14

Logistic and production models

In Chapter 13 we saw how the combination of relational marketing strategies with business intelligence and data mining models makes it possible to simultaneously increase revenues and reduce the costs of marketing actions, with an overall benefit for the profitability of an enterprise.

Besides acting on the marketing control levers, a manufacturing company can achieve further reductions in costs by improving its processes in another area that has received increasing attention in recent years: an effective *supply chain* management, understood as the logistic and production processes of a single enterprise as well as the network of companies composing the production chain of a given industry.

In this chapter we will focus on optimization models aimed at the integrated planning of the logistic chain from the perspective of a single company. In particular, we will begin with a qualitative description of the relevant processes within a logistic production system, by highlighting the major decisions that logistics managers have to face. The discussion will be confined to medium-term planning processes, which are concerned with some critical choices in the organization of the supply chain and can bring about substantial savings if appropriately optimized. We will then introduce some classes of optimization models, showing how the different features of logistic production systems can be formally represented. Finally, we will discuss a few business case studies, with particular emphasis on a decision support system for supply chain optimization developed for a company in the food industry.

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14.1 Supply chain optimization

In a broad sense, a *supply chain* may be defined as a network of connected and interdependent organizational units that operate in a coordinated way to manage, control and improve the flow of materials and information originating from the suppliers and reaching the end customers, after going through the procurement, processing and distribution subsystems of a company, as shown in Figure 14.1.

The aim of the integrated planning and operations of the supply chain is to combine and evaluate from a systemic perspective the decisions made and the actions undertaken within the various subprocesses that compose the logistic system of a company.

Many manufacturing companies, such as those operating in the consumer goods industry, have concentrated their efforts on the integrated operations of the supply chain, even to the point of incorporating parts of the logistic chain that are outside the company, both upstream and downstream.

The major purpose of an integrated logistic process is to minimize a function expressing the total cost, which comprises processing costs, transportation costs for procurement and distribution, inventory costs and equipment costs. Note that

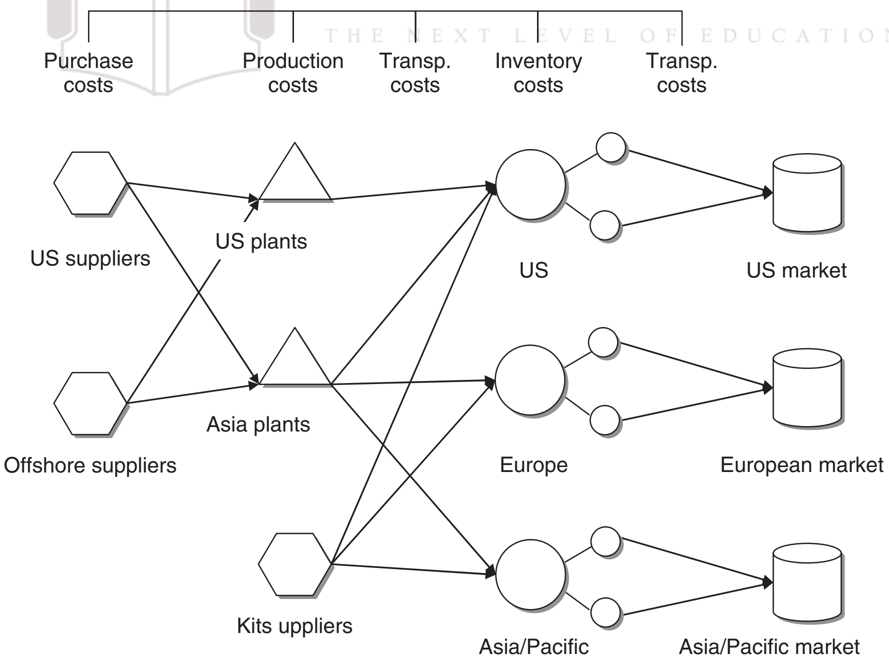

Figure 14.1 An example of global supply chain

the optimization of the costs for each single phase does not generally imply that the minimum total cost of the entire logistic process has been achieved, so that a holistic perspective is required to attain a really optimized supply chain.

The need to optimize the logistic chain, and therefore to have models and computerized tools for medium-term planning and for capacity analysis, is particularly critical in the face of the high complexity of current logistic systems, which operate in a dynamic and truly competitive environment. We are referring here to manufacturing companies that produce a vast array of products and that usually rely on a multicentric logistic system, distributed over several plants and markets, characterized by large investments in highly automated technology, by an intensive usage of the available production capacity and by short-order processing cycles. The features of the logistic system we have described reflect the profile of many enterprises operating in the consumer goods industry.

In the perspective outlined above, the aim of a medium-term planning process is therefore to devise an optimal logistic production plan, that is, a plan that is able to minimize the total cost, understood as the sum of procurement, processing, storage, distribution costs and the penalty costs associated with the failure to achieve the predefined service level. However, to be implemented in practice, an optimal logistic production plan should also be feasible, that is, it should be able to meet the physical and logical constraints imposed by limits on the available production capacity, specific technological conditions, the structure of the bill of materials, the configuration of the logistic network, minimum production lots, as well as any other condition imposed by the decision makers in charge of the planning process.

Optimization models represent a powerful and versatile conceptual paradigm for analyzing and solving problems arising within integrated supply chain planning, and for developing the necessary software. Due to the complex interactions occurring between the different components of a logistic production system, other methods and tools intended to support the planning activity seem today inadequate, such as electronic spreadsheets, simulation systems and planning modules at infinite capacity included in *enterprise resource planning* software. Conversely, optimization models enable the development of realistic mathematical representations of a logistic production system, able to describe with reasonable accuracy the complex relationships among critical components of the logistic system, such as capacity, resources, plans, inventory, batch sizes, lead times and logistic flows, taking into account the various costs. Moreover, the evolution of information technologies and the latest developments in optimization algorithms mean that decision support systems based on optimization models for logistics planning can be efficiently developed.

