Chapter 3

A Framework for Demand Management

In this chapter, we propose a classification framework for demand management. This framework is subsequently used to identify general types of models and software in relation to the most important key-decision variables in supply chain management. To demonstrate the correspondence of the identified general types of models with current scientific research, we present and discuss important review papers for each of the identified types. In contrast to the subsequent Chapter 4, we will not discuss single research papers in this chapter.

We start this chapter with a definition of demand management as it is understood in this work, following by a detailed description of the framework. Once the framework is introduced, we discuss the identified model types supplemented by references to important review papers.

3.1 Demand Management Defined

Demand management as it is understood in this work is closely related to the previously described demand fulfillment in APS. As we have seen, the notion of demand fulfillment is common in manufacturing, but similar concepts exist in other industries, e.g., the earlier mentioned revenue management in the service industries. Therefore—as we do not solely build on the notion of demand fulfillment—we refer to the concepts developed in this work as demand management concepts.
In order to define demand management in the following, we adopt the supply chain framework of Quante et al. (2009b) as shown in Fig. 3.1. Relevant in this work are the processes in the supply chain downstream of the CODP (order-driven processes). The framework shows the analogy between demand fulfillment and revenue management as it extends elements like the CODP (which is important for demand fulfillment) with elements representing revenue management concepts. For instance, pricing decisions can be linked to the item final product and capacity allocation decisions are linked to the item demand.

Demand management is closely tied to decisions in the depicted supply chain and therefore depends on its specific characteristics. For example, the current inventory at the CODP or the remaining production capacity may influence pricing decisions or promised due dates. By capturing these characteristics, the depicted elements of the supply chain framework provide a systematic basis for identifying demand management models and software.

3.2 General Model Types for Demand Management

3.2.1 Classifying Demand Management Models

This section introduces a framework for generic demand management types developed to classify different literature streams. The structure of the framework follows the work of Quante et al. (2009b). The authors distinguish demand management models according to demand or price decisions, and control over the replenishment quantity (as shown in Fig. 3.2). With these two dimensions, distinct model types corresponding to common research streams are identified. Quante et al. (2009b) note that these two dimensions are the "key decision variables regarding demand and supply". Before reviewing each model type in detail, the two dimensions are described in the following. Models in the first row of Fig. 3.2 take demand as entirely exogenous. They satisfy demand first-come-first-served (FCFS) at a given price. In particular, these models do not consider a segmentation of customers. The middle and bottom row of Fig. 3.2 represent a more active management of demand. The models in the second row influence the demand by adjusting prices. Like in the first row, the customers are not segmented into specific classes and treated all equal just distinguished according to their willingness to pay. The bottom row entails models that explicitly consider heterogeneous customers. In response to a customer request, these models face a trade-off between accepting a current, low-priority customer now versus reserving the resources for high-priority customers expected in the future. The distinction between the middle and bottom row in Fig. 3.2 corresponds with the classification of RM models of Talluri and van Ryzin.
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(2004). In order to follow their terminology, models are labeled as price-based or quantity-based.

The columns in Fig. 3.2 reflect the way models decide about inventory replenishment at the CODP. In the first column, models do not consider replenishments. As for example, in airline revenue management, the seats in an airplane can not be replenished when sold out. In the middle column, inventory replenishments are considered but not actively influenced. The right column entails models that actively decide about the quantities they want to replenish.

In the following, we briefly discuss each of the aforementioned model types. We will refer to available review papers for each of the model types. A detailed discussion of individual articles relevant in this work is following in Chapter 4.

3.2.2 Single-Class Exogenous Demand Models

No models were found fitting in the upper left cell of Fig. 3.2. This is not surprising since models with a given price and no consideration of replenishment or inventory, respectively, have nothing to decide on, neither on the demand nor on the replenishment side of the supply chain.

In the next cell to the right, the so-called order promising models consider price (i.e. demand), current inventory, and future replenishment quantities as given. This results in information about product availability and delivery times. For each incoming customer order the model decides real-time on the due date. The decision is made in a greedy fashion, based on availability of goods. As an example, the basic order promising model of Sect. 4.3.1 falls in
this category. An introduction and overview of this so-called “real-time mode” or “single-order-processing” models is given in Ball et al. (2004), Chen et al. (2001), and Fleischmann and Meyr (2004). Additionally, a broad overview of due date management models with an emphasis on stochastic models is included in the work of Keskinocak and Tayur (2004).

