final product to be completed in a given period based on the BOM and process routings for the individual BOM items (Vollmann et al. 2005: 339 ff.). Such Rough-Cut Capacity Planning (RCCP) procedures consider neither existing inventories nor the effects of lot sizing and can thus be quite inaccurate. More advanced methods such as Capacity Requirements Planning (Vollmann et al. 2005) are applied after the MRP computation, considering planned lead times, component inventories, and lot sizes.

In an ATO environment, the forecast-based MPS drives only the production of the components upstream of the CODP. Final Assembly Scheduling is driven by customer orders and controls the production of customer-specific products by the manufacturing stages downstream of the CODP. If any components are not yet available at assembly (due to inaccurate demand forecasts or production issues), exception orders are generated and their production expedited to minimize the delay at assembly. This structure leads to two interrelated control loops within the PPC system that are controlled based on the MPS and the final assembly schedule, respectively, as shown in Fig. 3.1.

This MPC structure is complemented by an aggregate planning level above the two control loops that performs seasonal planning of production and sales quantities, capacities and inventories over time, usually for product families and longer time buckets over a planning horizon of 12–18 months. Since the aggregate “products” representing product families cannot actually be produced, the planned

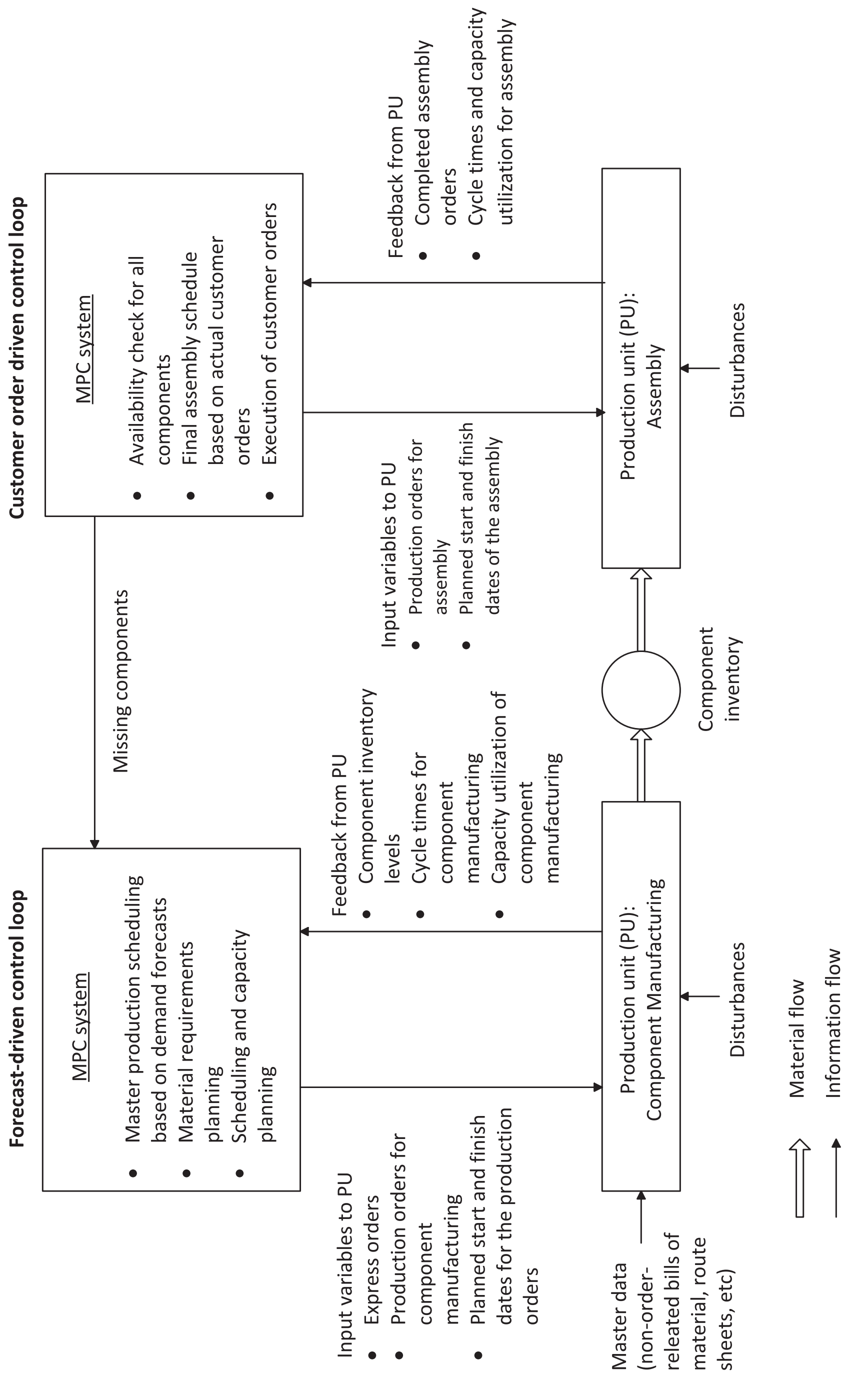

Fig. 3.1 Dual control loop structure for assemble-to-order production (from Zäpfel 2000: 215, authors' translation)

