CHAPTER 11 Aggregate Planning and Master Scheduling

CHAPTER OUTLINE

LEARNING OBJECTIVES

After completing this chapter, you should be able to:

1. Explain what aggregate planning is and how it is useful.
2. Identify the variables decision makers have to work with in aggregate planning and some of the possible strategies they can use.
3. Describe some of the graphical and quantitative techniques planners use.
4. Prepare aggregate plans and compute their costs.
5. Describe the master scheduling process and explain its importance.

Seasonal variations in demand are quite common in many industries and public services, such as air-conditioning, fuel, public utilities, police and fire protection, and travel. And these are just a few examples of industries and public services that have to deal with uneven demands. Generally speaking, organizations cannot predict exactly the quantity and timing of demands for specific products or services months in advance under these conditions. Even so, they typically must assess their capacity needs (e.g., labor, inventories) and costs months in advance in order to be able to handle demand. How do they do it? They use a process often referred to as *aggregate planning*. That is the subject of this chapter.

SUPPLY CHAIN

In the spectrum of production planning, **aggregate planning** is intermediate-range capacity planning that typically covers a time horizon of 2 to 12 months, although in some companies it may extend to as much as 18 months. It is particularly useful for organizations that experience seasonal or other fluctuations in demand or capacity. The goal of aggregate planning is to achieve a production plan that will effectively utilize the organization's resources to match expected demand. Planners must make decisions on output rates, employment levels and changes, inventory levels and changes, back orders, and subcontracting in or out.

Aggregate planning Intermediate-range capacity planning, usually covering 2 to 12 months.

Some organizations use the term "sales and operations planning" instead of aggregate planning for intermediate-range planning. Similarly, **sales and operations planning** is defined as making intermediate-range decisions to balance supply and demand, integrating financial and operations planning. Because the plan affects functions throughout the organization, it is typically prepared with inputs from sales (demand forecasts), finance (financial constraints), and operations (capacity constraints). Note that the sales and operations plan is important planning information that will have impacts throughout the supply chain, and it should be shared with supply chain partners, who might also have valuable inputs.

Sales and operations planning Intermediate-range decisions to balance supply and demand, integrating financial and operations planning.

TABLE 11.1
Overview of planning levels (chapter numbers are shown)

Long-Range Plans	Intermediate Plans	Short-Range Plans
Long-term capacity }5	(This chapter)	Detailed plans:
Location }8	General levels of:	Production lot size } 13
Layout }6	Employment	Order quantities } 13
Product design }4	Output	Machine loading } 16
Work system design }7	Finished-goods inventories	Job assignments } 16
	Subcontracting	Job sequencing } 16
	Back orders	Work schedules }16

INTRODUCTION

Intermediate Planning in Perspective

Organizations make capacity decisions on three levels: long term, intermediate term, and short term. Long-term decisions relate to product and service selection (i.e., determining which products or services to offer), facility size and location, equipment decisions, and layout of facilities. These long-term decisions essentially establish the capacity constraints within which intermediate planning must function. Intermediate decisions, as noted above, relate to general levels of employment, output, and inventories, which in turn establish boundaries within which short-range capacity decisions must be made. Thus, short-term decisions essentially consist of deciding the best way to achieve desired results within the constraints resulting from long-term and intermediate-term decisions. Short-term decisions involve scheduling jobs, workers and equipment, and the like. The three levels of capacity decisions are depicted in Table 11.1. Long-term capacity decisions were covered in Chapter 5, and scheduling and related matters are covered in Chapter 16. This chapter covers intermediate capacity decisions.

Many business organizations develop a *business plan* that encompasses both long-term and intermediate-term planning. The business plan establishes guidelines for the organization, taking into account the organization's strategies and policies; forecasts of demand for the organization's products or services; and economic, competitive, and political conditions.

Television manufacturers would not be concerned with various sizes. Instead, planners would treat them all as a single product in aggregate planning.

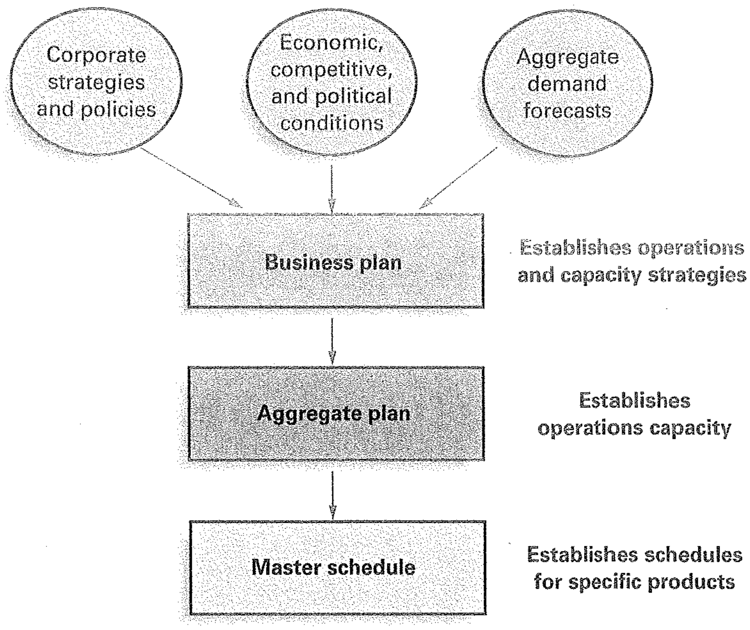


FIGURE 11.1
Planning sequence

A key objective in business planning is to coordinate the intermediate plans of various organization functions, such as marketing, operations, and finance. In manufacturing companies, coordination also includes engineering and materials management. Consequently, all of these functional areas must work together to formulate the aggregate plan. Aggregate planning decisions are strategic decisions that define the framework within which operating decisions will be made. They are the starting point for scheduling and production control systems. They provide input for financial plans; they involve forecasting input and demand management, and they may require changes in employment levels. And if the organization is involved in *time-based competition,* it will be important to incorporate some flexibility in the aggregate plan to be able to handle changing requirements promptly. As noted, the plans must fit into the framework established by the organization's long-term goals and strategies, and the limitations established by long-term facility and capital budget decisions. The aggregate plan will guide the more detailed planning that eventually leads to a *master schedule.* Figure 11.1 illustrates the planning sequence.

Aggregate planning also can serve as an important input to other strategic decisions; for example, management may decide to add capacity when aggregate planning alternatives for temporarily increasing capacity, such as working overtime and subcontracting, are too costly.

The Concept of Aggregation

Aggregate planning is essentially a "big-picture" approach to planning. Planners usually try to avoid focusing on individual products or services—unless the organization has only one major product or service. Instead, they focus on a group of similar products or services, or sometimes an entire product or service line. For example, planners in a company producing television sets would not concern themselves with 40-inch sets versus 46-inch or 55-inch sets. Instead, planners would lump all models together and deal with them as though they were a single product, hence the term *aggregate* planning. Thus, when fast-food companies such as McDonald's, Burger King, or Wendy's plan employment and output levels, they don't try to determine how demand will be broken down into the various menu options they offer; they focus on overall demand and the overall capacity they want to provide.

SERVICE

Now consider how aggregate planning might work in a large department store. Space allocation is often an aggregate decision. That is, a manager might decide to allocate 20 percent of the available space in the clothing department to women's sportswear, 30 percent to juniors, and so on, without regard for what brand names will be offered or how much of juniors will be jeans. The aggregate measure might be square feet of space or racks of clothing.

For purposes of aggregate planning, it is often convenient to think of capacity in terms of labor hours or machine hours per period, or output rates (barrels per period, units per period), without worrying about how much of a particular item will actually be involved. This approach frees planners to make general decisions about the use of resources without having to get into the complexities of individual product or service requirements. Product groupings make the problem of obtaining an acceptable unit of aggregation easier because product groupings may lend themselves to the same aggregate measures.

Why do organizations need to do aggregate planning? The answer is twofold. One part is related to *planning:* It takes time to implement plans. For instance, if plans call for hiring (and training) new workers, that will take time. The second part is strategic: *Aggregation* is important because it is not possible to predict with any degree of accuracy the timing and volume of demand for individual items. So if an organization were to "lock in" on individual items, it would lose the flexibility to respond to the market.

Generally speaking, aggregate planning is connected to the budgeting process. Most organizations plan their financial requirements annually on a department-by-department basis.

Finally, aggregate planning is important because it can help synchronize flow throughout the supply chain; it affects costs, equipment utilization, employment levels, and customer satisfaction.

A key issue in aggregate planning is how to handle variations.

Dealing with Variations

As in other areas of business management, variations in either supply or demand can occur. Minor variations are usually not a problem, but large variations generally have a major impact on the ability to match supply and demand, so they must be dealt with. Most organizations use rolling 3-, 6-, 9-, and 12-month forecasts—forecasts that are updated periodically—rather than relying on a once-a-year forecast. This allows planners to take into account any changes in either expected demand or expected supply and to develop revised plans.

Some businesses tend to exhibit a fair degree of stability, whereas in others, variations are more the norm. In those instances, a number of strategies are used to counter variations. One is to maintain a certain amount of excess capacity to handle increases in demand. This strategy makes sense when the opportunity cost of lost revenue greatly exceeds the cost of maintaining excess capacity. Another strategy is to maintain a degree of flexibility in dealing with changes. That might involve hiring temporary workers and/or working overtime when needed. Organizations that experience seasonal demands typically use this approach. Some of the design strategies mentioned in Chapter 4, such as delayed differentiation and modular design, may also be options. Still another strategy is to wait as long as possible before committing to a certain level of supply capability. This might involve scheduling products or services with known demands first, which allows some time to pass, shortening the time horizon, and perhaps enabling demands for the remaining products or services to become less uncertain.