The upper right cell of Fig. 3.2 holds the vast class of stochastic inventory control (SIC) models, which focus on optimal inventory replenishment. Some of these models primarily address the structure of optimal replenishment policies, as for example the famous $(s, S)$-policy proven by Scarf (1960). Other models seek to determine optimal control parameters of such policies, such as the optimal ordering time, order quantity and inventory review intervals. Many SIC models build on the classical newsvendor model, which seeks to determine the optimal order quantity for a perishable product under stochastic demand. An overview of single-period newsvendor problems is given by Khouja (1999). Silver (1981) provides an overview and typology of many standard inventory problems, such as the ones mentioned above. General up-to-date overviews of inventory models can be found in the textbooks by Silver et al. (1998), Porteus (2002) and Tempelmeier (2006).

### 3.2.3 Price-Based Demand Models

The model types in the middle row of Fig. 3.2 treat price as a decision, which influences the demand. Pure pricing models aim to determine an optimal selling price, without considering replenishments. For example, given a price-demand relation, the goal is to find the price which maximizes total revenues. Mild et al. (2006) review factors influencing demand and show how to find optimal prices.

**Markdown** models determine the right price path for inventory clearance for a given amount of inventory, which cannot be replenished during the planning horizon. Elmaghraby and Keskinocak (2003) classify several dynamic pricing models with and without replenishment decisions, the latter ones including markdown models.

**Auctions**, as discussed for example by Talluri and van Ryzin (2004, Sect. 6), take a fundamentally different approach to pricing. They provide a price-discovery mechanism and thereby an alternative to posting fixed prices. This approach is particularly valuable if little demand information is available. The aforementioned authors discuss the close connection between auctions and dynamic pricing.

**Trade promotion** models represent a type of pricing models that consider replenishments as an exogenous input and therefore fit in the second column.
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of Fig. 3.2. Neslin (2002) provides an overview and discusses the reasons for promotions.

Research in integrated pricing (IP) models dates back to Whitin (1955) who extends the EOQ-formula as well as the classical newsvendor model with price decisions. This field has seen extensive research in the last decades, which is summarized, for example, by Petruzzi and Dada (1999). Recent research focuses on multiple period models, which are discussed in the well-known literature reviews of Chan et al. (2004), Elmaghraby and Keskinocak (2003) and Yano and Gilbert (2003). Few models exist for environments in which replenishment, prices and due dates are set simultaneously. Some models of this type and other models dealing with due date setting can be found, for example, in the previously mentioned review paper by Keskinocak and Tayur (2004).

From an application-oriented perspective it is worthwhile comparing IP and a successive application of pricing & SIC models. While IP models recognize the interdependence between pricing and replenishment and therefore determine decisions simultaneously, they do so at the cost of a more simplified demand and supply representation. Pure pricing models may include sophisticated demand functions, including reference price effects, promotion effects, and competition (Mild et al., 2006). Similarly, SIC models consider factors such as multiple suppliers and quantity-discounts. IP models typically cannot deal with these factors due to tractability (Elmaghraby and Keskinocak, 2003, Sect. 4).

3.2.4 Quantity-Based Demand Models

Models in the bottom row of Fig. 3.2 take prices as exogenous but manage demand by means of rationing strategies. In contrast to the models of the top and middle row, the models distinguish multiple customer classes and prioritize them rather than fulfilling orders in an FCFS manner.

The type traditional revenue management (TRM) in the first cell of the third row refers to models that are common in airline applications. In these models, given units of a perishable product (e.g., seats on a flight on a specific day) are allocated to customers with different priorities or different willingness to pay. The basic question is whether to accept a given order or to reserve capacity in anticipation of more profitable future orders. McGill and van Ryzin (1999) and Pak and Piersma (2002) provide an overview and a short history of research in traditional revenue management with a focus on airline applications. Boyd and Bilegan (2003) discuss models focusing on e-commerce applications. The recent review by Chiang et al. (2007) includes an overview of RM practices in different industries.
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Models of the type *Allocated available-to-promise* (aATP) are similar to the order promising type of the top row except for differentiating between multiple customer classes. Scarce resources (inventory on hand, planned stock at the CODP or capacity downstream of the DP) are allocated to these classes according to customer profitability or other priority measures. Within each class, customer requests are usually handled FCFS, just as in traditional order promising. Examples of these type have been discussed before in Sect. 4.3.2. Guerrero and Kern (1988) introduce the general problem of accepting and refusing orders and discuss the requirements and implications of order promising mechanisms. For reviews of the mostly deterministic models of this type the reader is referred to Kilger and Meyr (2008) and Pibernik (2005).

If customer requests do not have to be answered instantaneously, several customer orders can be collected and jointly promised in a *batch*, thereby creating higher degrees of freedom for selecting the most important or profitable orders within a simultaneous optimization process. Overviews of these so-called “batch order promising models” can again be found in the work of Ball et al. (2004), Chen et al. (2001) or Fleischmann and Meyr (2004).