production quantities at this level represent capacity reservations for each product family that serve to coordinate production and capacity planning. Aggregate production quantities also largely determine possible sales, inventory levels, and cash inflows and outflows, etc., and thus are crucial to coordinating the functional areas of the company. They also serve as a coordination instrument with strategic planning since planned changes in sales quantities in different markets are reflected there. This task, termed *Sales & Operation Planning* (S&OP), links production planning and the larger corporate planning process, forming an important input to the MPS.

This structure leads to a hierarchical PPC system that, at least conceptually, simultaneously considers all resources necessary for production (primarily material and capacities) at each level, which are

- Sales and operations planning—resource planning
- Master production scheduling—rough-cut capacity planning
- MRP—capacity requirements planning and load levelling
- Shop-floor control—detailed scheduling

with increasing levels of detail as one moves down the list. This type of PPC system, often termed MRP II (Wight 1983; Landvater and Gray 1995) or the Manufacturing Planning and Control framework, is depicted in Fig. 3.2.

PPC systems of this type allow seasonal inventories only for MPS items, which are generally final products but may also include important subassemblies. All estimated capacity requirements are derived from the MPS. However, this approach does not allow integrated planning of the material flow across the supply chain when inventory levels at each stage must be considered. If coordination across the supply chain is necessary, the production quantities at each production unit, the transportation quantities between the production units and their inventory levels in each planning period must be defined as separate decision variables whose values determine the MPS, requiring a high level of detail in the MPS. This type of master planning, described in Chap. 1 for semiconductor manufacturing, is a standard function of today's Advanced Planning Systems (APS). Voss and Woodruff (2003) discuss its formulation as a mathematical program and its relationship to MRP II. The resulting planning and control structure is described in Sect. 3.2.

In the MRP II framework, sales and operations planning is performed for aggregate product families, and the MPS is obtained by disaggregating this aggregate production plan. To accomplish this effectively, products in the same family should share similar seasonal demand patterns and resource requirements, even if the strong assumptions of *perfect aggregation* (Axsäter 1981) do not hold. Similarly, master planning for product families requires aggregate bills of material and determination of safety stock levels that allow feasible disaggregation even if the mix of individual product demands within the aggregate demand varies (disaggregation slack). These issues, raised in Bitran et al. (1981), remain critical today.

MRP/MRP II thus has its origins in the material coordination task addressed by the planning level. Several important issues related to this task have attracted extensive research, such as MRP nervousness (Blackburn et al. 1985, 1986; Sahin et al.

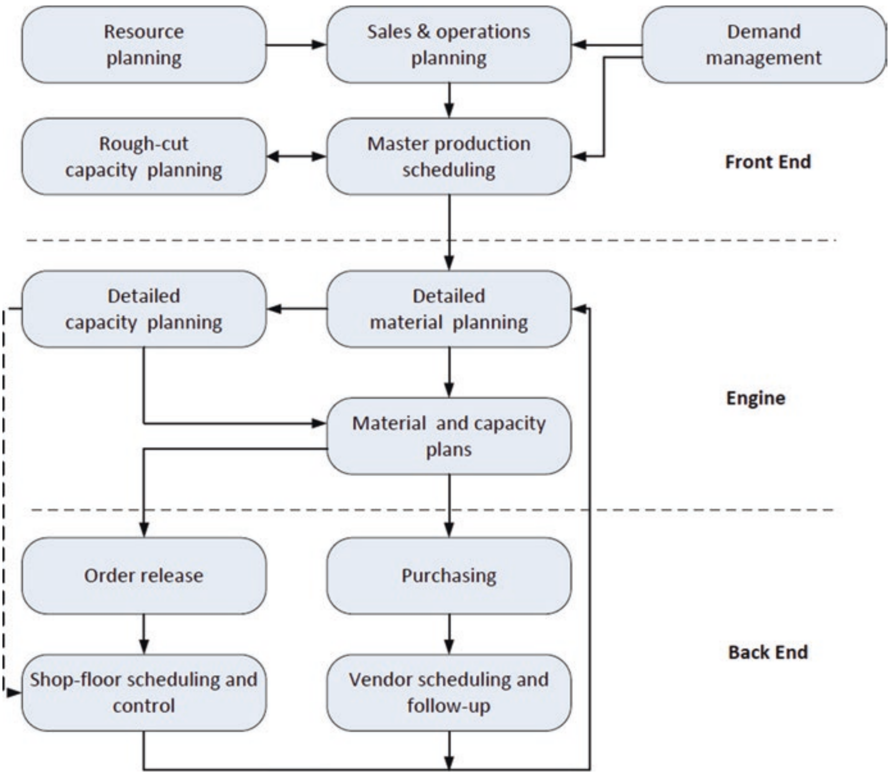

Fig. 3.2 Hierarchical structure of a MRP II/MPC system (Vollmann et al. 2005: 371, modified)