An Overview of Aggregate Planning

Aggregate planning begins with a forecast of aggregate demand for the intermediate range. This is followed by a general plan to meet demand requirements by setting output, employment, and finished-goods inventory levels or service capacities. Managers might consider a number of plans, each of which must be examined in light of feasibility and cost. If a plan is reasonably good but has minor difficulties, it may be reworked. Conversely, a poor plan should be discarded and alternative plans considered until an acceptable one is uncovered. The production plan is essentially the output of aggregate planning.

Aggregate plans are updated periodically, often monthly, to take into account updated forecasts and other changes. This results in a *rolling planning horizon* (i.e., the aggregate plan always covers the next 12 to 18 months).

TABLE 11.2
Aggregate planning inputs and outputs

Inputs	Outputs
Resources	Total cost of a plan
Workforce/production rates	Projected levels of
Facilities and equipment	Inventory
Demand forecast	Output
Policies on workforce changes	Employment
Subcontracting	Subcontracting
Overtime	Backordering
Inventory levels/changes	
Back orders	
Costs	
Inventory carrying cost	
Back orders	
Hiring/firing	
Overtime	
Inventory changes	
Subcontracting	

Demand and Supply. Aggregate planners are concerned with the *quantity* and the *timing* of expected demand. If total expected demand for the planning period is much different from available capacity over that same period, the major approach of planners will be to try to achieve a balance by altering capacity, demand, or both. On the other hand, even if capacity and demand are approximately equal for the planning horizon as a whole, planners may still be faced with the problem of dealing with uneven demand *within* the planning interval. In some periods, expected demand may exceed projected capacity, in others expected demand may be less than projected capacity, and in some periods the two may be equal. The task of aggregate planners is to achieve rough equality of demand and capacity over the entire planning horizon. Moreover, planners are usually concerned with minimizing the cost of the aggregate plan, although cost is not the only consideration.

Inputs to Aggregate Planning. Effective aggregate planning requires good *information.* First, the available resources over the planning period must be known. Then, a forecast of expected demand must be available. Finally, planners must take into account any policies regarding changes in employment levels (e.g., some organizations view layoffs as extremely undesirable, so they would use that only as a last resort).

Table 11.2 lists the major inputs to aggregate planning.

Companies in the travel industry and some other industries often experience duplicate orders from customers who make multiple reservations but only intend to keep at most one of them. This makes capacity planning all the more difficult.

Aggregate Planning and the Supply Chain

SUPPLY CHAIN

It is essential to take supply chain capabilities into account when doing aggregate planning, to assure that there are no quantity or timing issues that need to be resolved. While this is particularly true if new or changed goods or services are involved, it is also true even when no changes are planned. Supply chain partners should be consulted during the planning stage so that any issues or advice they may have can be taken into account, and they should be informed when plans have been finalized.

Duplicate Orders Can Lead to Excess Capacity

READING

We've all heard about someone who booked seats on two airlines, or reserved two hotel rooms, usually because travel plans weren't firmed up, but the person didn't want to miss out on the trip. Later, the person canceled one set of reservations. This sort of duplicate ordering isn't just limited to the travel industry. The trouble is, companies base their capacity planning on demand estimates, and when there are numerous duplicate orders, it is easy to overestimate demand and end up with excess capacity. In some instances, this has led companies to expand at a time when demand was actually leveling off or even decreasing! The problem is further compounded if companies conclude that canceled orders reflect customers' reluctance to wait, and respond by *adding* capacity when, in fact, order cancellation may actually reflect duplicate ordering.

Some semiconductor companies downplay data on bookings because it is too difficult to distinguish between duplicate orders and actual demand.

Yet it is important to account for double orders. Otherwise, by counting duplicate orders as true demand, you overestimate the demand rate, and by counting the cancellations of duplicate orders as lost sales, you overestimate customers' sensitivity to delay, and then you wind up with excess capacity.

"The optimal level of capacity increases with customers' sensitivity to delay, so estimating customers' sensitivity to delay is a very important part of the puzzle."

Duplicate orders can make capacity planning very difficult. The key is to carefully estimate both the rate of duplicate ordering and the degree of order cancellation that can be attributed to duplicate ordering.

Source: Based on Mor Armony and Erica L. Plambeck, "The Impact of Duplicate Orders on Demand Estimation and Capacity Investment," GSB Research Paper #1740, Graduate School of Business, Stanford University, June 2002.

Demand and Supply Options

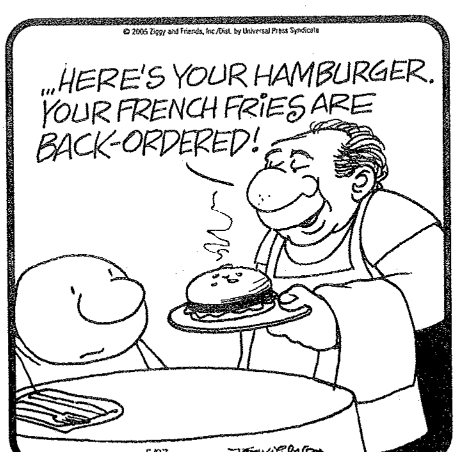
Aggregate planning strategies can be described as proactive, reactive, or mixed. *Proactive* strategies involve demand options: They attempt to alter demand so that it matches capacity. *Reactive* strategies involve capacity options: They attempt to alter capacity so that it matches demand. *Mixed* strategies involve an element of each of these approaches.

Demand Options. Demand options include pricing, promotions, using back orders (delaying order filling), and creating new demand.

SERVICE

1. **Pricing.** Pricing differentials are commonly used to shift demand from peak periods to off-peak periods. Some hotels, for example, offer lower rates for weekend stays, and some airlines offer lower fares for night travel. Movie theaters may offer reduced rates for matinees, and some restaurants offer "early bird specials" in an attempt to shift some of the heavier dinner demand to an earlier time that traditionally has less traffic. Some restaurants also offer smaller portions at reduced rates, and most have smaller portions and prices for children. To the extent that pricing is effective, demand will be shifted so that it corresponds more closely to capacity, albeit for an *opportunity cost* that represents the lost profit stemming from capacity insufficient to meet demand during certain periods.

An important factor to consider is the *degree* of price elasticity for the product or service: The more the elasticity, the more effective pricing will be in influencing demand patterns.



2. **Promotion.** Advertising and other forms of promotion, such as displays and direct marketing, can sometimes be very effective in shifting demand so that it conforms more closely to capacity. Obviously, timing of these efforts and knowledge of response rates and response patterns will be needed to achieve the desired results. Unlike pricing policy, there is much less control over the timing of demand, so there is the risk that promotion can worsen the condition it was intended to improve, by bringing in demand at the wrong time, further stressing capacity.

3. **Back orders.** An organization can shift demand fulfillment to other periods by allowing back orders. That is, orders are taken in one period and deliveries promised for a later period. The success of this approach depends on how willing customers are to wait for delivery. Moreover, the costs associated with back

orders can be difficult to pin down since they would include lost sales, annoyed or disappointed customers, and perhaps additional paperwork.

4. **New demand.** Many organizations are faced with the problem of having to provide products or services for peak demand in situations where demand is very uneven. For instance, demand for bus transportation tends to be more intense during the morning and late afternoon rush hours but much lighter at other times. Creating new demand for buses at other times (e.g., trips by schools, clubs, and senior citizen groups) would make use of the excess capacity during those slack times. Similarly, many fast-food restaurants are open for breakfast to use their capacities more fully, and some landscaping firms in northern climates use their equipment during the winter months for snow removal. Manufacturing firms that experience seasonal demands for certain products (e.g., snowblowers) are sometimes able to develop a demand for a complementary product (e.g., lawn mowers, garden equipment) that makes use of the same production processes. They thereby achieve a more consistent use of labor, equipment, and facilities. Another option may be "insourcing" work from another organization.

Supply Options. Supply options include hiring/laying off workers, overtime/slack time, part-time or temporary workers, inventories, and subcontractors.

1. **Hire and lay off workers.** The extent to which operations are labor intensive determines the impact that changes in the workforce level will have on capacity. The resource requirements of each worker also can be a factor. For instance, if a supermarket usually has 10 of 14 checkout lines operating, an additional four checkout workers could be added. Hence, the ability to add workers is constrained at some point by other resources needed to support the workers. Conversely, there may be a lower limit on the number of workers needed to maintain a viable operation (e.g., a skeleton crew).

Union contracts may restrict the amount of hiring and laying off a company can do. Moreover, because laying off can present serious problems for workers, some firms have policies that either prohibit or limit downward adjustments to a workforce. On the other hand, hiring presumes an available supply of workers. This may change from time to time and, at times of low supply, have an impact on the ability of an organization to pursue this approach.

Another consideration is the skill level of workers. Highly skilled workers are generally more difficult to find than lower-skilled workers, and recruiting them involves greater costs. So the usefulness of this option may be limited by the need for highly skilled workers.

Use of hiring and laying off entails certain costs. Hiring costs include recruitment, screening, and training to bring new workers "up to speed." And quality may suffer. Some savings may occur if workers who have recently been laid off are rehired. Layoff costs include severance pay, the cost of realigning the remaining workforce, potential bad feelings toward the firm on the part of workers who have been laid off, and some loss of morale for workers who are retained (i.e., in spite of company assurances, some workers will believe that in time they too will be laid off).

An increasing number of organizations view workers as assets rather than as variable costs, and would not consider this approach. Instead, they might use slack time for other purposes.