14.2 Optimization models for logistics planning

In this section we will describe some optimization models that may be used to represent the most relevant features of logistic production systems. As already observed when introducing salesforce planning models in Chapter 13, for the sake of simplicity we have chosen to illustrate for each model a single feature of a logistic system. Readers should keep in mind that real-world logistic production systems feature simultaneously more than one of the elements considered, so that the models developed in applications, such as the business case studies presented in Section 14.4, will be substantially more complex as they result from the combination of the different features.

Before proceeding with the description of specific models, it is useful to introduce some notation common to most models presented in this section. The logistic system includes I products, which will be denoted by the index $i \in \mathcal{I} = \{1, 2, \ldots, I\}$. The planning horizon is subdivided into T time intervals $t \in \mathcal{T} = \{1, 2, \ldots, T\}$, generally of equal length and usually corresponding to weeks or months.

The manufacturing process has at its disposal a set of critical resources shared among the different products and available in limited quantities. These resources may consist of production and assembly lines, to manpower, to specific fixtures and tools required by manufacturing. The R critical resources considered in the logistic production system will be denoted by the index $r \in \mathcal{R} = \{1, 2, \ldots, R\}$. Whenever a single resource is relevant to the manufacturing process, the index r will be omitted for sake of simplicity.

14.2.1 Tactical planning

In its simplest form, the aim of tactical planning is to determine the production volumes for each product over the T periods included in the medium-term planning horizon in such a way as to satisfy the given demand and capacity limits for a single resource, and also to minimize the total cost, defined as the sum of manufacturing production costs and inventory costs.

We therefore consider the decision variables

$$P_{it} = \text{ units of product } i \text{ to be manufactured in period } t,$$

$$I_{it} = \text{ units of product } i \text{ in inventory at the end of period } t,$$

and the parameters

$$d_{it} = \text{ demand for product } i \text{ in period } t,$$

$$c_{it} = \text{ unit manufacturing cost for product } i \text{ in period } t,$$

h_{it} = unit inventory cost for product i in period t,

e_i = capacity absorption to manufacture a unit of product i,

b_t = capacity available in period t.

The resulting optimization problem is formulated as follows:

$$\min \quad \sum_{t \in \mathcal{T}} \sum_{i \in \mathcal{I}} (c_{it} P_{it} + h_{it} I_{it}) \tag{14.1}$$

$$\text{s.to} \quad P_{it} + I_{i,t-1} - I_{it} = d_{it}, \quad i \in \mathcal{I}, t \in \mathcal{T}, \tag{14.2}$$

$$\sum_{i \in \mathcal{I}} e_i P_{it} \leq b_t, \quad t \in \mathcal{T}, \tag{14.3}$$

$$P_{it}, I_{it} \geq 0, \quad i \in \mathcal{I}, t \in \mathcal{T}. \tag{14.4}$$

Constraints (14.2) express the balance conditions among production, inventory and demand, by establishing a connection between successive periods along the planning horizon. Inequalities (14.3) constrain the absorbed capacity not to exceed the available capacity for each period.

Model (14.1) is a linear optimization problem which can be therefore solved efficiently even with a very large number of variables and constraints, of the order of a few million, by means of current state-of-art algorithms and computer technologies.

14.2.2 Extra capacity

A first extension of the basic model (14.1) deals with the possibility of resorting to *extra capacity*, perhaps in the form of overtime, part-time or third-party capacity. In addition to the decision variables already included in model (14.1), we define the variables

O_t = extra capacity used in period t,

and the parameters

q_t = unit cost of extra capacity in period t.

The optimization problem now becomes

$$\min \quad \sum_{t \in \mathcal{T}} \sum_{i \in \mathcal{I}} (c_{it} P_{it} + h_{it} I_{it}) + \sum_{t \in \mathcal{T}} q_t O_t \tag{14.5}$$

$$\text{s.to} \quad P_{it} + I_{i,t-1} - I_{it} = d_{it}, \quad i \in \mathcal{I}, t \in \mathcal{T}, \tag{14.6}$$

$$\sum_{i \in \mathcal{I}} e_i P_{it} \leq b_t + O_t, \quad t \in \mathcal{T}, \tag{14.7}$$

$$P_{it}, I_{it}, O_t \geq 0, \quad i \in \mathcal{I}, t \in \mathcal{T}. \tag{14.8}$$

Constraints (14.7) have been modified to include the available extra capacity. The extended model (14.5) is still a linear optimization problem which can be therefore solved efficiently.

14.2.3 Multiple resources

If the manufacturing system requires R critical resources, a further extension of model (14.1) can be devised by considering multiple capacity constraints. The decision variables already included in model (14.1) remain unchanged, though it is necessary to consider the additional parameters

$b_{rt} =$ quantity of resource r available in period t,

$e_{ir} =$ quantity of resource r absorbed to manufacture one unit of product i.

The resulting optimization problem is given by

$$\min \quad \sum_{t\in\mathcal{T}}\sum_{i\in\mathcal{I}} (c_{it}P_{it} + h_{it}I_{it}) \tag{14.9}$$

$$\text{s.to} \quad P_{it} + I_{i,t-1} - I_{it} = d_{it}, \qquad i \in \mathcal{I}, t \in \mathcal{T}, \tag{14.10}$$

$$\sum_{i\in\mathcal{I}} e_{ir}P_{it} \leq b_{rt}, \qquad r \in \mathcal{R}, t \in \mathcal{T}, \tag{14.11}$$

$$P_{it}, I_{it} \geq 0, \qquad i \in \mathcal{I}, t \in \mathcal{T}. \tag{14.12}$$

Constraints (14.11) have been modified to take into account the upper limits on the capacity of the R resources in the system. Model (14.9) remains a linear optimization problem which can be solved efficiently.

14.2.4 Backlogging

Another feature that needs to be modeled in some logistic systems is *backlogging*. The term *backlog* refers to the possibility that a portion of the demand due in a given period may be satisfied in a subsequent period, incurring an additional penalty cost. Backlogs are a feature of production systems more likely to occur in B2B or make-to-order manufacturing contexts. In B2C industries, such as mass production consumer goods, on the other hand, one is more likely to find a variant of the backlog, known as *lost sales*, in which unfulfilled demand in a period cannot be transferred to a subsequent period and is lost.