2013; Lin and Uzsoy 2016), multilevel lot sizing (Kimms 1997) and determination of safety stocks and safety times (Meal 1979; Miller 1979; de Bodt and Van Wassenhove 1983; Grubbstrom 1999). As expected, when a complex stochastic production—inventory system operating in a rolling horizon environment is controlled by a simple procedure like MRP, the complexity that is not addressed by MRP emerges elsewhere, and the resulting control system will be as complex as required by the planning problem according to the Law of Requisite Variety (Ashby 1956: 202 ff.). However, our focus in this volume is on the ability of MRP/MRP II to effectively control the system state within the production units in order to manage the cycle times and other performance measures of the manufacturing system.

3.1.2 Lead Time Management in MRP/MRP II Systems

The observed cycle times of production orders through the production units and the planned lead times estimated from them play a crucial role in the performance of PPC systems, and hence of the production systems they control. As discussed in

Chap. 2, Little's Law (Little 1961; Hopp and Spearman 2008) implies that average cycle times determine the average WIP level at a given throughput rate, while their variability determines how consistently the production system is able to meet the planned lead times, influencing due date performance and safety stock levels. The lead times also constrain the location of the CODP since the total lead time of the make to order portions of the system cannot exceed the customer's requested delivery time. Thus the planned lead times strongly influence essential elements of the MPC problem, making lead time management an important issue.

Planned lead times in MRP/MRP II are treated as *forecast* variables to be estimated from observations of realized cycle times. It is assumed that, as long as some maximum capacity loading is not exceeded, historical cycle times will provide a reasonable estimate of the cycle times of production orders released in the current time frame; the past is representative of the future. This use of planned lead times and maximum capacity loads to coordinate the production planning and detailed scheduling levels for the production unit poses substantial problems. First of all, it requires accurate time-phased load projections and sufficient planning capability to avoid the unduly long cycle times that arise when resources are temporarily overloaded. Capacity planning methods are provided in MRP II both at the MPS level (RCCP) and after the MRP run (CRP). However, since RCCP can only approximate the time-phased capacity requirements with no information on lot sizes or component inventories, and load leveling after the MRP run is based on predetermined lot sizes and lead times (and is a very complex task in its own right), the result can be far from optimal. Integrating MRP and capacity planning by solving multilevel capacitated lot-sizing models remains challenging for practical applications despite substantial progress in recent years (Tempelmeier and Buschkühl 2009; Helber and Sahling 2010). Thus there is always a substantial possibility that capacities are overloaded in certain periods or that overloading is avoided by suboptimal measures.

If realized cycle times deviate from the planned lead times, the latter are often updated to maintain high due date performance, and the release schedule is adapted accordingly. As discussed in detail in Chap. 2, however, the workload in the production unit—controlled by the order release function—determines the cycle times. This inconsistency—treating a control variable as a forecast variable—can lead to a vicious cycle called the *lead time syndrome* illustrated in Fig. 3.3: planners respond to long and unreliable cycle times by specifying longer planned lead times, causing orders to be released earlier in order to meet their required due dates. This increases the number of orders in the production unit (i.e., the WIP level), leading to longer queues at the workcenters, which, in turn, increases the average cycle time. Planners often react by increasing the planned lead times still further, causing the next batch of orders to be released even earlier. This effect is often further exacerbated in practice by uncontrolled releases of urgent orders (usually for missing parts that are delaying assembly of an order).

The lead time syndrome was first described in the 1970s (Wight 1974; Mather and Plossl 1978). Although rigorous studies are quite recent (Selcuk et al. 2006, 2009), anecdotal evidence suggests that it can inflate planned lead times beyond any defensible level (Wight 1974: 108 ff.). Whether the lead time syndrome is reversible