2. **Overtime/slack time.** Use of overtime or slack time is a less severe method for changing capacity than hiring and laying off workers, and it can be used across the board or selectively as needed. It also can be implemented more quickly than hiring and laying off and allows the firm to maintain a steady base of employees. The use of overtime can be especially attractive in dealing with seasonal demand peaks by reducing the need to hire and train people who will have to be laid off during the off-season. Overtime also permits the company to maintain a skilled workforce and employees to increase earnings, and companies may save money because fringe and other benefits are generally fixed. Moreover, in situations with crews, it is often necessary to use a full crew rather than to hire one or two additional people. Thus, having the entire crew work overtime would be preferable to hiring extra people.

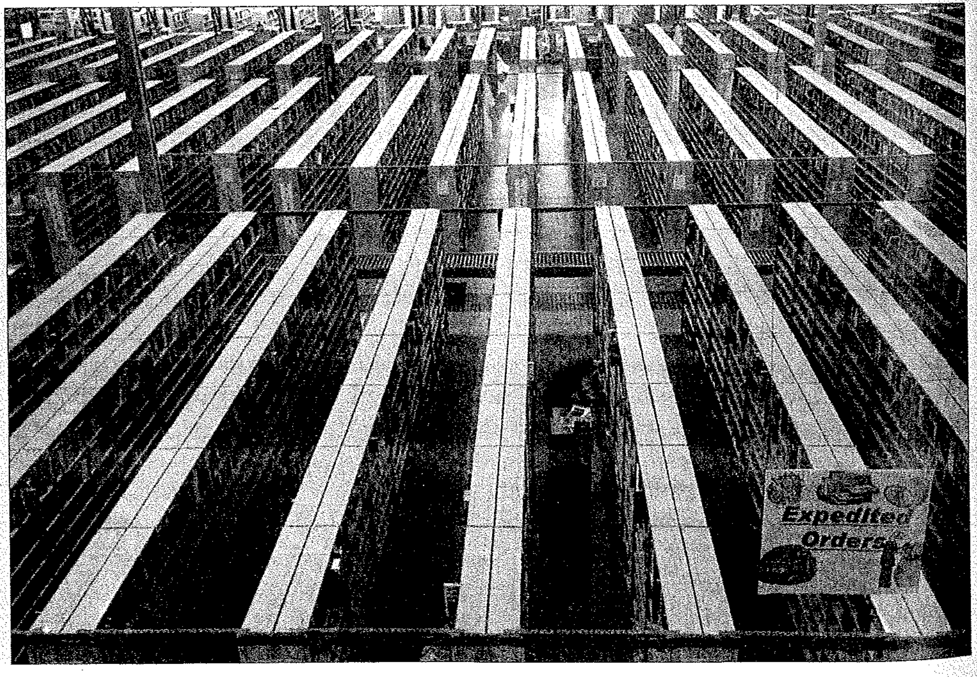
It should be noted that some union contracts allow workers to refuse overtime. In those cases, it may be difficult to muster a full crew to work overtime or to get an entire production line into operation after regular hours. Although workers often like the additional income overtime can generate, they may not appreciate having to work on short notice or the fluctuations in income that result. Still other considerations relate to the fact that overtime often results in lower productivity, poorer quality, more accidents, and increased payroll costs, whereas idle time results in less efficient use of machines and other fixed assets.

The use of slack when demand is less than capacity can be an important consideration. Some organizations use this time for training. It also can give workers time for problem solving and process improvement, while retraining skilled workers.

3. **Part-time workers.** In certain instances, the use of part-time workers is a viable option—much depends on the nature of the work, training and skills needed, and union agreements. Seasonal work requiring low-to-moderate job skills lends itself to part-time workers, who generally cost less than regular workers in hourly wages and fringe benefits. However, unions may regard such workers unfavorably because they typically do not pay union dues and may lessen the power of unions. Department stores, restaurants, and supermarkets make use of part-time workers. So do parks and recreation departments, resorts, travel agencies, hotels, and other service organizations with seasonal demands. In order to be successful, these organizations must be able to hire part-time employees when they are needed.

Some companies use contract workers, also called *independent contractors,* to fill certain needs. Although they are not regular employees, often they work alongside regular workers. In addition to having different pay scales and no benefits, they can be added or subtracted from the workforce with greater ease than regular workers, giving companies great flexibility in adjusting the size of the workforce.

4. **Inventories.** The use of finished-goods inventories allows firms to produce goods in one period and sell or ship them in another period, although this involves holding or carrying those goods as inventory until they are needed. The cost includes not only storage costs and the cost of money tied up that could be invested elsewhere, but also the cost of insurance, obsolescence, deterioration, spoilage, breakage, and so on. In essence, inventories can be built



Amazon is very aggressive about managing its inventory levels. This may mean that rarely ordered items are not kept in inventory and may require time to source from a supplier. It also means that Amazon tries to move inventory out to customers as quickly as possible.

up during periods when production capacity exceeds demand and drawn down in periods when demand exceeds production capacity.

This method is more amenable to manufacturing than to service industries since manufactured goods can be stored whereas services generally cannot. However, an analogous approach used by services is to make efforts to streamline services (e.g., standard forms) or otherwise do a portion of the service during slack periods (e.g., organize the workplace). In spite of these possibilities, services tend not to make much use of inventories to alter capacity requirements.

5. **Subcontracting.** Subcontracting enables planners to acquire temporary capacity, although it affords less control over the output and may lead to higher costs and quality problems. The question of whether to make or buy (i.e., in manufacturing) or to perform a service or hire someone else to do the work generally depends on factors such as available capacity, relative expertise, quality considerations, cost, and the amount and stability of demand.

Conversely, in periods of excess capacity, an organization may subcontract *in,* that is, conduct work for another organization. As an alternative to subcontracting, an organization might consider *outsourcing:* contracting with another organization to supply some portion of the goods or services on a regular basis.

BASIC STRATEGIES FOR MEETING UNEVEN DEMAND

As you see, managers have a wide range of decision options they can consider for achieving a balance of demand and capacity in aggregate planning. Since the options that are most suited to influencing demand fall more in the realm of marketing than in operations (with the exception of backlogging), we shall concentrate on the capacity options, which are in the realm of operations but include the use of back orders.

SCREENCAM TUTORIAL

Aggregate planners might adopt a number of strategies. Some of the more prominent ones are the following:

1. Maintain a level workforce.
2. Maintain a steady output rate.
3. Match demand period by period.
4. Use a combination of decision variables.

While other strategies might be considered, these will suffice to give you a sense of how aggregate planning operates in a vast number of organizations. The first three strategies are "pure" strategies because each has a single focal point; the last strategy is "mixed" because it lacks the single focus. Under a **level capacity strategy**, variations in demand are met by using some combination of inventories, overtime, part-time workers, subcontracting, and back orders while maintaining a steady rate of output. Matching capacity to demand implies a **chase demand strategy**; the planned output for any period would be equal to expected demand for that period.

Level capacity strategy Maintaining a steady rate of regular-time output while meeting variations in demand by a combination of options.

Chase demand strategy Matching capacity to demand; the planned output for a period is set at the expected demand for that period.

Many organizations regard a level workforce as very appealing. Since workforce changes through hiring and laying off can have a major impact on the lives and morale of employees and can be disruptive for managers, organizations often prefer to handle uneven demand in other ways. Moreover, changes in workforce size can be very costly, and there is always the risk that there will not be a sufficient pool of workers with the appropriate skills when needed. Aside from these considerations, such changes can involve a significant amount of paperwork. Unions tend to favor a level workforce because the freedom to hire and lay off workers diminishes union strengths.

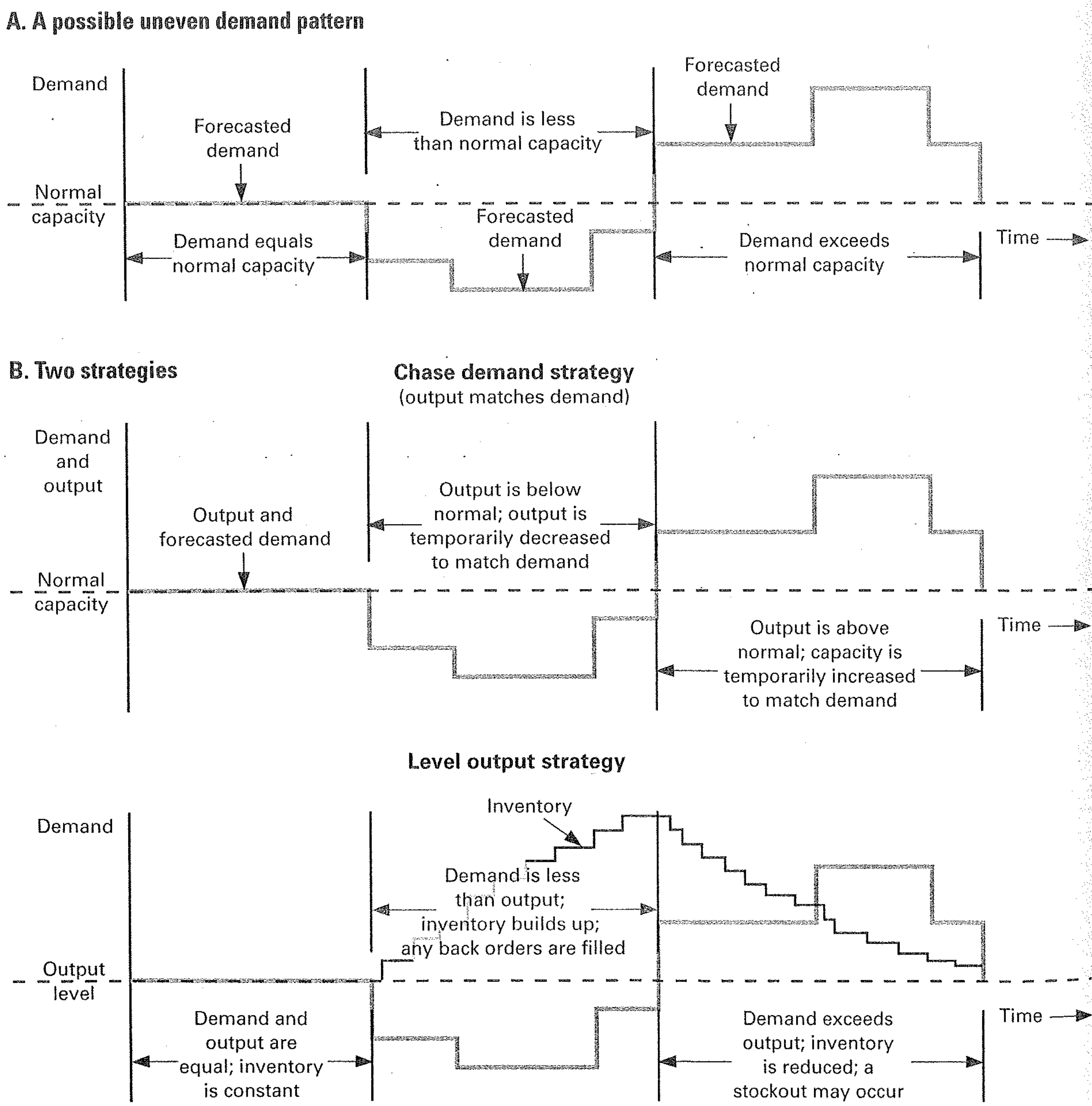
To maintain a constant level of output and still satisfy varying demand, an organization must resort to some combination of subcontracting, backlogging, and use of inventories to absorb fluctuations. Subcontracting requires an investment in evaluating sources of supply as well as possible increased costs, less control over output, and perhaps quality considerations.