A review of integrated due-date management and job-scheduling models with deterministic orders is provided by Gordon et al. (2002). The article considers batch-models in which due dates are determined according to current capacity and the desired delivery date. Keskinocak and Tayur (2004) give a general overview of due-date setting models.

aATP and TRM models are similar in that they decide about demand fulfillment with respect to different customer classes. The most significant difference concerns the perishability of resources. TRM considers “perishable” products, e.g., empty seats on a specific flight, which are lost after the departure date, whereas the ATP quantities managed in aATP models are generally storable. Another difference concerns the time horizon. TRM models typically consider a fixed day of capacity availability, e.g., the departure date of a flight. In contrast, aATP models consider multiple periods linked through the storability of excess inventory. Furthermore, aATP models usually assume deterministic demand whereas demand in TRM models is stochastic.

The last model type within the grid concerns *inventory rationing* (IR) models. Similar to the relationship between aATP and order promising, IR models extend SIC models by distinguishing and prioritizing multiple customer classes. For an early review refer to Kleijn and Dekker (1998). As traditional SIC models, IR models may consider deterministic or stochastic replenishment lead times. A further distinction within this class of models concerns the number of demand classes considered, which may be general or limited to two classes.
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IR and aATP models differ in terms of exogenous versus endogenous replenishment. Specifically, IR models consider replenishment decisions with stationary deterministic or stochastic lead times. In contrast, aATP typically considers capacitated, dynamic and deterministic arrivals of push-based production (=replenishment) quantities. To this end, aATP usually assumes deterministic and dynamic demand forecasts whereas IR models assume stochastic demand.

In addition to the model types captured in Fig. 3.2, a few recent research streams aim to combine several types by simultaneously considering multiple attributes. For example, Kocabıyıkoglu and Popescu (2005) jointly analyze price and allocation decisions with two customer classes. Since most quantity-based models assume exogenous prices, this seems to be a promising direction for future research. Bitran and Caldentey (2003) formulate a general model of this problem and review the current state of research. Another approach is pursued in Ding et al. (2006) in which trade promotion models are combined with inventory rationing models. The authors denote the resulting new problem type by ADP, referring to the allocation of available stock, discounting and prioritization of customers.

3.3 General Software Types for Demand Management

3.3.1 Classifying Demand Management Software

The software market for demand and supply chain solutions has changed in recent years. For many years the focus was on the supply side. The interest is now, however, turning to end-to-end solutions including the demand side. Big supply chain solution providers like Oracle and SAP are investing large amounts in the acquisition of demand-related know-how. For example, in 2005 SAP took over Khimetrics, a leading vendor of markdown, price, and promotion-optimization solutions. Oracle—after taking over one of its largest competitors in supply chain solutions, Peoplesoft, in 2005—simultaneously invested in the demand solutions of Demantra (2006), ProfitLogic (2005) and Retek (2005), all of them leading vendors of retail revenue management software. Another big consolidation occurred in 2006 when JDA Software—a provider of specialized retail solutions—took over Manugistics, a supply chain solution provider focusing on profit optimization in the consumer goods industry.

The scope of our current analysis is restricted to software supporting short-term decision making in DM. These solutions draw data from other software systems, such as Customer Relationship Management systems on the demand side (Buttle, 2004) and Enterprise Resource Planning systems (Stadtler and
Kilger, 2008) on the supply side. Since these systems themselves do not focus on decision making we do not include them in our analysis.

As discussed in the previous section, scientific optimization models are fairly well described in the literature. One can easily identify data, decision variables, restrictions and solution strategies. Moreover, the solution quality is often analyzed in detailed numerical studies. This is different for commercial software solutions. Usually, available information is scarce and reveals little of the underlying technology. Software users can only assess the supported input data, available options, and the resulting output that is automatically calculated. The solution quality can hardly be evaluated objectively and is usually judged by user experience.

Our analysis of software modules reflects this limited availability of objective information. We build our characterization of software types and functionalities primarily on available software reviews and whitepapers. As a starting point we use essentially the same dimensions as for the scientific models. Model data and decisions roughly correspond with software input and output, respectively.

Fig. 3.3 structures software types along the same axes as the model types of Section 3.2. We choose names according to the functionality of commercial software modules on the market. The remainder of this section briefly reviews each of these software types.

Figure 3.3: Types of Demand Management Software (Quante et al., 2009b)
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3.3.2 Single-Class Exogenous Demand Solutions

The mid upper cell of Fig. 3.3 denoted by traditional order promising contains traditional software modules for short-term order promising under known inventory availability. When a customer order arrives, the software simply determines whether the order can be satisfied out of available inventory. If not, the order is backlogged according to a standard lead time without considering future capacity or additional incoming supply. It is easy to see that this approach can lead to an order peak after the standard lead time and thus to severe capacity problems in the future. Kilger and Meyr (2008) illustrate this situation in a simple example.