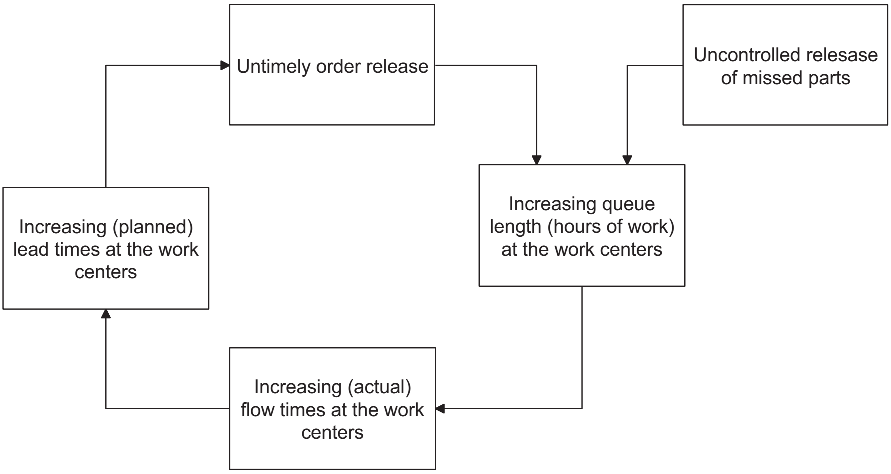

Fig. 3.3 Lead time syndrome

and the circumstances under which the system can become "locked" in a long lead time regime are still not well understood. Selcuk et al. (2009) show that the variability of planned lead times increases with their update frequency, suggesting a trade-off between lead time accuracy and system stability when lead times are treated as forecast variables.

Overcoming the lead time syndrome requires a fundamental change of perspective: instead of treating lead times as an exogenous parameter to be forecast, they should be treated as a *control* variable whose value can be influenced by order release and capacity decisions. This requires replacing the forecasting task of MRP/MRP II by an anticipation task—that of understanding the relationship between order release and capacity adjustment decisions and the cycle times that will be realized when these decisions are implemented. This view of lead times as endogenous to the planning process lies at the heart of this volume and will be discussed in more detail in later chapters.

3.2 Hierarchical Production Planning (HPP) and Advanced Planning Systems (APS)

Developments in information technologies over the second half of the twentieth century, most notably the development of ever more powerful computers, relational database systems capable of organizing the massive amounts of data involved, and the evolution of client-server computing, brought the possibility of Hierarchical Production Planning (HPP) systems where material flows and capacities are planned simultaneously at multiple time frames from medium-term aggregate planning to very short-term dispatching. Conceptually, this is a vertical decomposition of the overall PPC problem into a series of (hopefully!) tractable planning subproblems that avoids the well-known problems of solving and implementing a single monolithic model of the overall production planning problem as a single planning task. The advantages of hierarchical planning in companies are obvious, and the observation that hierarchical planning systems fit the organizational structure better than monolithic models may well be due to the fact that the organizational structure is an adaptation to the same factors that make hierarchical planning systems desirable. Thus ideas for Hierarchical Production Planning (HPP) systems were expressed very early in the literature on production planning and management (Holt et al. 1960; Anthony 1966).

Mathematical models have been developed to support a range of planning tasks within this hierarchy. However, due to the complexity of the planning problem, especially in multistage production systems with complex BOM structures, deriving this decision hierarchy and the respective planning models by mathematical decomposition of a monolithic model has not proved possible, although it remains an interesting theoretical goal.

For simpler production planning problems a theoretically sound hierarchical production planning system should be within reach, and a body of research addressing this problem has emerged alongside the MRP approach. We now describe the essence of this work on Hierarchical Production Planning, using this term not in the general sense that each PPC system exhibits a hierarchical structure (although this is usually the case), but to refer to specific PPC systems within this research tradition, although the boundary is often ambiguous. We then describe the structure of Advanced Planning Systems (APS) based on this hierarchical concept and have a different focus compared to the MRP/MRP II framework.

3.2.1 Hierarchical Production Planning

The seminal paper in this research tradition is that of Hax and Meal (1975), who model a tire manufacturer as a single-stage production system. The number of products is high, and the planning horizon must cover at least one entire seasonal cycle due to substantial demand seasonality. A centralized PPC approach must determine the production, sales, and inventory quantities of each product in each period of the planning horizon using a single monolithic model. This requires medium-term demand forecasts for each product and period, including forecast updating before each planning cycle, and makes medium-term decisions (e.g., how to handle seasonal demand) and short-term production decisions (production quantities for the next production run) simultaneously. Such an approach, although feasible from a modeling and algorithmic perspective, is very likely to fail; Meal (1984) describes the failure of such a centralized approach. The hierarchical approach provides a way out of this dilemma. Products that share setups constitute natural product families with negligible setup times between products of the same family and hence can be aggregated. Product families with similar seasonal demand patterns, capacity requirements, revenues, and unit costs (or inventory investment produced per unit time; see Graves (1982)) can be further aggregated into product types. This three-level structure is specific to the particular case of the tire manufacturer, but has proven to be viable in many batch manufacturing environments (Hax 2013: 709).

Once this aggregation hierarchy is identified, planning tasks can be assigned to the aggregation levels as follows:

Seasonal planning can be performed at the product type level since this level determines capacities and their usage or reservation, and the parameters that determine the seasonal plan are similar for products of the same type. The decision model is usually a linear program.