SERVICE

Backlogs can lead to lost sales, increased record keeping, and lower levels of customer service. Allowing inventories to absorb fluctuations can entail substantial costs by having money tied up in inventories, having to maintain relatively large storage facilities, and incurring other costs related to inventories. Furthermore, inventories are not usually an alternative for service-oriented organizations. However, there are certain advantages, such as minimum costs of recruitment and training, minimum overtime and idle-time costs, fewer morale problems, and stable use of equipment and facilities.

A chase demand strategy presupposes a great deal of ability and willingness on the part of managers to be flexible in adjusting to demand. A major advantage of this approach is that inventories can be kept relatively low, which can yield substantial savings for an organization. A major disadvantage is the lack of stability in operations—the atmosphere is one of dancing to demand's tune. Also, when forecast and reality differ, morale can suffer, since it quickly becomes obvious to workers and managers that efforts have been wasted. Figure 11.2 provides

FIGURE 11.2 A varying demand pattern and a comparison of a chase demand strategy versus a level strategy



a comparison of the two strategies, using a varying demand pattern to highlight the differences in the two approaches. The same demand pattern is used for each approach. In the upper portion of the figure the pattern is shown. Notice that there are three situations: (1) demand and capacity are equal; (2) demand is less than capacity; and (3) demand exceeds capacity.

The middle portion of the figure illustrates what happens with a chase approach. When normal capacity would exceed demand, capacity is cut back to match demand. Then, when demand exceeds normal capacity, the chase approach is to temporarily increase capacity to match demand.

The bottom portion of the figure illustrates the level-output strategy. When demand is less than capacity, output continues at normal capacity, and the excess output is put into inventory in anticipation of the time when demand exceeds capacity. When demand exceeds capacity, inventory is used to offset the shortfall in output.

Organizations may opt for a strategy that involves some combination of the pure strategies. This allows managers greater flexibility in dealing with uneven demand and perhaps in experimenting with a wide variety of approaches. However, the absence of a clear focus may lead to an erratic approach and confusion on the part of employees.

Choosing a Strategy

Whatever strategy an organization is considering, three important factors are *company policy, flexibility,* and *costs.* Company policy may set constraints on the available options or the extent to which they can be used. For instance, company policy may discourage layoffs except under extreme conditions. Subcontracting may not be a viable alternative due to the desire to maintain secrecy about some aspect of the manufacturing of the product (e.g., a secret formula or blending process). Union agreements often impose restrictions. For example, a union contract may specify both minimum and maximum numbers of hours part-time workers can be used. The degree of flexibility needed to use the chase approach may not be present for companies designed for high, steady output, such as refineries and auto assembly plants.

As a rule, aggregate planners seek to match supply and demand within the constraints imposed on them by policies or agreements and at minimum cost. They usually evaluate alternatives in terms of their overall costs. Table 11.3 compares reactive strategies. In the next section, a number of techniques for aggregate planning are described and presented with some examples of cost evaluation of alternative plans.

TABLE 11.3
Comparison of reactive strategies

Chase approach

Capacities (workforce levels, output rates, etc.) are adjusted to match demand requirements over the planning horizon. A chase strategy works best when inventory carrying costs are high and costs of changing capacity are low.

Advantages:
- Investment in inventory is low.
- Labor utilization is kept high.

Disadvantage:
- The cost of adjusting output rates and/or workforce levels.

Level approach

Capacities (workforce levels, output rates, etc.) are kept constant over the planning horizon. A level strategy works best when inventory carrying costs and backlog costs are relatively low.

Advantage:
- Stable output rates and workforce levels.

Disadvantages:
- Greater inventory costs.
- Increased overtime and idle time.
- Resource utilizations that vary over time.

SCREENCAM TUTORIAL

TECHNIQUES FOR AGGREGATE PLANNING

Numerous techniques are available to help with the task of aggregate planning. Generally, they fall into one of two categories: Informal trial-and-error techniques and mathematical techniques. In practice, informal techniques are more frequently used. However, a considerable amount of research has been devoted to mathematical techniques, and even though they are not as widely used, they often serve as a basis for comparing the effectiveness of alternative techniques for aggregate planning. Thus, it will be instructive to briefly examine them as well as the informal techniques.

A general procedure for aggregate planning consists of the following steps:

1. Determine demand for each period.
2. Determine capacities (regular time, overtime, subcontracting) for each period.
3. Identify company or departmental policies that are pertinent (e.g., maintain a safety stock of 5 percent of demand, maintain a reasonably stable workforce).
4. Determine unit costs for regular time, overtime, subcontracting, holding inventories, back orders, layoffs, and other relevant costs.
5. Develop alternative plans and compute the cost for each.
6. If satisfactory plans emerge, select the one that best satisfies objectives. Otherwise, return to step 5.

It can be helpful to use a worksheet or spreadsheet, such as the one illustrated in Table 11.4, to summarize demand, capacity, and cost for each plan. In addition, graphs can be used to guide development of alternatives.

Trial-and-Error Techniques Using Graphs and Spreadsheets

Trial-and-error approaches consist of developing simple tables or graphs that enable planners to visually compare projected demand requirements with existing capacity. Alternatives are usually evaluated in terms of their overall costs. The chief disadvantage of such techniques is that they do not necessarily result in the optimal aggregate plan.

Two examples illustrate the development and comparison of aggregate plans. In the first example, regular output is held steady, with inventory absorbing demand variations. In the second example, a lower rate of regular output is used, supplemented by use of overtime. In both examples, some backlogs are allowed to build up.

These examples and other examples and problems in this chapter are based on the following assumptions:

1. The regular output capacity is the same in all periods. No allowance is made for holidays, different numbers of workdays in different months, and so on. This assumption simplifies computations.
2. Cost (back order, inventory, subcontracting, etc.) is a linear function composed of unit cost and number of units. This often has a reasonable approximation to reality, although there may be only narrow ranges over which this is true. Cost is sometimes more of a step function.
3. Plans are feasible; that is, sufficient inventory capacity exists to accommodate a plan, subcontractors with appropriate quality and capacity are standing by, and changes in output can be made as needed.
4. All costs associated with a decision option can be represented by a lump sum or by unit costs that are independent of the quantity involved. Again, a step function may be more realistic; but for purposes of illustration and simplicity, this assumption is appropriate.
5. Cost figures can be reasonably estimated and are constant for the planning horizon.

TABLE 11.4
Worksheet/spreadsheet

Period	1	2	3	4	5	Total
Forecast						
Output						
Regular time						
Overtime						
Subcontract						
Output – Forecast						
Inventory						
Beginning						
Ending						
Average						
Backlog						
Costs						
Output						
Regular						
Overtime						
Subcontract						
Hire/Lay off						
Inventory						
Back orders						
Total						

6. Inventories are built up and drawn down at a uniform rate and output occurs at a uniform rate throughout each period. However, backlogs are treated as if they exist for an entire period, even though in periods where they initially appear, they would tend to build up toward the end of the period. Hence, this assumption is a bit unrealistic for some periods, but it simplifies computations.

In the examples and problems in this chapter, we use the following relationships to determine the number of workers, the amount of inventory, and the cost of a particular plan.

The number of workers available in any period is calculated as follows:

$$\text{Number of workers in a period} = \text{Number of workers at end of the previous period} + \text{Number of new workers at start of the period} - \text{Number of laid-off workers at start of the period}$$

Note: An organization would not hire and lay off simultaneously, so at least one of the last two terms will equal zero.