To model backlogging, it is necessary to introduce new decision variables

$B_{it} =$ units of demand for product i delayed in period t,

and the parameters

$g_{it} =$ unit cost of delaying the demand for product i in period t.

The resulting optimization problem is

$$\min \quad \sum_{t \in \mathcal{T}} \sum_{i \in \mathcal{I}} (c_{it} P_{it} + h_{it} I_{it} + g_{it} B_{it}) \tag{14.13}$$

$$\text{s.to} \quad P_{it} + I_{i,t-1} - I_{it} + B_{it} - B_{i,t-1} = d_{it}, \quad i \in \mathcal{I}, t \in \mathcal{T}, \tag{14.14}$$

$$\sum_{i \in \mathcal{I}} e_i P_{it} \le b_t, \qquad t \in \mathcal{T}, \tag{14.15}$$

$$P_{it}, I_{it}, B_{it} \ge 0, \qquad i \in \mathcal{I}, t \in \mathcal{T}. \tag{14.16}$$

The balance constraints (14.14) have been modified to take backlog variables into account. Specifically, in each period t one is allowed to delay a portion of the demand d_{it}, given precisely by the backlog variable B_{it}, whereas the demand d_{it} itself is increased by the units held as backlog in the previous period. Model (14.13) is again a linear optimization problem which can be therefore solved efficiently.

An alternative way to model backlog is to suppose that the demand d_{it} is made up of separate orders k, each characterized by a request for w_{ik} units of product i and a due delivery date t_{ik}:

$$d_{it} = \sum_{k \in \mathcal{K}_{it}} w_{ik}, \qquad \mathcal{K}_{it} = \{k | t_{ik} = t\}. \tag{14.17}$$

We further assume that each order should be completed within at most two periods from its due delivery date.

To model this second form of backlogging, define the following binary decision variables:

$$\beta_{ik0} = \begin{cases} 1 & \text{if order } k \text{ for product } i \text{ is delivered on time,} \\ 0 & \text{otherwise;} \end{cases}$$

$$\beta_{ik1} = \begin{cases} 1 & \text{if order } k \text{ for product } i \text{ is delayed by one period,} \\ 0 & \text{otherwise;} \end{cases}$$

$$\beta_{ik2} = \begin{cases} 1 & \text{if order } k \text{ for product } i \text{ is delayed by two periods,} \\ 0 & \text{otherwise.} \end{cases}$$

Consider also the parameters

$g_{ik1} =$ cost of delivering order k for product i delayed by one period,

$g_{ik2} =$ cost of delivering order k for product i delayed by two periods.

The resulting optimization problem is formulated as

$$\min \quad \sum_{t\in\mathcal{T}}\sum_{i\in\mathcal{I}}(c_{it}P_{it}+h_{it}I_{it})+ \\ \sum_{t\in\mathcal{T}}\sum_{i\in\mathcal{I}}\left(\sum_{k\in\mathcal{K}_{i,t-1}} g_{ik1}\beta_{ik1}+\sum_{k\in\mathcal{K}_{i,t-2}} g_{ik2}\beta_{ik2}\right) \tag{14.18}$$

$$\text{s.to} \quad P_{it}+I_{i,t-1}-I_{it}=\sum_{k\in\mathcal{K}_{it}} w_{ik}\beta_{ik0} \\ +\sum_{k\in\mathcal{K}_{i,t-1}} w_{ik}\beta_{ik1}+\sum_{k\in\mathcal{K}_{i,t-2}} w_{ik}\beta_{ik2}, \qquad i\in\mathcal{I}, t\in\mathcal{T}, \tag{14.19}$$

$$\sum_{i\in\mathcal{I}} e_i P_{it}\le b_t, \qquad t\in\mathcal{T}, \tag{14.20}$$

$$\beta_{ik0}+\beta_{ik1}+\beta_{ik2}=1, \qquad i\in\mathcal{I}, k\in\mathcal{K}, \tag{14.21}$$

$$P_{it}, I_{it}\ge 0,\ \beta_{ik0},\beta_{ik1},\beta_{ik2}\in\{0,1\}, \qquad i\in\mathcal{I}, t\in\mathcal{T}. \tag{14.22}$$

The balance constraints (14.19) have been modified to take the binary backlog variables into account. Specifically, in each period t are fulfilled the orders k due for period t for which there is no delayed delivery (i.e. such that $\beta_{ik0}=1$), the orders due for the previous period $t-1$ for which the delivery is delayed by one period (i.e. such that $\beta_{ik1}=1$), and finally the orders due for period $t-2$ for which the delivery is delayed by two periods (i.e. such that $\beta_{ik2}=1$). The multiple choice constraints (14.21) establish that each order be fulfilled in exactly one of the three alternative ways corresponding to variables $\beta_{ik0}, \beta_{ik1}, \beta_{ik2}$.

Compared to previous model (14.13), formulation (14.18) allows us to attach a different penalty cost to the K orders, therefore assigning preferences to some customers, for example those considered of strategic importance. In B2B customer–supplier relationships this possibility can be of considerable value.

Unlike the models previously considered, model (14.18) is a mixed binary linear optimization problem, whose solution requires computation times that grow exponentially fast with the number of variables and constraints. However, when the problem size is too large to yield an optimal solution in a reasonable time, for instance through a general purpose exact algorithm such as branch-and-bound, it is usually possible to devise an approximation algorithm achieving suboptimal solutions. This can be done by truncating a branch-and-bound procedure, or by designing *ad hoc* approximation algorithms.

Finally, notice that a multi-objective optimization model can also be formulated by requiring, for instance, that a proportion of at least n_1 of the orders be delivered on time and that a proportion of at most $1 - n_2$ be delayed by two periods, by introducing into model (14.18) the additional constraints

$$\sum_{k=1}^{K_i} \beta_{ik0} \geq n_1 K_i, \quad \sum_{k=1}^{K_i} \beta_{ik0} + \beta_{ik1} \geq n_2 K_i, \tag{14.23}$$

where K_i is the total number of orders referring to product i.

14.2.5 Minimum lots and fixed costs

A further feature often appearing in manufacturing systems is represented by *minimum lot* conditions: for technical or scale economy reasons, it is sometimes necessary that the production volume for one or more products be either equal to 0 (i.e. the product is not manufactured in a specific period) or not less than a given threshold value, the minimum lot.