Lot sizes are determined at the level of product families since setups only occur with a change of product family. The decision model is specific to the case of the tire manufacturer and is solved by a heuristic.

Production quantities for individual products within the product families are determined in the short term to approximately equalize the projected run-out times of the products, when inventory will be exhausted and must be replenished by another production run. Since all costs are determined at the product type and product family levels, this allows products of the same family to share a family setup.

Only the seasonal planning performed at the product type level considers multiple planning periods. Product family and item-level planning are only performed for the first planning period, and the entire process is repeated at the start of the next planning period.

The key issue in HPP is that of aggregation, primarily of products in this case, but also of capacities (machines to workcenters to production units) and time. The higher level decisions constrain the lower level ones; only if these constraints are satisfied are the decisions at the different levels consistent. The ability to aggregate products depends on the specific situation, although common structures such as aggregate products that allow capacity-oriented seasonal production planning can be identified in many cases.

The vertical decomposition and strict top-down approach of the Hax/Meal approach impose some important limitations. Although the planning models are specified at all levels and the production quantities of product types, product families, and individual products are consistent, overall optimality is not guaranteed, for two primary reasons:

1. The production plan obtained from the optimal aggregate plan is only equal to the optimal production plan obtained from a model formulated at the item level under the strong assumptions of perfect aggregation (Axsäter 1981, 1986). In practice the data of individual products differ to some extent, making only approximate aggregation possible.
2. The decision models at higher levels often cannot accurately anticipate the impact of their decisions on the costs of the base-level decisions. For instance, in the Hax/Meal framework, the seasonal planning carried out at the product-type level does not accurately represent the impact of its decisions on the total setup

costs determined by the product family subproblem at the next lower level (Graves 1982: 263 ff.). This information can only be obtained by feedback from the product family level. Graves (1982) extends the Hax/Meal approach with a feedback mechanism based on Lagrangian techniques that modifies the holding cost coefficients used in the product type problem, dividing the holding costs between the product type and product family subproblems (Graves 1982: 265).

The Hax/Meal case study considers only one production stage. Extending the approach to a two-stage system as in Bitran et al. (1982) raises additional issues. Product aggregation now requires aggregation of multistage material flows, requiring the definition of aggregate bills of material (Axsäter 1986). Secondly, minimum inventory levels must be defined for aggregate planning in order to guarantee SKU availability at the item level. Determining these minimum inventory levels is a complex research topic in its own right (Axsäter 1986; Lasserre and Mercé 1990; Gfrerer and Zäpfel 1995).

In the 1980s and 1990s, the HPP research tradition was largely pursued through case studies, with some conceptual work (Bitran and Tirupati 1993). McKay et al. (1995) present a review and critique of the approach, while Leachman (1993, 2001) presents an extensive case study in the semiconductor industry. Conceptual issues are discussed in Schneeweiss (2003).

Since HPP emphasizes the capacity aspects of the PPC problem that are the principal weak point of MRP, whose focus is material planning, integrating the two frameworks seems reasonable. Meal et al. (1987) attempt this integration for a manufacturer of computer peripherals, noting that HPP encompasses the allocation of production among plants that is not considered in MRP. At the plant level, although "both MRP and HPP deal with capacity and material plans" (p. 952), HPP tends to focus on the capacity side of the MPC hierarchy (Fig. 3.2) "communicating the constraints from the front end to the engine to the back end," whereas MRP focuses on the material side communicating the material requirements from production planning to Master Production Schedule to detailed material requirements. The distinction between "capacity oriented" and "product oriented" planning approaches (Bertrand et al. 1990: 57 ff.) expresses this difference. Hence capacity requirements can be derived from MRP, while estimates of available capacity can come from HPP (Meal et al. 1987: 953). MRP determines material and capacity requirements, while HPP "starts with capacity available and schedules the jobs to fill the capacity" (p. 954).

This capacity-oriented view of HPP raises the question of how much the maximum possible output the system can produce is affected by the aggregate capacity loading. High capacity loading may allow more effective optimization of lot sizes than is possible when there is less work available to the resources. A large amount of work available to a machine reduces the probability of its idling due to lack of material. The clearing function models discussed in Chaps. 7 and 8 formulate several different models of this relationship between workload and output. We now discuss the Advanced Planning Systems framework that has its roots in the HPP research we have just briefly reviewed.

3.2.2 Advanced Planning Systems (APS)

Today's Advanced Planning Systems (APS) (Stadtler et al. 2015) seek to implement essential PPC functions, emphasizing planning and coordination of the material flow between companies or manufacturing plants using the data collection and organization capabilities of the Enterprise Resource Planning (ERP) and Manufacturing Execution Systems (MES) used by many companies today. The Supply Chain Planning Matrix (Fleischmann et al. 2015), shown in Fig. 3.4, provides a basic framework for the development of these systems. In the figure, which is modified somewhat from the original to avoid additional terminology, each planning function, represented by a rectangle, produces decisions that may form inputs for other planning functions. The horizontal axis represents material flow across business functions (procurement, production, distribution, and sales), and the vertical axis the time frame associated with those decisions (long-, mid-, and short-term).