The amount of inventory at the end of a given period is calculated as follows:

$$\text{Inventory at the end of a period} = \text{Inventory at end of the previous period} + \text{Production in the current period} - \text{Amount used to satisfy demand in the current period}$$

The average inventory for a period is equal to

$$\frac{\text{Beginning inventory} + \text{Ending inventory}}{2}$$

The cost of a particular plan for a given period can be determined by summing the appropriate costs:

$$\text{Cost for a period} = \text{Output cost (Reg + OT + Subcontract)} + \text{Hire/lay-off cost} + \text{Inventory cost} + \text{Back-order cost}$$

The appropriate costs are calculated as follows:

Type of Cost	How to Calculate
Output	
Regular	Regular cost per unit × Quantity of regular output
Overtime	Overtime cost per unit × Overtime quantity
Subcontract	Subcontract cost per unit × Subcontract quantity
Hire/lay off	
Hire	Cost per hire × Number hired
Lay off	Cost per layoff × Number laid off
Inventory	Carrying cost per unit × Average inventory
Back order	Back-order cost per unit × Number of back-order units

The following examples are only two of many possible options that could be tried. Perhaps some of the others would result in a lower cost. With trial and error, you can never be completely sure you have identified the lowest-cost alternative unless every possible alternative is evaluated. Of course, the purpose of these examples is to illustrate the process of developing and evaluating an aggregate plan rather than to find the lowest-cost plan. Problems at the end of the chapter cover still other alternatives.

In practice, successful achievement of a good plan depends on the resourcefulness and persistence of the planner. Computer software such as the Excel templates that accompany this book can eliminate the computational burden of trial-and-error techniques.

EXAMPLE 1

eXcel

www.mhhe.com/stevenson11e

Planners for a company that makes several models of skateboards are about to prepare the aggregate plan that will cover six periods. They have assembled the following information:

Period	1	2	3	4	5	6	Total
Forecast	200	200	300	400	500	200	1,800

Costs
- Output
  - Regular time = $2 per skateboard
  - Overtime = $3 per skateboard
  - Subcontract = $6 per skateboard
- Inventory = $1 per skateboard per period on average inventory
- Back orders = $5 per skateboard per period

They now want to evaluate a plan that calls for a steady rate of regular-time output, mainly using inventory to absorb the uneven demand but allowing some backlog. Overtime and subcontracting are not used because they want steady output. They intend to start with zero inventory on hand in the first period. Prepare an aggregate plan and determine its cost using the preceding information. Assume a level output rate of 300 units (skateboards) per period with regular time (i.e., 1,800/6 = 300). Note that the planned ending inventory is zero. There are 15 workers, and each can produce 20 skateboards per period.

SOLUTION

Period	1	2	3	4	5	6	Total
Forecast	200	200	300	400	500	200	1,800
Output							
Regular	300	300	300	300	300	300	1,800
Overtime	—	—	—	—	—	—	
Subcontract	—	—	—	—	—	—	
Output − Forecast	100	100	0	(100)	(200)	100	0
Inventory							
Beginning	0	100	200	200	100	0	
Ending	100	200	200	100	0	0	
Average	50	150	200	150	50	0	600
Backlog	0	0	0	0	100	0	100

Period	1	2	3	4	5	6	Total
Costs							
Output							
Regular	$600	600	600	600	600	600	$3,600
Overtime	—	—	—	—	—	—	
Subcontract	—	—	—	—	—	—	
Hire/Lay off	—	—	—	—	—	—	
Inventory	$ 50	150	200	150	50	0	$ 600
Back orders	$ 0	0	0	0	500	0	$ 500
Total	$650	750	800	750	1,150	600	$4,700

Note that the total regular-time output of 1,800 units equals the total expected demand. Ending inventory equals beginning inventory plus or minus the quantity Output − Forecast. If Output − Forecast is negative, inventory is decreased in that period by that amount. If insufficient inventory exists, a backlog equal to the shortage amount appears, as in period 5. This is taken care of using the excess output in period 6.

The costs were computed as follows. Regular cost in each period equals 300 units × $2 per unit or $600. Inventory cost equals average inventory × $1 per unit. Back-order cost is $5 per unit. The total cost for this plan is $4,700.

Note that the first two quantities in each column are givens. The remaining quantities in the upper portion of the table were determined working down each column, beginning with the first column. The costs were then computed based on the quantities in the upper part of the table.

Very often, graphs can be used to guide the development of alternatives. Some planners prefer cumulative graphs while others prefer to see a period-by-period breakdown of a plan. For instance, Figure 11.3 shows a cumulative graph for a plan with steady output (the slope of the dashed line represents the production rate) and inventory absorption of demand variations. Figure 11.2 is an example of a period-by-period graph. The obvious advantage of a graph is that it provides a visual portrayal of a plan. The preference of the planner determines which of these two types of graphs is chosen.

EXAMPLE 2

eXcel

www.mhhe.com/stevenson11e

After reviewing the plan developed in the preceding example, planners have decided to develop an alternative plan. They have learned that one person is about to retire from the company. Rather than replace that person, they would like to stay with the smaller workforce and use overtime to make up for the lost output. The reduced regular-time output is 280 units per period. The maximum amount of overtime output per period is 40 units. Develop a plan and compare it to the previous one.

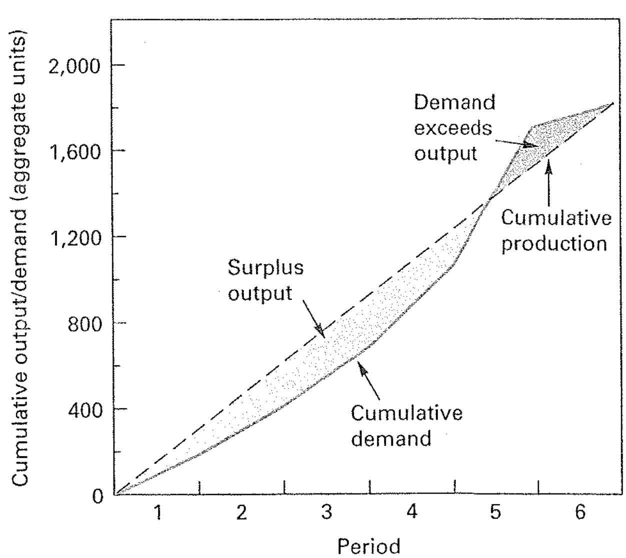


FIGURE 11.3
A cumulative graph

SOLUTION

Period	1	2	3	4	5	6	Total
Forecast	200	200	300	400	500	200	1,800
Output							
Regular	280	280	280	280	280	280	1,680
Overtime	0	0	40	40	40	0	120
Subcontract	—	—	—	—	—	—	
Output − Forecast	80	80	20	(80)	(180)	80	0
Inventory							
Beginning	0	80	160	180	100	0	
Ending	80	160	180	100	0	0	
Average	40	120	170	140	50	0	520
Backlog	0	0	0	0	80	0	80
Costs							
Output							
Regular	$560	560	560	560	560	560	$3,360
Overtime	0	0	120	120	120	0	$ 360
Subcontract	—	—	—	—	—	—	
Hire/Lay off	—	—	—	—	—	—	
Inventory	40	120	170	140	50	0	$ 520
Back orders	$ 0	0	0	0	400	0	$ 400
Total	$600	680	850	820	1,130	560	$4,640

The amount of overtime that must be scheduled has to make up for lost output of 20 units per period for six periods, which is 120. This is scheduled toward the center of the planning horizon since that is where the bulk of demand occurs. Scheduling it earlier would increase inventory carrying costs; scheduling it later would increase the backlog cost.

Overall, the total cost for this plan is $4,640, which is $60 less than the previous plan. Regular-time production cost and inventory cost are down, but there is overtime cost. However, this plan achieves savings in backorder cost, making it somewhat less costly overall than the plan in Example 1.

Mathematical Techniques

SCREENCAM TUTORIAL

A number of mathematical techniques have been developed to handle aggregate planning. They range from mathematical programming models to heuristic and computer search models. This section briefly describes some of the better-known techniques.

Linear Programming. Linear programming (LP) models are methods for obtaining optimal solutions to problems involving the allocation of scarce resources in terms of cost minimization or profit maximization. With aggregate planning, the goal is usually to minimize the sum of costs related to regular labor time, overtime, subcontracting, carrying inventory, and costs associated with changing the size of the workforce. Constraints involve the capacities of the workforce, inventories, and subcontracting.

The problem can be formulated as a transportation-type programming model (described in detail in the supplement to Chapter 8) as a way to obtain aggregate plans that would match capacities with demand requirements and minimize costs. In order to use this approach, planners must identify capacity (supply) of regular time, overtime, subcontracting, and inventory on a period-by-period basis, as well as related costs of each variable.

Table 11.5 shows the notation and setup of a transportation table. Note the systematic way that costs change as you move across a row from left to right. Regular cost, overtime cost, and subcontracting cost are at their lowest when the output is consumed (i.e., delivered, etc.) in the same period it is produced (at the intersection of period 1 row and column for regular cost, at the intersection of period 2 row and column for regular cost, and so on). If goods are made available in one period but carried over to later periods (i.e., moving across a row), holding costs are incurred at the rate of h per period. Thus, holding goods for two periods results in a unit cost of $2h$, whether or not the goods came from regular production, overtime, or subcontracting. Conversely, with back orders, the unit cost increases as you move across a row

TABLE 11.5 Transportation notation for aggregate planning

Period		Period 1	Period 2	Period 3	. . .	Ending inventory period n	Unused capacity	Capacity
	Beginning inventory	0	h	$2h$	. . .	$(n-1)h$	0	I_0
1	Regular time	r	$r+h$	$r+2h$	. . .	$r+(n-1)h$	0	R_1
	Overtime	t	$t+h$	$t+2h$	. . .	$t+(n-1)h$	0	O_1
	Subcontract	s	$s+h$	$s+2h$	. . .	$s+(n-1)h$	0	S_1
2	Regular time	$r+b$	r	$r+h$	. . .	$r+(n-2)h$	0	R_2
	Overtime	$t+b$	t	$t+h$	. . .	$t+(n-2)h$	0	O_2
	Subcontract	$s+b$	s	$s+h$	. . .	$s+(n-2)h$	0	S_2
3	Regular time	$r+2b$	$r+b$	r	. . .	$r+(n-3)h$	0	R_3
	Overtime	$t+2b$	$t+b$	t	. . .	$t+(n-3)h$	0	O_3
	Subcontract	$s+2b$	$s+b$	s	. . .	$s+(n-3)h$	0	S_3
	Demand				. . .			Total

r = Regular production cost per unit
t = Overtime cost per unit
s = Subcontracting cost per unit
h = Holding cost per unit period
b = Back order cost per unit per period
n = Number of periods in planning horizon

from right to left, beginning at the intersection of a row and column for the same period (e.g., period 3). For instance, if some goods are produced in period 3 to satisfy back orders from period 2, a unit back-order cost of b is incurred. And if goods in period 3 are used to satisfy back orders two periods earlier (e.g., from period 1), a unit cost of $2b$ is incurred. Unused capacity is generally given a unit cost of 0, although it is certainly possible to insert an actual cost if that is relevant. Finally, beginning inventory is given a unit cost of 0 if it is used to satisfy demand in period 1. However, if it is held over for use in later periods, a holding cost of h per unit is added for each period. If the inventory is to be held for the entire planning horizon, a total unit cost of h times the number of periods, n, will be incurred.