To incorporate minimum lot conditions into the model, we define the binary decision variables

$$Y_{it} = \begin{cases} 1 & \text{if } P_{it} > 0, \\ 0 & \text{otherwise,} \end{cases} \tag{14.24}$$

and the parameters

$l_i =$ minimum lot for product i,

$\gamma =$ constant value larger than any producible volume for i.

The optimization problem is now

$$\min \quad \sum_{t \in \mathcal{T}} \sum_{i \in \mathcal{I}} (c_{it} P_{it} + h_{it} I_{it}) \tag{14.25}$$

$$\text{s.to} \quad P_{it} + I_{i,t-1} - I_{it} = d_{it}, \qquad i \in \mathcal{I}, t \in \mathcal{T}, \tag{14.26}$$

$$\sum_{i \in \mathcal{I}} e_i P_{it} \leq b_t, \qquad t \in \mathcal{T}, \tag{14.27}$$

$$P_{it} \geq l_i Y_{it}, \qquad i \in \mathcal{I}, t \in \mathcal{T}, \tag{14.28}$$

$$P_{it} \leq \gamma Y_{it}, \qquad i \in \mathcal{I}, t \in \mathcal{T}, \tag{14.29}$$

$$P_{it}, I_{it} \geq 0, Y_{it} \in \{0, 1\}, \qquad i \in \mathcal{I}, t \in \mathcal{T}. \tag{14.30}$$

Constraints (14.28) express the minimum lot conditions. Constraints (14.29) are logical consistency conditions between the variables Y_{it} and P_{it} needed to force the binary variable Y_{it} to take the value 1 whenever the corresponding production volume P_{it} is greater than 0. The constant γ in (14.29) must be chosen sufficiently large that the condition does not constitute an actual upper bound on the producible volume for product i. Indeed, it should be bounded above only by the available capacity and by the assigned demand.

In all previous model formulations we have implicitly assumed that production costs are proportional to production volumes. For some logistic systems, however, in order to manufacture a product it may be necessary to set up a machine and incur a *setup cost*. However, such costs are required only if the production volume is strictly greater than 0, that is, if production of the product concerned is actually accomplished. A further parameter,

$$f_{it} = \text{ unit setup cost for product } i \text{ in period } t,$$

is then assigned and the optimization problem becomes

$$\min \quad \sum_{t\in\mathcal{T}}\sum_{i\in\mathcal{I}} (c_{it}P_{it} + h_{it}I_{it} + f_{it}Y_{it}) \tag{14.31}$$

$$\text{s.to} \quad P_{it} + I_{i,t-1} - I_{it} = d_{it}, \qquad i \in \mathcal{I}, t \in \mathcal{T}, \tag{14.32}$$

$$\sum_{i\in\mathcal{I}} e_i P_{it} \leq b_t, \qquad t \in \mathcal{T}, \tag{14.33}$$

$$P_{it} \leq \gamma Y_{it}, \qquad i \in \mathcal{I}, t \in \mathcal{T}, \tag{14.34}$$

$$P_{it}, I_{it} \geq 0, Y_{it} \in \{0, 1\}, \qquad i \in \mathcal{I}, t \in \mathcal{T}. \tag{14.35}$$

Constraints (14.34) represent the logical consistency conditions between variables Y_{it} and P_{it}, as already observed for model (14.25).

Models (14.25) and (14.31) are mixed binary linear optimization problems, for whose solution the same remarks as for model (14.13) apply.

14.2.6 Bill of materials

A further extension of the basic planning model deals with the representation of products with a complex structure, described via the so-called *bill of materials*, where end-items are made by components that in turn may include other components.

Formally, the following parameters are defined to describe the structure of the bill of materials:

$$a_{ij} = \text{ units of product } i \text{ directly required by one unit of product } j,$$

where the term *product* refers here to both end-items and components at various levels of the bill of materials. For each product i we assign an *external* demand d_{it} and an *internal* demand, the latter induced by the requirements of product i needed to manufacture the components or the end-items for which i represents a direct component. The external demand for components may originate from other plants of the same manufacturing company or from outside customers that also buy components.

The resulting optimization problem is formulated as

$$\min \quad \sum_{t\in\mathcal{T}}\sum_{i\in\mathcal{I}}(c_{it}P_{it}+h_{it}I_{it}) \tag{14.36}$$

$$\text{s.to} \quad P_{it}+I_{i,t-1}-I_{it}=d_{it}+\sum_{j\in\mathcal{I},j\neq i}a_{ij}P_{jt}, \quad i\in\mathcal{I},t\in\mathcal{T}, \tag{14.37}$$

$$\sum_{i\in\mathcal{I}}e_iP_{it}\leq b_t, \qquad t\in\mathcal{T}, \tag{14.38}$$

$$P_{it},I_{it}\geq 0, \qquad i\in\mathcal{I},t\in\mathcal{T}. \tag{14.39}$$

The balance constraints (14.37) have been modified to take into account the demand internally generated. Model (14.36) is a linear optimization problem which can be therefore solved efficiently.

14.2.7 Multiple plants

In this section it is assumed that a manufacturing company has a network of M production plants, located in geographically distinct sites, that manufacture a single product. The logistic system is responsible for supplying N peripheral depots, located in turn at distinct sites. Each production plant $m\in\mathcal{M}=\{1,2,\ldots,M\}$ is characterized by a maximum availability of product, denoted by s_m, while each plant $n\in\mathcal{N}=\{1,2,\ldots,N\}$ has a demand d_n. We further assume that a transportation cost c_{mn} is incurred by sending a unit of product from plant m to depot n, for each pair (m,n) of origins and destinations in the logistic network. The objective of the company is to determine an optimal logistic plan that satisfies at minimum cost the requests of the depots, without violating the maximum availability at the plants. It should be clear that the problem described arises frequently in logistic systems, at different levels in the logistic network (e.g. from suppliers to plants, from plants to warehouses or from warehouses to customers).