Strategic Network Design is an ongoing long-term process across all business functions, determining the products to be produced, the markets to be served, and the locations and sizes of the facilities to produce and distribute them. As in the MPC framework in Sect. 3.1, Demand Management involves developing demand forecasts at different levels of aggregation: long-term aggregate forecasts at the level of product families, large time buckets and regional geographies required for Strategic Network Planning, and the disaggregated, shorter-term forecasts used for Master Planning. Master Planning takes as inputs the long-term Strategic Network Design decisions and determines a time-phased plan specifying how much of each

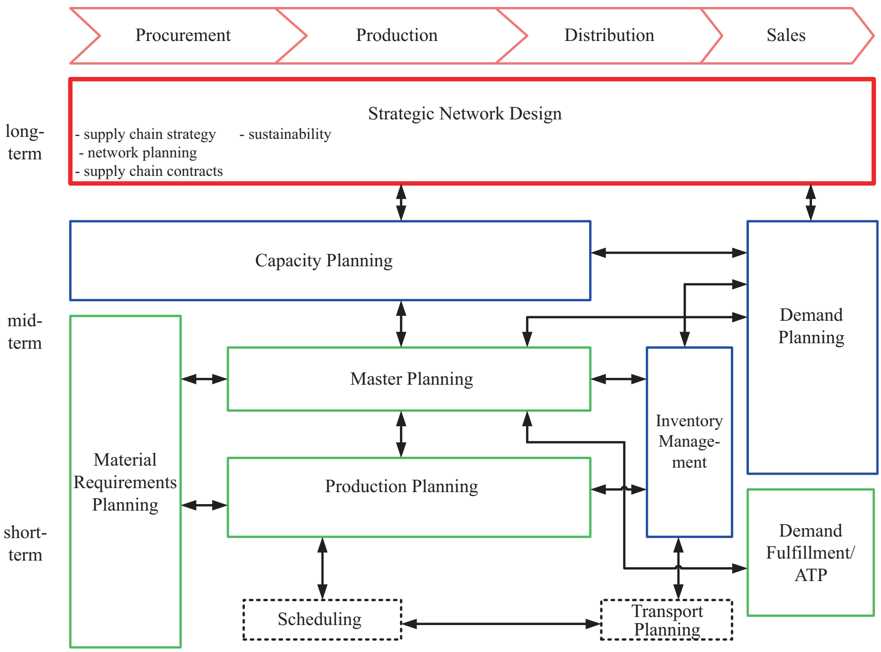

Fig. 3.4 Supply chain planning matrix (Fleischmann et al. 2015, modified by Moench et al. 2017)

product or product family will be produced in what facilities in order to coordinate material flow through the supply chain. Since the management of seasonal demand fluctuations by building inventories ahead of demand peaks, outsourcing, or delaying demand is an important consideration, the time frame for Master Planning must consider an entire seasonal cycle. The level of aggregation in the Master Planning activity can vary; it is usually focused on potentially constraining resources and product families, but can also be performed at the level of individual products. Note that the Master Plan of the Supply Chain Planning Matrix is not necessarily the same thing as the Master Production Schedule of the MPC framework; the Master Plan is not necessarily computed at the level of specific items and usually considers multiple production units and capacity constraints at potentially limiting workcenters. The Master Production Schedule, on the other hand, does not consider the bill of material explosion necessary to synchronize material flow across multiple production units; in the MPC framework, this is performed by the MRP logic.

After Master Planning is complete, Production Planning seeks a capacity-feasible release plan that will allow each facility in the supply chain to meet the production targets set for it by Master Planning. Again, the Supply Chain Planning Matrix uses the term “Production Planning” in a different meaning than that in the MPC framework (and this volume); in the latter it encompasses all planning activities leading up to the computation of the order releases, while under the Supply Chain Planning Matrix, it is limited to computing capacity-feasible order releases that will meet the production goals set by Master Planning for the individual production units. Once work is released into a production unit, its progress towards completion is controlled by that unit’s internal scheduling function.