Example 3 illustrates the setup and final solution of a transportation model of an aggregate planning problem.

EXAMPLE 3

excel

www.mhhe.com/stevenson11e

Given the following information set up the problem in a transportation table and solve for the minimum-cost plan:

	PERIOD 1	2	3
Demand	550	700	750
Capacity			
Regular	500	500	500
Overtime	50	50	50
Subcontract	120	120	100
Beginning inventory	100		
Costs			
Regular time	$60 per unit		
Overtime	$80 per unit		
Subcontract	$90 per unit		
Inventory carrying cost	$1 per unit per month		
Back-order cost	$3 per unit per month		

SOLUTION

The transportation table and solution are shown in Table 11.6. Some of the entries require additional explanation:

a. In this example, inventory carrying costs are $1 per unit per period (costs are shown in the upper right-hand corner of each cell in the table). Hence, units produced in one period and carried over to a later period will incur a holding cost that is a linear function of the length of time held.

b. Linear programming models of this type require that supply (capacity) and demand be equal. A dummy column has been added (nonexistent capacity) to satisfy that requirement. Since it does not "cost" anything extra to not use capacity in this case, cell costs of $0 have been assigned.

c. No backlogs were needed in this example.

d. The quantities (e.g., 100 and 450 in column 1) are the amounts of output or inventory that will be used to meet demand requirements. Thus, the demand of 550 units in period 1 will be met using 100 units from inventory and 450 obtained from regular-time output.

Where backlogs are not permitted, the cell costs for the backlog positions can be made prohibitively high so that no backlogs will appear in the solution.

The main limitations of LP models are the assumptions of linear relationships among variables, the inability to continuously adjust output rates, and the need to specify a single objective (e.g., minimize costs) instead of using multiple objectives (e.g., minimize cost while stabilizing the workforce).

TABLE 11.6
Transportation solution

Period	Supply from	Demand for: Period 1	Period 2	Period 3	Unused capacity (dummy)	Total capacity available (supply)
	Beginning inventory	[0] 100	[1]	[2]	[0]	100
1	Regular time	[60] 450	[61] 50	[62]	[0]	500
	Overtime	[80]	[81] 50	[82]	[0]	50
	Subcontract	[90]	[91] 30	[92]	[0] 90	120
2	Regular time	[63]	[60] 500	[61]	[0]	500
	Overtime	[83]	[80] 50	[81]	[0]	50
	Subcontract	[93]	[90] 20	[91] 100	[0]	120
3	Regular time	[66]	[63]	[60] 500	[0]	500
	Overtime	[86]	[83]	[80] 50	[0]	50
	Subcontract	[96]	[93]	[90] 100	[0]	100
	Demand	550	700	750	90	2,090

TABLE 11.7
Summary of planning techniques

Technique	Solution Approach	Characteristics
Spreadsheet	Heuristic (trial and error)	Intuitively appealing, easy to understand; solution not necessarily optimal
Linear programming	Optimizing	Computerized; linear assumptions not always valid
Simulation	Heuristic (trial and error)	Computerized models can be examined under a variety of conditions

Simulation Models. A number of **simulation models** have been developed for aggregate planning. (Simulation is described in detail on the textbook Web site.) The essence of simulation is the development of computerized models that can be tested under a variety of conditions in an attempt to identify reasonably acceptable (although not always optimal) solutions to problems.

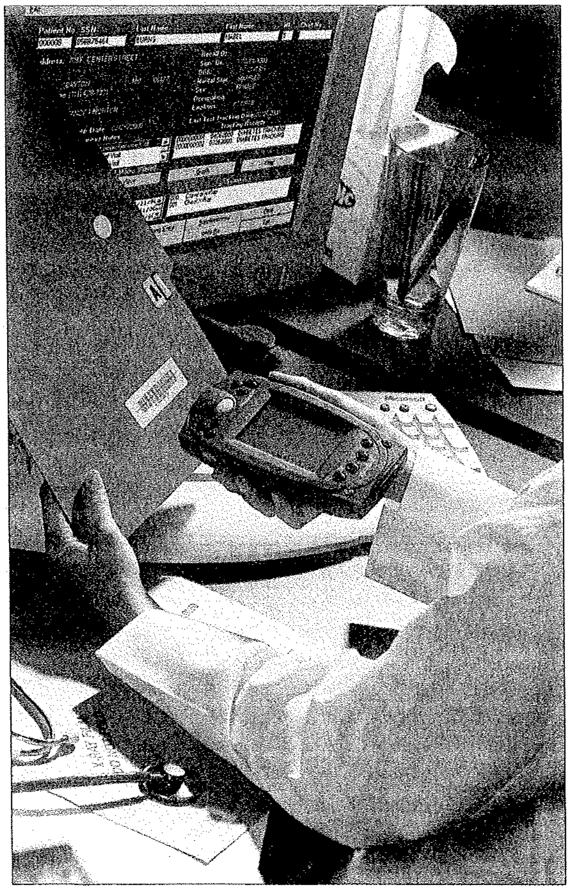
Simulation models Computerized models that can be tested under different scenarios to identify acceptable solutions to problems.

Table 11.7 summarizes planning techniques.

Aggregate planning techniques other than trial and error do not appear to be widely used. Instead, in the majority of organizations, aggregate planning seems to be accomplished more on the basis of experience along with trial-and-error methods. It is difficult to say exactly why some of the mathematical techniques mentioned are not used to any great extent. Perhaps the level of mathematical sophistication discourages greater use, or the assumptions required in certain models appear unrealistic, or the models may be too narrow in scope. Whatever the reasons, none of the techniques to date have captured the attention of aggregate planners on a broad scale. Simulation is one technique that seems to be gaining favor. Research on improved approaches to aggregate planning is continuing.

SERVICE

AGGREGATE PLANNING IN SERVICES



Aggregate planning for services takes into account projected customer demands, equipment capacities, and labor capabilities. The resulting plan is a time-phased projection of service staff requirements.

Here are examples of service organizations that use aggregate planning:

Hospitals: Hospitals use aggregate planning to allocate funds, staff, and supplies to meet the demands of patients for their medical services. For example, plans for bed capacity, medications, surgical supplies, and personnel needs are based on patient load forecasts.

Airlines: Aggregate planning in the airline industry is fairly complex due to the need to take into account a wide range of factors (planes, flight personnel, ground personnel) and multiple routes and landing/departure sites. Also, capacity decisions must take into account the percentage of seats to be allocated to various fare classes in order to maximize profit or yield.

Restaurants: Aggregate planning in the case of a high-volume product output business such as a restaurant is directed toward smoothing the service rate, determining the size of the workforce, and managing demand to match a fixed capacity. The general approach usually involves building inventory during slack periods and depleting it during peak periods. Because this is very similar to manufacturing, traditional aggregate planning methods can be applied, although two differences must be taken into account. One difference is that in restaurants, inventory is perishable: Cooked food can be held for only a very short time. Another difference, particularly in fast-food restaurants, is that peak and slack periods occur often and are relatively short-lived.

Other services: Financial, hospitality, transportation, and recreation services provide a high-volume, intangible output. Aggregate planning for these and similar services involves managing demand and planning for human resource requirements. The main goals are to accommodate peak demand and to find ways to effectively use labor resources during periods of low demand.

Aggregate planning for manufacturing and aggregate planning for services share similarities in some respects, but there are some important differences—related in general to the differences between manufacturing and services:

1. **Demand for service can be difficult to predict.** The volume of demand for services is often quite variable. In some situations, customers may *need* prompt service (e.g., police, fire, medical emergency), while in others, they simply *want* prompt service and may be willing to go elsewhere if their wants are not met. These factors place a greater burden on service providers to anticipate demand. Consequently, service providers must pay careful attention to planned capacity levels.
2. **Capacity availability can be difficult to predict.** Processing requirements for services can sometimes be quite variable, similar to the variability of work in a job shop setting. Moreover, the variety of tasks required of servers can be great, again similar to the variety of tasks in a job shop. However, in services, the types of variety are more pervasive than they are in manufacturing. This makes it more difficult to establish simple measures of capacity. For example, what would be the capacity of a person who paints interiors of houses? The number of rooms per day or the number of square feet per hour are possible measures, but rooms come in many different sizes, and because the level of detail (and, thus, the painting implements that can be used) vary tremendously, a suitable measure for planning purposes can be quite difficult to arrive at. Similarly, bank tellers are called upon to handle a wide variety of transactions and requests for information, again making it difficult to establish a suitable measure of their capacity.
3. **Labor flexibility can be an advantage in services.** Labor often comprises a significant portion of service compared to manufacturing. That, coupled with the fact that service providers are often able to handle a fairly wide variety of service requirements, means that to some extent, planning is easier than it is in manufacturing. Of course, manufacturers recognize this advantage, and many are cross-training their employees to achieve the same flexibility. Moreover, in both manufacturing and service systems, the use of part-time workers can be an important option. Note that in self-service systems, the (customer) labor automatically adjusts to changes in demand!
4. **Services occur when they are rendered.** Unlike manufacturing output, most services can't be inventoried. Services such as financial planning, tax counseling, and oil changes can't be stockpiled. This removes the option of building up inventories during a slow period in anticipation of future demand. Moreover, service capacity that goes unused is essentially wasted. Consequently, it becomes even more important to be able to match capacity and demand.