The decision variables needed to model the problem described represent the quantity to be transported for each plant–depot pair,

$$x_{mn}= \text{ unit of product to be transported from } m \text{ to } n.$$

The resulting optimization problem is

$$\min \quad \sum_{m \in \mathcal{M}} \sum_{n \in \mathcal{N}} c_{mn} x_{mn} \tag{14.40}$$

$$\text{s.to} \quad \sum_{n \in \mathcal{N}} x_{mn} \leq s_m, \qquad m \in \mathcal{M}, \tag{14.41}$$

$$\sum_{m \in \mathcal{M}} x_{mn} \geq d_n, \qquad n \in \mathcal{N}, \tag{14.42}$$

$$x_{mn} \geq 0, \qquad m \in \mathcal{M}, n \in \mathcal{N}. \tag{14.43}$$

Constraints (14.41) ensure that the availability of each plant is not exceeded, whereas constraints (14.42) establish that the demand of each depot be satisfied. Model (14.40) is a linear optimization problem, and can be therefore solved efficiently.

14.3 Revenue management systems

Revenue management is a managerial policy whose purpose is to maximize profits through an optimal balance between demand and supply. It is mainly intended for marketing as well as logistic activities and has found growing interest in the service industry, particularly in the air transportation, tourism and hotel sectors. More recently these methods have also begun to spread within the manufacturing and distribution industries.

The strong interest shown by such enterprises in the themes considered by revenue management should come as no surprise, if we consider the complexity and strategic relevance of decision-making processes concerning demand management, which are addressed by marketing and logistics managers. Consider, for example, the complex interactions among decisions on pricing, sales promotions, markdowns, mix definition and allocation to points of sale, in a highly dynamic and competitive context characterized by multiple sales channels and several alternative ways of contacting customers.

Despite the potential advantages that revenue management initiatives may offer for enterprises, there are certain difficulties that hamper the actual implementation of practical projects and actions aimed at adopting revenue management methodologies and tools. We can identify several explanations for the gap between intentions and initiatives actually undertaken. Certainly the fear of implementation costs and uncertainty over the results that can be achieved play an important role, as happens for many innovation projects. Empirical investigations show, however, that the primary reason for prudence in adopting revenue management should be sought in the prerequisite conditions necessary to successfully start a revenue management project. There is a high level of interaction between revenue management and two other themes that we described earlier – optimization of the supply chain and relational marketing. On the one hand, in order to apply revenue management methods and tools it is necessary to have an integrated and optimized logistic chain that guarantees the efficiency and responsiveness of the logistic flows. On the other hand, it is also necessary to possess a deep knowledge of the customers and an accurate micro-segmentation of the market, achieved through data mining analytical models and therefore based on the analysis of the actual purchasing behaviors regularly recorded in the marketing data mart. Hence, to profitably adopt revenue management a company should be able to enhance and transform into knowledge, through the use of business intelligence methodologies, the huge amount of information collected by means of automatic data gathering technologies.

14.3.1 Decision processes in revenue management

Revenue management involves the application of mathematical models to predict the behavior of customers at a micro-segmentation level and to optimize the availability and price of products in order to maximize profits. In this respect, we can use the same definition introduced in Chapter 13 to summarize relational marketing objectives: to formulate for each segment, ideally for each customer, the appropriate offer through the most suitable channel, at the right time and at the best price.

The purpose of revenue management is therefore to maximize profits, aligning the offer of products and services to the expected demand, using both the major levers of the marketing mix (e.g. prices, promotions, assortment) and the levers of logistics (e.g. efficiency and timeliness). Specific and innovative features of revenue management strategies are a closer focus on demand than supply and a greater emphasis on costs than revenues; such features are often absent from the managerial policies adopted by most enterprises.

As already observed, in recent years revenue management has been applied with more and more success by many companies operating in the service industry. Among the pioneers in this field are airlines, hotel chains, automobile rental companies, theme parks, theaters and other entertainment-related enterprises. The common characteristics of these fields are well apparent: a highly perishable product, a fairly low marginal sales cost and the possibility of applying dynamic pricing policies and exploiting multiple sales channels.

Revenue management affects some highly complex decision-making processes of strategic relevance, as shown in Figure 14.2:

- market segmentation, by product, distribution channel, consumer type and geographic area, performed using data mining models;

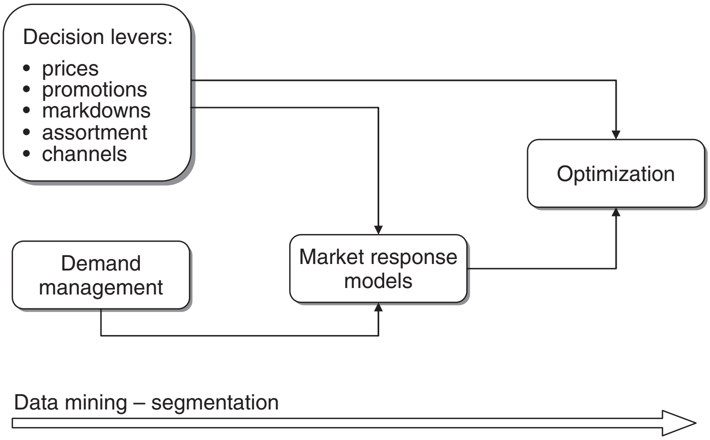

Figure 14.2 Decision processes in revenue management

- prediction of future demand, using time series and regression models;
- identification of the optimal assortment, i.e. the mix of products to be allocated to each point of sale;
- definition of the market response function, obtained by identifying models and rules that explain the demand based on company actions, the initiatives of competitors and other exogenous contextual events;
- management of activities aimed at determining the price of each product (*pricing*) as well as the timing and the amount of markdowns;
- planning, management and monitoring of sales promotions, and assessment of their effectiveness;
- sales analysis and control, and use of the information gathered to evaluate market trends;
- material procurement and stock management policies, such as control policy, frequency of issued orders, reorder quantities;
- integrated management of the different sales and distribution channels.

Revenue management relies on the following basic principles:

- To address sales to micro-segments: segmentation carried out by means of business intelligence and data mining models is critical to achieve an adequate knowledge of the market.

- To exploit the product value cycle: to generate the highest revenues, it is required to grasp the value cycle of products and services, in order to optimally synchronize their availability over time and to determine the price for each market micro-segment. Notice that the value cycle also depends on the sensitivity of micro-segments to price variations.