The structures of the mathematical models for Master Planning and Aggregate Production Planning are quite similar; in fact, the term “Sales and Operations Planning” is used in both the frameworks (Vollmann et al. 2005, Chap. 3 and Stadtler et al. 2015: 173 f.). The principal decision variables are either releases or production quantities of each product (or product family) in each period in the planning horizon at each facility considered; we show in Chap. 5 that under the assumption of fixed, workload-independent lead times, these two quantities are equivalent. The models must include material balance constraints for all inventory locations considered, capacity constraints for critical resources, and domain-specific constraints representing technological and business policy constraints specific to the application of interest. Models for Aggregate Production Planning or Master Production Scheduling are usually formulated for one level in the product structure, mostly final products or—more generally—MPS items, whereas Master Planning explicitly models flows and inventories for all facilities considered at the specified level of detail. As the level of detail in Master Planning models is increased to model the process more precisely, at least some portions of a Master Planning model can easily acquire the level of detail usually associated with the Production Planning function of APS. Hence the authors of both MPC and APS frameworks emphasize that they need to be adapted to different situations. The primary function of the combined problems is to coordinate the flow of material through the supply chain to best meet the firm’s objectives.

Both PPC frameworks described here—the MPC framework based on MRP/MRP II and APS—eventually yield production orders for the production units: from MRP and lot sizing in the MPC framework, or from the master planning and production planning functions under APS. Production orders can also be generated from independent demand inventory control systems (e.g., for spare parts), and in MTO companies, production orders can result directly from customer orders. A (hopefully small) fraction of the production orders might be unplanned, resulting, e.g., from specific material requirements of customer-specific product variants in assemble-to-order production as described in Sect. 3.1. All these orders must be released to the production units in a way that guarantees that the planned due dates are satisfied, which requires keeping the cycle times under control.

Mechanisms for managing cycle times within PPC systems fall into two basic camps: those that treat cycle time as an exogenous variable to be forecast and those that view it as a variable to be controlled (Tatsiopoulos and Kingsman 1983). The former contradicts the queueing perspective developed in Chap. 2, which makes it quite clear that the average cycle time T is determined by the planning level's release decisions through their effect on resource utilization and the variability of material flows. The other camp, motivated by Little's Law discussed in Sect. 2.2, attempts to maintain stable mean cycle times T by regulating the short-term release of work into production units over time to maintain a constant workload W. We now turn to a discussion of these latter approaches.

References

Anthony RN (1966) Planning and control systems: a framework for analysis. Harvard University Press, Cambridge

Ashby WR (1956) An introduction to cybernetics. Chapman and Hall, London

Axsäter S (1981) Aggregation of product data for hierarchical production planning. Oper Res 29(4):744–756

Axsäter S (1986) On the feasibility of aggregate production plans. Oper Res 34(5):796–800

Baker KR (1993) Requirements planning. In: Graves SC, Rinnooy Kan AHG, Zipkin PH (eds) Handbooks in operations research and management science, Logistics of production and inventory, vol 3. Elsevier Science, Amsterdam, pp 571–627

Berry W, Vollmann T, Whybark D (1979) Master production scheduling: principles and practice. American Production and Inventory Control Society, Chicago

Bertrand JWM, Wortmann JC, Wijngaard J (1990). Production Control: A Structural and Design Oriented Approach. Amsterdam, Elsevier

Bitran GR, Tirupati D (1993) Hierarchical production planning. In: Graves SC, Rinnooy Kan AHG, Zipkin P (eds) Logistics of production and inventory, vol 4. Elsevier, Amsterdam, pp 523–568

Bitran GR, Haas EA, Hax AC (1981) Hierarchical production planning: a single stage system. Oper Res 29(4):717–743

Bitran GR, Haas EA, Hax AC (1982) Hierarchical production planning: a two-stage system. Oper Res 30(2):232–251

Blackburn JD, Kropp DH, Millen RA (1985) MRP system nervousness: causes and cures. Eng Costs Prod Econ 9(1–3):141–146

Blackburn JD, Kropp DH, Millen RA (1986) A comparison of strategies to dampen nervousness in MRP systems. Manag Sci 32(4):412–439

Chandler AD (1962) Strategy and structure: chapters in the history of the American industrial enterprise. MIT Press, Cambridge

Chandler AD (1980) The visible hand: the managerial revolution in American business. Belknap Press, Cambridge

de Bodt MA, Van Wassenhove LN (1983) Lot sizes and safety stocks in MRP: a case study. Prod Inventory Manag (First Quarter):1–15

Fleischmann B, Meyr H, Wagner M (2015) Advanced planning. In: Stadtler H, Kilger C, Meyr H (eds) Supply chain management and advanced planning. Springer, Berlin, pp 71–95

Gfrerer H, Zäpfel G (1995) Hierarchical model for production planning in the case of uncertain demand. Eur J Oper Res 86:142–161

Graves SC (1982) Using Lagrangian techniques to solve hierarchical production planning problems. Manag Sci 28(3):260–275

Grubbstrom RW (1999) A net present value approach to safety stocks in a multi-level MRP system. Int J Prod Econ 59:361–375