Yield management The application of pricing strategies to allocate capacity among various categories of demand.

Because service capacity is perishable (e.g., an empty seat on an airplane flight can't be saved for use on another flight), aggregate planners need to take that into account when deciding how to match supply and demand. **Yield management** is an approach that seeks to maximize revenue by using a strategy of variable pricing; prices are set relative to capacity availability. Thus, during periods of low demand, price discounts are offered to attract a wider population. Conversely, during peak periods, higher prices are posted to take advantage of limited supply relative to demand. Users of yield management include airlines, restaurants, theaters, hotels, resorts, cruise lines, and parking lots.

DISAGGREGATING THE AGGREGATE PLAN

For the production plan to be translated into meaningful terms for production, it is necessary to *disaggregate* the aggregate plan. This means breaking down the aggregate plan into specific product requirements in order to determine labor requirements (skills, size of workforce), materials, and inventory requirements. This process is described in Chapter 12. At this stage, however, it will be helpful for you to have some understanding of the need for disaggregation and what the term implies.

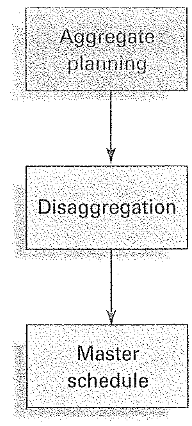


FIGURE 11.4
Moving from the aggregate plan to a master production schedule

Working with aggregate units facilitates intermediate planning. However, to put the production plan into operation, one must convert, or decompose, those aggregate units into units of actual products or services that are to be produced or offered. For example, a lawn mower manufacturer may have an aggregate plan that calls for 200 lawn mowers in January, 300 in February, and 400 in March. That company may produce push mowers, self-propelled mowers, and riding mowers. Although all the mowers probably contain some of the same parts and involve some similar or identical operations for fabrication and assembly, there would be some differences in the materials, parts, and operations that each type requires. Hence, the 200, 300, and 400 aggregate lawn mowers that are to be produced during those three months must be translated into specific numbers of mowers of each type prior to actually purchasing the appropriate materials and parts, scheduling operations, and planning inventory requirements.

The result of disaggregating the aggregate plan is a **master production schedule (MPS)**, or simply master schedule, showing the quantity and timing of *specific* end items for a scheduled horizon, which often covers about six to eight weeks ahead. A master schedule shows the planned output for individual products rather than an entire product group, along with the timing of production. The master schedule contains important information for marketing as well as for production. It reveals when orders are scheduled for production and when completed orders are to be shipped.

Master production schedule (MPS) This schedule indicates the quantity and timing of planned completed production.

Figure 11.4 shows an overview of the context of disaggregation.

Figure 11.5 illustrates disaggregating the aggregate plan. The illustration makes a simple assumption in order to clearly show the concept of disaggregation: The totals of the aggregate and the disaggregated units are equal. In reality, that is not always true. As a consequence, disaggregating the aggregate plan may require considerable effort.

Figure 11.5 shows the aggregate plan broken down by units. However, it also can be useful to show the breakdown in *percentages* for different products or product families.

MASTER SCHEDULING

The master schedule is the heart of production planning and control. It determines the quantities needed to meet demand from all sources, and that governs key decisions and activities throughout the organization.

Aggregate plan	***Month***	***Jan.***	***Feb.***	***Mar.***
	Planned output*	200	300	400
**Aggregate units*				
Master schedule	***Month***	***Jan.***	***Feb.***	***Mar.***
	Planned output*			
	Push	100	100	100
	Self-propelled	75	150	200
	Riding	25	50	100
	Total	200	300	400
**Actual units*				

FIGURE 11.5
Disaggregating the aggregate plan

The master schedule interfaces with marketing, capacity planning, production planning, and distribution planning: It enables marketing to make valid delivery commitments to warehouses and final customers; it enables production to evaluate capacity requirements; it provides the necessary information for production and marketing to negotiate when customer requests cannot be met by normal capacity; and it provides senior management with the opportunity to determine whether the business plan and its strategic objectives will be achieved. The master schedule also drives the material requirements planning (MRP) system that will be discussed in the next chapter.

The capacities used for master scheduling are based on decisions made during aggregate planning. Note that there is a time lapse between the time the aggregate plan is made and the development of a master schedule. Consequently, the outputs shown in a master schedule will not necessarily be identical to those of the aggregate plan for the simple reason that more up-to-date demand information might be available, which the master schedule would take into account.

The central person in the master scheduling process is the master scheduler.

The Master Scheduler

Most manufacturing organizations have (or should have) a master scheduler. The duties of the master scheduler generally include

1. Evaluating the impact of new orders.
2. Providing delivery dates for orders.
3. Dealing with problems:
   a. Evaluating the impact of production delays or late deliveries of purchased goods.
   b. Revising the master schedule when necessary because of insufficient supplies or capacity.
   c. Bringing instances of insufficient capacity to the attention of production and marketing personnel so that they can participate in resolving conflicts.

THE MASTER SCHEDULING PROCESS

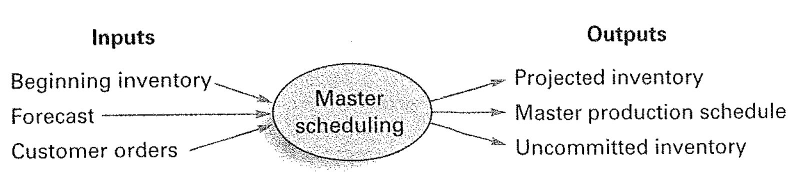
A master schedule indicates the quantity and timing (i.e., delivery times) for a product, or a group of products, but it does not show planned *production.* For instance, a master schedule may call for delivery of 50 cases of cranberry-apple juice to be delivered on May 1. But this may not require any production; there may be 200 cases in inventory. Or it may require *some* production: If there were 40 cases in inventory, an additional 10 cases would be needed to achieve the specified delivery amount. Or it may involve production of 50 or more cases: In some instances, it is more economical to produce large amounts rather than small amounts, with the excess temporarily placed in inventory until needed. Thus, the *production lot size* might be 70 cases, so if additional cases were needed (e.g., 50 cases), a run of 70 cases would be made.

The master production schedule is one of the primary outputs of the master scheduling process, as illustrated in Figure 11.6.

Rough-cut capacity planning (RCCP) Approximate balancing of capacity and demand to test the feasibility of a master schedule.

Once a *tentative* master schedule has been developed, it must be validated. This is an extremely important step. Validation is referred to as **rough-cut capacity planning (RCCP)**. It involves testing the feasibility of a proposed master schedule relative to available capacities, to assure that no obvious capacity constraints exist. This means checking capacities of production and warehouse facilities, labor, and vendors to ensure that no gross deficiencies

FIGURE 11.6
The master scheduling process



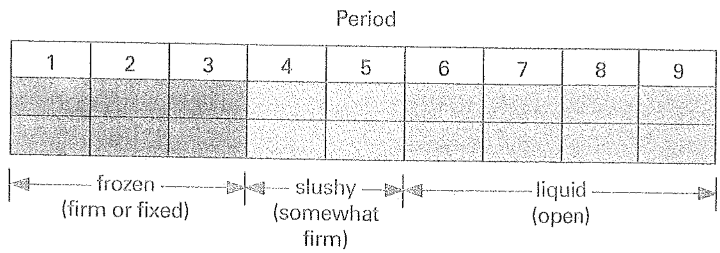


FIGURE 11.7
Time fences in an MPS

exist that will render the master schedule unworkable. The master production schedule then serves as the basis for *short-range* planning. It should be noted that whereas the aggregate plan covers an interval of, say, 12 months, the master schedule covers only a portion of this. In other words, the aggregate plan is disaggregated in stages, or phases, that may cover a few weeks to two or three months. Moreover, the master schedule may be updated monthly, even though it covers two or three months. For instance, the lawn mower master schedule would probably be updated at the end of January to include any revisions in planned output for February and March as well as new information on planned output for April.

Time Fences

Changes to a master schedule can be disruptive, particularly changes to the early, or near, portions of the schedule. Typically, the further out in the future a change is, the less the tendency to cause problems.

High-performance organizations have an effective master scheduling process. A key component of effective scheduling is the use of *time fences* to facilitate order promising and the entry of orders into the system. **Time fences** divide a scheduling time horizon into three sections or phases, sometimes referred to as *frozen, slushy,* and *liquid,* in reference to the firmness of the schedule (see Figure 11.7).

Time fences Points in time that separate phases of a master schedule planning horizon.

Frozen is the near-term phase that is so soon that delivery of a new order would be impossible, or only possible using very costly or extraordinary options such as delaying another order. Authority for new-order entry in this phase usually lies with the VP of manufacturing. The length of the frozen phase is often a function of the total time needed to produce a product, from procuring materials to shipping the order. There is a high degree of confidence in order-promise dates.