- To have a price-oriented rather than cost-oriented approach in balancing supply and demand: when supply and demand are out of balance, most enterprises tend to react by increasing or decreasing capacity. In many instances it might, however, be more convenient to adopt price variations, avoiding repeated variations in capacity.

- To make informed and knowledge-based decisions: a consistent use of prediction models tends to mean that decisions rest on a more robust knowledge basis. In particular, a correct prediction of consumer purchasing behaviors is essential to evaluate elasticity and reactions to price variations.

- To regularly examine new opportunities to increase revenues and profits: the possibility of timely access to the available information, combined with the possibility of considering alternative scenarios, strengthens the competencies of marketing analysts and increases the effectiveness of their activity.

The adoption of revenue management methods and tools requires a few prerequisite conditions to be satisfied within a company, since without them the expected results are unlikely to be achieved. As with any innovation project, it is the people and the organization that constitute a key success factor rather than the use of specific software tools. In this case too, the culture and the structure of the processes within an organization must be prepared to adopt powerful tools that may turn out to be unsafe and disrupting if improperly used. It is therefore necessary to develop within the enterprise an information culture, particularly among those knowledge workers who operate in the marketing and logistics departments, more directly involved with the application of revenue management strategies. This means that all marketing data must be systematically gathered, controlled, normalized, integrated and stored in a data mart. To segment the market and to create micro-segments, business intelligence methods and analytical models should be used. It is therefore advisable for an enterprise turning to revenue management to have already developed relational marketing initiatives or at least to be able to carry out data mining analyses.

On the other hand, the decisions involved in revenue management strategies share many aspects with the logistics department, and in particular with the management of flows in the supply chain. In this case too, particularly for manufacturing companies, it is advisable for an enterprise considering revenue management to have previously embarked on supply chain integration and rationalization projects, in order to guarantee an adequate cost reduction that, combined with the increased revenues obtained through revenue management, may lead to a significant increase in profits. Moreover, effective supply chain management is also required to guarantee timely restocking.

14.4 Business case studies

This section describes two examples of real-world applications of optimization models for logistic and production planning. The first is concerned with an enterprise operating in the food industry, while the second refers to a company that manufactures integrated solutions for liquid food product packaging.

14.4.1 Logistics planning in the food industry

The logistic system of the food manufacturing company consists of a network whose nodes represent suppliers of raw materials, production plants and central and peripheral warehouses, as shown in Figure 14.3. Retail and wholesale distribution to the points of sale, placed downstream of the warehouses, is regarded as external to the logistic subsystem considered here.

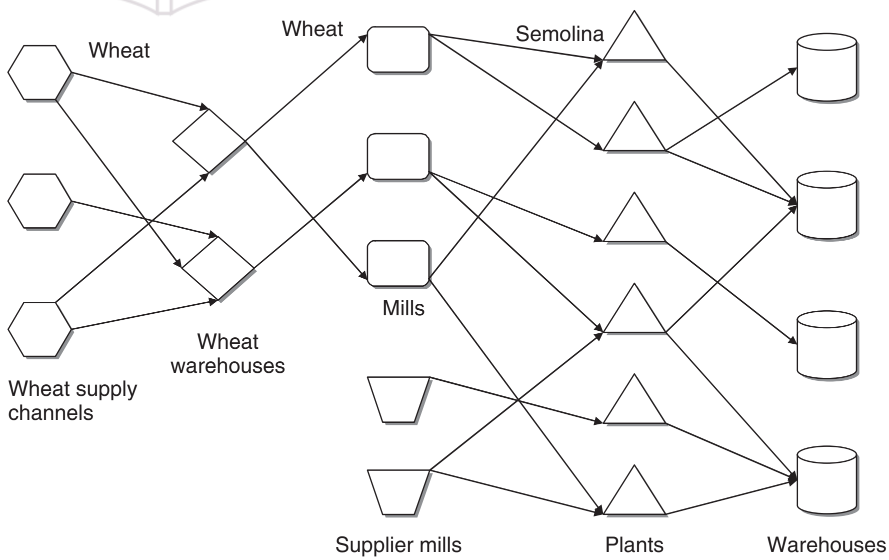

Figure 14.3 Structure of the logistic production system for a company in the food industry

Logistics planning is driven by the demand plan, which in turn depends on the sales forecasts for individual items, disaggregated by warehouse and by period. Supply, production and primary distribution plans are therefore meant to feed end items into central and peripheral warehouses.

Industrial processing manufactures products of low complexity on *transfer lines*, that is, highly automated production lines designed to achieve high output rates even with a limited plant flexibility. The processing cycle basically includes two major phases: during the *production* phase, raw materials are transformed into semi-finished goods, which during the *packaging* phase are then turned into end items. Both production and packaging lines operate in a batch processing mode. Generally, each item can be produced at several plants and on several lines within a given plant. Each plant includes both production and packaging lines, while the transfer of semi-finished goods from one plant to another is not allowed. Based on the demand profile, and on the related production capacity requirements, each of the two phases of the production cycle may represent a bottleneck of the manufacturing system during the periods included in the planning horizon. Since the enterprise targets consumer goods markets, if the demand for an item for a specific warehouse cannot be satisfied in a given period, it is assumed that this translates into lost sales. Therefore, the company does not allow any demand backlog to be met during following periods.

The logistic system is made up of dozens of plants housing hundreds of production and packaging lines. More than a thousand end items are produced and later stored in central and peripheral warehouses. Each production or packaging line may produce up to dozens of semi-finished goods or end products. There are plants that manufacture a small number of items (two or three) and plants that are able to produce a considerable portion of the product range.

Several decisions depend on the company's logistic plan, and would benefit from a production and distribution plan that is more efficient and stable. Some of these decisions are:

- the optimal sizing of the stocks, so as to guarantee the required service level;
- the plan of allocation to the plants of the demand originating at each market warehouse, in order to achieve an optimal balance between production, distribution and supply costs;
- the plan of allocation of the production capacity, with the possible addition of extra capacity, by using extra work shifts and part-time work or by subcontracting some of the production to external partners (*co-packers*); moreover, the company needs to set out medium-term contractual obligations with co-packers, which are significantly affected by the stability and reliability of the logistic plan devised;

- the supply plan, and the corresponding medium-term contracts with suppliers for the procurement of raw materials and packaging.