Hax AC (2013) Hierarchical production planning. In: Gass SI, Fu MC (eds) Encyclopedia of operations research and management science. Springer, Boston

Hax AC, Meal HC (1975) Hierarchical integration of production planning and scheduling. In: Geisler MA (ed) Logistics. MIT Press, Amsterdam, pp 53–69

Helber S, Sahling F (2010) A fix-and-optimize approach for the multi-level capacitated lot sizing problem. Int J Prod Econ 123(2):247–256

Holt CC, Modigliani F, Muth JF, Simon HA (1960) Planning production, inventories and work force. Prentice Hall, Englewood Cliffs

Hopp WJ, Spearman ML (2008) Factory physics: foundations of manufacturing management. Irwin/McGraw-Hill, Boston

Kimms A (1997) Multi-level lot sizing and scheduling: methods for capacitated, dynamic, and deterministic models. Physica-Verlag, Heidelberg

Landvater DV, Gray CD (1995) MRP II standard system: a handbook for manufacturing software survival. Wiley, New York

Lasserre JB, Mercé C (1990) Robust hierarchical production planning under uncertainty. Ann Oper Res 26(1):73–87

Leachman RC (1993) Modeling techniques for automated production planning in the semiconductor industry. In: Cinani TA, Leachman RC (eds) Optimization in industry. Wiley, Chichester, pp 1–30

Leachman RC (2001) Semiconductor production planning. In: Pardalos PM, Resende MGC (eds) Handbook of applied optimization. Oxford University Press, New York, pp 746–762

Lin PC, Uzsoy R (2016) Chance constrained formulations in rolling horizon production planning: an experimental study. Int J Prod Res 54(13):3927–3942

Little JDC (1961) A proof of the queueing formula $L = \lambda W$. Oper Res 9:383–387

Mather H, Plossl GW (1978) Priority fixation versus throughput planning. Prod Invent Manag J 19(3):27–51

McKay KN (2010) The historical foundations of manufacturing planning and control practices. In: Kempf KG, Keskinocak P, Uzsoy R (eds) Planning production and inventories in the extended enterprise, vol 12. Springer, New York, pp 21–32

McKay KN, Safayeni FR, Buzacott JA (1995) A review of hierarchical production planning and its applicability for modern manufacturing. Prod Plan Control 6(5):384–394

Meal H (1979) Safety stocks in MRP systems. Operations Research Center, Massachusetts Institute of Technology, Cambridge

Meal HC (1984) Putting production decisions where they belong. Harv Bus Rev 62:102–111

Meal HC, Wachter MH, Whybark DC (1987) Material requirements planning in hierarchical production planning systems. Int J Prod Res 25(7):947–956

Miller JG (1979) Hedging the master schedule. In: Ritzman LP (ed) Disaggregation problems in manufacturing and service organizations. Martinus Nijhoff, Boston

Moench L, Uzsoy R, Fowler J (2017) A survey of semiconductor supply chain models part I: semiconductor supply chains and strategic network design. Int J Prod Res 56(13):4524–4545

Orlicky J (1975) Material requirements planning: the new way of life in production and inventory management. McGraw-Hill, New York

Sahin F, Narayanan A, Robinson EP (2013) Rolling horizon planning in supply chains: review, implications and directions for future research. Int J Prod Res 51(18):5413–5436

Schneeweiss C (2003) Distributed decision making. Springer, Berlin

Selcuk B, Fransoo JC, De Kok AG (2006) The effect of updating lead times on the performance of hierarchical planning systems. Int J Prod Econ 104(2):427–440

Selcuk B, Adan I, de Kok AG, Fransoo JC (2009) An explicit analysis of the lead time syndrome: stability condition and performance evaluation. Int J Prod Res 47(9):2507–2529

Stadtler H, Kilger C, Meyr H (2015) Supply chain management and advanced planning. Concepts, models, software, and case studies. Springer, Berlin

Tardif V, Spearman ML (1997) Diagnostic scheduling in finite-capacity production environments. Comput Ind Eng 32:867–878

Tatsiopoulos IP, Kingsman BP (1983) Lead time management. Eur J Oper Res 14:351–358

Tempelmeier H, Buschkühl L (2009) A heuristic for the dynamic multi-level capacitated lotsizing problem with linked lotsizes for general product structures. OR Spectr 31(2):385–404

Vollmann TE, Berry WL, Whybark DC, Jacobs FR (2005) Manufacturing planning and control for supply chain management. McGraw-Hill, New York

Voss S, Woodruff DL (2003) Introduction to computational optimization models for production planning in a supply chain. Springer, Berlin

Wight O (1974) Production and inventory management in the computer age. Wiley, Boston

Wight O (1983) MRPII: unlocking America's productivity potential. Oliver Wight Limited Publications, Williston

Zäpfel G (2000) Strategisches Produktionsmanagement. Oldenbourg, Munich