Refilling of inventory is usually left to purchasing & materials requirements planning modules, which are part of enterprise resource planning (ERP) systems. Essentially, these systems support refilling of non-bottleneck material and components from a single vendor. An overview of these classical systems can be found, for example, in the textbook of Vollmann et al. (2005). Since these classical systems provide sufficient solution quality only for very simple settings, specialized inventory modules consider extensions such as capacitated replenishment, stochastic demand, and multiple suppliers (Stadtler, 2008). Such modules usually are part of larger advanced planning and supply chain planning software suites. Additionally, there are specialized vendors of supply-chain wide inventory optimization tools, such as Optiant (Optiant, 2007) with its inventory suite Powerchain and Smartops (Smartops, 2007).

3.3.3 Price-Based Solutions

Markdown management systems are mainly used in retail, for example for end-of-season stock clearance. An example of markdown management systems is B_Line, described by Mantrala and Rao (2001) under the name MARK. The system takes possible prices and corresponding demand probability distributions for each period as inputs and can find both markdown and markup price paths. The output consists of a specific price in each period. Furthermore, MARK is capable of finding a suitable amount of initial inventory by iterating through a discrete set of possible inventory levels. Elmaghraby and Keskinocak (2003, Sect. 3.2) describe the capability of markdown solutions.

Software systems of the type pricing management are relatively new. This is due to improvements in computing power and increased availability of past sales data. The rise of data warehouses and cheap computing power has recently allowed the use of automated pricing systems for many applications. Pricing management systems are based on complex price-demand functions for which suitable parameters have to be estimated, a process requiring vast amounts of past sales data. For example, to estimate price elasticity, the sales
data must include a certain degree of diversity, corresponding with at least a few past price changes. Capacity or inventory restrictions are usually not considered in these types of software (see for example Mild et al., 2006).

The quick expansion of e-commerce applications has boosted the use of auction systems. The large number of different systems merits a review in its own right and exceeds the scope of our analysis. We refer to Kambil and van Heck (2002) for a systematic introduction to this field. Vakali et al. (2001) discuss the characteristics of internet-based auction systems and present a short survey of popular applications.

Similar to the previously described markdown systems, promotion optimization is also used in retail environments, as described by Elmaghraby and Keskinocak (2003, Sect. 3.2). Very detailed information about the capability of such systems can be found on-line, for example from the vendors mentioned at the beginning of this section.

The term enterprise profit optimization (EPO) was coined by the software company Manugistics, who claims to be the first vendor offering an integrated pricing and supply solution (Manugistics, 2002). Furthermore, Manugistics software is meant to be able to allocate scarce resources to the most profitable customers, thus simultaneously applying ideas of quantity-based DM. Demand and supply planning is realized in many solutions, but not in an integrated way and not including price decisions. Most APS forecast demand for different price levels and then successively analyze—within the context of mid-term planning—several what-if scenarios and their effects on the total supply chain.

3.3.4 Quantity-Based Solutions

APS software modules that support mid-term, aggregated supply and demand decisions are known as master planning modules (Meyr et al., 2008b) as previously mentioned in Sect. 2.2. They receive deterministic demand forecasts and prices as inputs from the demand planning module of APS (Kilger and Wagner, 2008) and then determine the best combinations of sales, production and replenishment quantities and the corresponding inventories under given capacity constraints. Quantities can be allocated to different customer classes. In terms of the supply chain framework in Fig. 3.1, master planning modules deal with forecast-driven planning activities (e.g., push-based replenishment of the CODP) and therefore fall outside the scope of our definition of DM. However, we feel that they deserve mention since their resulting allocations serve as the primary input for the short-term, capacity-checked order promising, executed by the Demand Fulfillment and ATP modules of APS. A detailed list
of options considered in master planning modules can be found in the work of Rohde and Wagner (2008).

The type in the lower middle cell takes capacity and inventory replenishments into account and corresponds to the demand fulfillment & ATP modules of APS previously described in Chapter 2. These modules extend the aforementioned traditional order promising and determine due dates for incoming customer orders, which promise to be more reliable than simple standard lead times. In addition, if ATP quantities are allocated to customer priority classes—in the usually implemented aggregated way—order promising differentiates with respect to customer importance, based on customer profitability or strategic impact.

Revenue management software is widely used by airlines, hotel chains, and car rental agencies. RM software systems basically take the given capacity and offered tariffs as input and decide on acceptance or rejection of customer orders. One of the main differences with demand fulfillment & ATP is that RM software focuses on revenues rather than costs. Furthermore, RM systems usually forecast demand in much more detail than demand fulfillment modules, e.g., for each flight, on each day, and for each customer class. These forecasts require a large amount of historical sales data in order to be reliable. Modern revenue management systems can handle many additional industry-specific issues, such as overbooking and connecting flights in the airline context (Talluri and van Ryzin, 2004, Sect. 10.1.3, 11.2).