Before the new planning system based on an optimization model was introduced, it was customary to work out the logistic plan in an aggregate way, by families of items and with infinite capacity, without duly considering costs and therefore with no attempt at optimization. Subsequent simulations were used to determine the corresponding level of production capacity engagement and the portions of the logistic plan that turned out not to be feasible. In some instances, such preliminary processing activities were followed by more focused analyses developed by the planners using simple spreadsheets. This development process proved largely unable to effectively manage such a highly complex supply chain; furthermore, it was also inefficient, since operators were required to continuously apply corrections and assessments.

The optimization system for logistics planning

The reengineering of the supply chain management process has led to the development of a logistic decision support system whose *intelligence* is represented by an integrated optimization model of the entire logistic production system. Figure 14.4 shows a sketch of the system architecture.

The system uses a logistic data mart that constitutes a local database, also to increase the efficiency in the generation and solution of the optimization model by means of the algorithmic engine. The information contained in the data

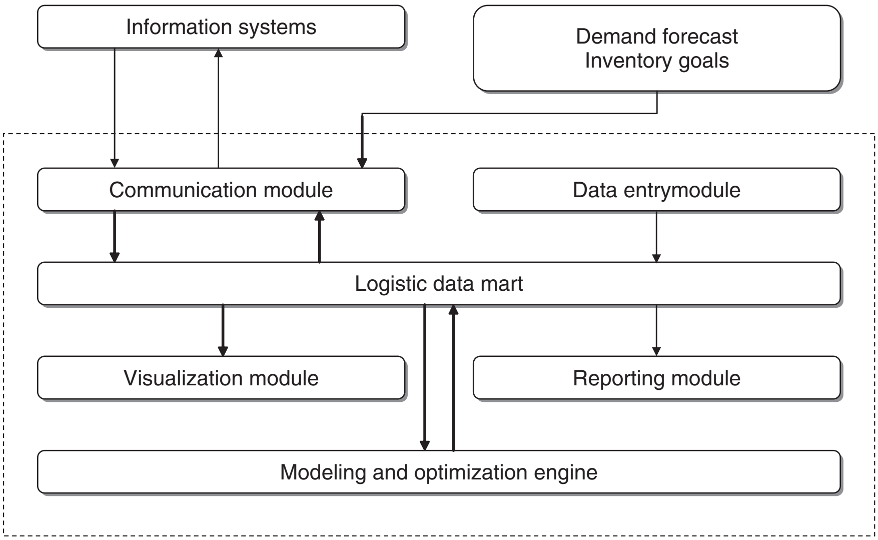

Figure 14.4 Architecture of the logistic production optimization system

mart is entered and updated in two different ways: on the one hand, through the automatic acquisition of data from the company information system; and on the other hand, through direct data entry by the users for those data and parameters required to devise the optimal logistic plan and not contained in the company information system.

Primary input data acquired from the information system are represented by the demand plan, formulated by item, warehouse and period. The demand plan is determined based on sales forecasts, which are available at the highest level of accuracy. Sales forecasts for each point of sale are therefore aggregated, allocating the demand to each central and peripheral warehouse. Finally, to obtain the demand plan, the aggregated sales forecasts are corrected to take into account the desired level of stocks, defined for the purpose of guaranteeing a preset level of service to customers.

The logistic plan, updated every week on a *rolling* basis, is usually developed over a time span of a year, divided into weeks. Downstream, the planning system is integrated with other modules that allow raw and packaging material requirements to be determined via *manufacturing resource planning*.

At the heart of the planning decision support system is the modeling and algorithmic module, which in turn is based on a finite-capacity optimization model of the entire logistic system. In particular, this is a discrete-time deterministic model that uses a network representation of the logistic system. The nodes of the network represent the supply centers, plants and warehouses where the demand is placed, as indicated in Figure 14.3. For each plant, the model considers the two phases of the manufacturing process – both production and packaging lines. The two phases are planned in a coordinated way, by properly adjusting the volume of products processed at each phase during each period of the planning horizon.

Each production and packaging line is assigned the available capacity, expressed in hours, for each period of the planning horizon. The available manpower capacity at the packaging lines is also assigned, plant by plant, since the human resources employed in packaging are multi-skilled workers and can be shared among different lines of the same plant. Finally, one assigns the potential manpower availability in terms of overtime, holidays or seasonal work, which can be used when needed at additional cost.

Regarding stock management, the model input data specify both a safe level of stock, defined on the basis of the demand profile and the desired service level, and an overstock value not to be exceeded. The logistic plan must guarantee at each period that stocks are above the safe level and below the overstock threshold. For each violation of these conditions, a penalty cost assigned as input is applied.

The size of the minimum lots is also specified, both for production and packaging lines, depending on the specific semi-finished goods and end items. Finally, the model deals with secondary conditions, to be assigned at the discretion of the planners, such as enforcing minimum and maximum volumes for selected end items, or specifying a set of semi-finished goods and products allowed to be manufactured at the beginning or end of each period.

The model also determines the supply of semolina to the plants. This can be procured through two channels: it can be purchased from external suppliers; or it can be obtained from production plants (mills) owned by the company, which in turn have to obtain stocks of wheat from supply markets. In brief, the input data to the system are:

- the demand plan, specified for each warehouse, item and period;
- the initial inventory for each warehouse;
- the bill of materials;
- the technological maps, which list all possible combinations and the corresponding yields between semi-finished goods and production lines, as well as between end items and packaging lines;
- the capacity of production and packaging lines over the periods of the planning horizon;
- the time availability of labor, in terms of regular working hours, extra shifts, holidays and seasonal working time;
- the minimum lots and the forced excess of production and packaging;
- the availability of the different types of wheat on the supply markets;
- the capacity at the mills to transform wheat into semolina;
- the availability of semolina at third-party mills;
- the blending quality requirements for the transformation of wheat into semolina.

The objective function of the model takes the following cost factors into account:

- the transportation costs of transferring end items from each plant to each warehouse;
- the production costs for production lines, net of labor costs;

- the production costs for packaging lines, net of labor cost;
- the penalty cost of failing to reach the desired stock level;
- the penalty cost of overstocking;
- the cost determined by lost sales due to the required product being unavailable in the appropriate period;
- the unit cost of labor, regular working hours, extra shifts, holidays and seasonal working;
- the cost of different wheat types available on the supply markets;
- the milling cost;
- the cost of semolina bought at third-party mills.

The representation of the logistic system described leads to a large-scale mixed binary optimization model, due to the presence of binary decision variables. However, despite its high level of complexity, the model requires no more than a few minutes' computation time, due to the existence of an *ad hoc* algorithm which yields an approximate solution.

At the end of the computation, the model provides an optimal integrated logistic plan, providing the following information:

- the allocation of the demand to the plants;
- the distribution plan, expressing the volumes of end products shipped weekly from each plant to the central and peripheral warehouses;
- the production and packaging plans for each plant, indicating the volumes of semi-finished goods and end products processed weekly by each production and packaging line, with the possibility of processing ahead of time with respect to the due dates, whenever needed or advantageous;
- the inventory plan, specifying the optimal levels of weekly stock for the end products at each warehouse;
- the possibly unmet demand for end items for each warehouse;
- the production capacity engagement plan, for both the lines and the labor;
- the supply of raw materials and packaging;

- the employment of additional labor, in the form of extra shifts, holiday work or seasonal work;
- the purchase from the supply markets and storage cost of wheat, based on the foreseen availability;
- the transportation of wheat from supply markets to the company's own mills;
- the blending and processing of wheat into semolina at the company's own mills;
- the purchase of semolina from the mills of third-party suppliers;
- the transportation of semolina from internal mills and from supplier mills to plants.

Main advantages

The use of the decision support system for logistics planning affords several advantages, both in terms of efficiency in devising the plan and effectiveness of the plans generated.

It requires less effort on the part of planners, while at the same time contributing to a substantial job enrichment, since they are required to play a decision-making role that is more gratifying on a personal level and of greater value to the company. Indeed, the system enables users to perform and manage different scenario analyses by experimenting with the input data and the parameters of the model. In this way, planners may simulate and evaluate the effect of different conditions and assumptions, carrying out what-if analyses in order to achieve the most effective logistic plan. For example, they can modify some cost parameters, or the level of the required stocks, or the labor availability, in order to assess the consequences of such changes. Particularly noteworthy and of great practical advantage is the possibility of assigning predetermined quantities for the production volumes, by single item or group of items, as well as by single period or group of periods.

The planners responsible for wheat procurement can also use the system to easily carry out what-if analyses of different alternative scenarios, formulated by varying model parameters such as transportation costs, wheat purchase costs, currency exchange rates, and the processing capacity of the company's own mills.

In addition, the system encourages closer integration between the sales planning department and the supply chain management department, by reducing interdepartmental conflicts and improving the quality of decisions regarding the marketing mix, intended to maximize the overall economic benefits for the company.

Other advantages that are worth mentioning concern the vast array of managerial decisions that benefit from the introduction of an optimized logistic plan, among which are:

- the possibility of assessing the feasibility of the restocking plan devised by the sales department;
- the definition of contracts with the suppliers of raw materials and packaging, as well as with third-party co-packers;
- the definition of the budget, formulated on a rolling basis and with a planning horizon of 18 months;
- the hiring and training plans for seasonal labor;
- the possibility of assessing the impact of expansion plans for the production capacity, obtainable through the expansion of production and packaging lines within existing plants, the construction of new manufacturing plants and the activation of relationships with new co-packers;
- the optimal allocation of the demand to the plants consistent with the plan of distribution to the markets.

14.4.2 Logistics planning in the packaging industry

The second case study considered here refers to an enterprise that produces integrated solutions for processing, packaging and handling liquid food products. The highly complex logistic and production network includes approximately 60 plants, 1000 different end products and 200 market areas assigned to more than 100 sales divisions, called *market companies*.

The organizational structure entails considerable independence in decision making on the part of local market companies, which leads them to assign production to their preferred plant, without taking into account global optimization goals at the enterprise level. The policy of independence in decision making also means a lack of homogeneity of costs and service performance among the various production sites. Delivery costs and times depend on the number of distinct products manufactured at a given plant, and the lack of homogeneity in the allocations is considerable, since the number of products assigned to the various production plants may vary from 10 to 100.

A decision support system for medium-term logistics planning was developed, with functionalities and features not much dissimilar from those described in the previous section. Its primary objective was to allocate the demand to the plants so as to minimize the overall logistic and production costs.

The optimization model representing the *intelligence* component of the system considers for each plant the two stages of production required by the processing technology of the company. For each stage, the model takes into account:

- the production costs by line and by plant;
- the cost of procurement of raw materials from suppliers;
- the transportation costs for raw materials;
- the transportation costs from plants to markets for end products;
- the limitations imposed by the capacity of the production lines;
- the limited availability of some technological components required by the production process;
- the technological maps that describe all possible combinations of lines and products, along with the relative processing times.

The optimization model also determines transfers from one plant to another for some technological process components, whose total number is limited by cost considerations. The solution of the resulting model leads to an optimal logistic and production plan, which includes the following choices:

- the supply plan of raw materials from suppliers, for each plant and for each period;
- the production plan for each line, plant, product and period, and therefore the optimal allocation of the demand to plants;
- the distribution plan for each product, plant, market area and period;
- the allocation and possible transfer between plants of critical technological process components in each period.

14.5 Notes and readings

There are several general texts that take a qualitative approach to supply chain management, among them Poirier and Reiter (1999) and Chopra and Meindl (2003). For a discussion closer to optimization themes we recommend Shapiro (2000), Simchi-Levi *et al*. (2002, 2004a,b), Graves *et al*. (2002), and Graves and De Kok (2003). For an application of logistic and production optimization in the textile industry see Dumoulin and Vercellis (2000), and for an application to tyres production see Fumero and Vercellis (1997, 1999); see also Battistini *et al*. (1999) for food production.