Slushy is the next phase, and its time fence is usually a few periods beyond the frozen phase. Order entry in this phase necessitates trade-offs, but is less costly or disruptive than in the frozen phase. Authority for order entry usually lies with the master scheduler. There is relative confidence in order-promise dates, and capacity planning becomes very specific.

Liquid is the farthest out on the time horizon. New orders or cancellations can be entered with ease. Order promise dates are tentative, and will be firmed up with the passage of time when orders are in the firm phase of the schedule horizon.

A key element in the success of the master scheduling process is strict adherence to time fence policies and rules. It is essential that they be adhered to and communicated throughout the organization.

Inputs

The master schedule has three inputs: the beginning inventory, which is the actual quantity on hand from the preceding period; forecasts for each period of the schedule; and customer orders, which are quantities already *committed* to customers. Other factors that might need to be taken into consideration include any hiring or firing restrictions imposed by HR, skill levels, limits on inventory such as available space, whether items are perishable, and whether there are some market lifetime (e.g., seasonal or obsolescence) considerations.

Outputs

The master scheduling process uses this information on a period-by-period basis to determine the projected inventory, production requirements, and the resulting uncommitted inventory,

FIGURE 11.8A
Weekly forecast requirements for industrial pumps

	June				July			
	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40

FIGURE 11.8B
Eight-week schedule showing forecasts, customer orders, and beginning inventory

Beginning inventory	June				July			
64	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40
Customer orders (committed)	33	20	10	4	2			

Available-to-promise (ATP) inventory Uncommitted inventory.

which is referred to as **available-to-promise (ATP) inventory.** Knowledge of the uncommitted inventory can enable marketing to make realistic promises to customers about deliveries of new orders.

The master scheduling process begins with a preliminary calculation of projected on-hand inventory. This reveals when additional inventory (i.e., production) will be needed. Consider this example. A company that makes industrial pumps wants to prepare a master production schedule for June and July. Marketing has forecasted demand of 120 pumps for June and 160 pumps for July. These have been evenly distributed over the four weeks in each month: 30 per week in June and 40 per week in July, as illustrated in Figure 11.8A.

Now, suppose that there are currently 64 pumps in inventory (i.e., beginning inventory is 64 pumps), and that there are customer orders that have been committed (booked) and must be filled (see Figure 11.8B).

Figure 11.8B contains the three primary inputs to the master scheduling process: the beginning inventory, the forecast, and the customer orders that have been booked or committed. This information is necessary to determine three quantities: the projected on-hand inventory, the master production schedule, and the uncommitted (ATP) inventory. The first step is to calculate the projected on-hand inventory, one week at a time, until it falls below a specified limit. In this example, the specified limit will be zero. Hence, we will continue until the projected on-hand inventory becomes negative.

The projected on-hand inventory is calculated as follows:

$$\text{Projected on-hand inventory} = \text{Inventory from previous week} - \text{Current week's requirements} \quad (11\text{–}1)$$

where the current week's requirements are the *larger* of forecast and customer orders (committed).

For the first week, projected on-hand inventory equals beginning inventory minus the larger of forecast and customer orders. Because customer orders (33) are larger than the forecast (30), the customer orders amount is used. Thus, for the first week, we obtain

$$\text{Projected on-hand inventory} = 64 - 33 = 31$$

Projected on-hand inventories are shown in Figure 11.9 for the first three weeks (i.e., until the projected on-hand amount becomes negative).

Beginning inventory 64	June				July			
	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40
Customer orders (committed)	33	20	10	4	2			
Projected on-hand inventory	31	1	−29					

Customer orders are larger than forecast in week 1; projected on-hand inventory is 64 − 33 = 31

Forecast is larger than customer orders in week 2; projected on-hand inventory is 31 − 30 = 1

Forecast is larger than customer orders in week 3; projected on-hand inventory is 1 − 30 = −29

FIGURE 11.9
Projected on-hand inventory is computed week by week until it becomes negative

When the projected on-hand inventory becomes negative, this is a signal that production will be needed to replenish inventory. Hence, a negative projected on-hand inventory will require planned production. Suppose that a production lot size of 70 pumps is used, so that whenever production is called for, 70 pumps will be produced. (The determination of lot size is described in Chapter 13.) Hence, the negative projected on-hand inventory in the third week will require production of 70 pumps, which will meet the projected shortfall of 29 pumps and leave 41 (i.e., 70 − 29 = 41) pumps for future demand.

These calculations continue for the entire schedule. Every time projected inventory becomes negative, another production lot of 70 pumps is added to the schedule. Figure 11.10 illustrates the calculations. The result is the master schedule and projected on-hand inventory for each week of the schedule. These can now be added to the master schedule (see Figure 11.11).

It is now possible to determine the amount of inventory that is uncommitted and, hence, available to promise. Several methods are used in practice. The one we shall employ involves a "look-ahead" procedure: Sum booked customer orders week by week until (but not including) a week in which there is an MPS amount. For example, in the first week, this procedure results in summing customer orders of 33 (week 1) and 20 (week 2) to obtain 53. In the first

Week	Inventory from Previous Week	Requirements*	Net Inventory before MPS		(70) MPS		Projected Inventory
1	64	33	31				31
2	31	30	1				1
3	1	30	−29	+	70	=	41
4	41	30	11				11
5	11	40	−29	+	70	=	41
6	41	40	1				1
7	1	40	−39	+	70	=	31
8	31	40	−9	+	70	=	61

*Requirements equals the larger of forecast and customer orders in each week.

FIGURE 11.10
Determining the MPS and projected on-hand inventory

FIGURE 11.11
Projected on-hand inventory and MPS are added to the master schedule

	June				July			
64	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40
Customer orders (committed)	33	20	10	4	2			
Projected on-hand inventory	31	1	41	11	41	1	31	61
MPS			70		70		70	70

FIGURE 11.12
The available-to-promise inventory quantities have been added to the master schedule

	June				July			
64	1	2	3	4	5	6	7	8
Forecast	30	30	30	30	40	40	40	40
Customer orders (committed)	33	20	10	4	2			
Projected on-hand inventory	31	1	41	11	41	1	31	61
MPS			70		70		70	70
Available-to-promise inventory (uncommitted)	11		56		68		70	70

week, this amount is subtracted from the beginning inventory of 64 pumps plus the MPS (zero in this example) to obtain the amount that is available to promise. Thus,

$$64 + 0 - (33 + 20) = 11$$

This inventory is uncommitted, and it can be delivered in either week 1 or 2, or part can be delivered in week 1 and part in week 2. (Note that the ATP quantity is only calculated for the first week and for other weeks in which there is an MPS quantity. Hence, it is calculated for weeks 1, 3, 5, 7, 8.) See Figure 11.12.

For weeks other than the first week, the beginning inventory drops out of the computation, and ATP is the look-ahead quantity subtracted from the MPS quantity.

Thus, for week 3, the promised amounts are $10 + 4 = 14$, and the ATP is $70 - 14 = 56$.

For week 5, customer orders are 2 (future orders have not yet been booked). The ATP is $70 - 2 = 68$.

For weeks 7 and 8, there are no customer orders, so for the present, all of the MPS amount is available to promise.

As additional orders are booked, these would be entered in the schedule, and the ATP amounts would be updated to reflect those orders. Marketing can use the ATP amounts to provide realistic delivery dates to customers.

SUMMARY

Aggregate planning establishes general levels of employment, output, and inventories for periods of 2 to 12 months. In the spectrum of planning, it falls between the broad decisions of long-range planning and the very specific and detailed short-range planning decisions. It begins with an overall forecast for the planning horizon and ends with preparations for applying the plans to specific products and services.

The essence of aggregate planning is the aggregation of products or services into one "product" or "service." This permits planners to consider overall levels of employment and inventories without having to become involved with specific details that are better left to short-range planning. Planners often use informal graphic and charting techniques to develop plans, although various mathematical techniques have been suggested. It appears that the complexity and the restrictive assumptions of these techniques limit their widespread use in practice.

After the aggregate plan has been developed, it is disaggregated or broken down into specific product requirements. This leads to a master schedule, which indicates the planned quantities and timing of specific outputs. Inputs to the master schedule are on-hand inventory amounts, forecasts of demand, and customer orders. The outputs are projected production and inventory requirements, and the projected uncommitted inventory, which is referred to as available-to-promise (ATP) inventory.

KEY POINTS

1. An aggregate plan is an intermediate-range plan for a collection of similar products or services that sets the stage for shorter-range plans. See Table 11.8 for a convenient summary of aggregate planning.
2. Master scheduling breaks an aggregate plan into specific shorter-range output quantity and timing requirements.
   a. Rough-cut capacity planning tests the feasibility of a tentative master plan in terms of capacity.
   b. Time fences describe the various time period in terms of the degree to which the master schedule is firm or flexible. Early periods do not generally allow changes, while later periods have more flexibility.
3. It is essential to include the entire supply chain when developing the aggregate plan.

TABLE 11.8
Summary of aggregate planning

Purpose
Decide on the combination of
- Output rates
- Employment levels
- On-hand inventory levels

Objectives
- Minimize cost
- Others, may include
  - Maintain a desirable level of customer service
  - Minimize workforce fluctuations

Possible Strategies

A. Supply Management (reactive)

Level Production
- Allow inventory to absorb variations in demand
- Use back ordering during periods of high demand

Chase Production
- Vary output by varying the number of workers by hiring or layoffs to track demand
- Vary output throughout the use of overtime or idle time
- Vary output using part-time workers
- Use subcontracting to supplement output

Mixed Strategy
- Use a combination of level and chase approaches

B. Demand Management (proactive)
- Influence demand through promotion, pricing, etc.
- Produce goods or services that have complementary demand patterns

Managerial Importance of Aggregate Planning
- Has an effect on
  - Costs
  - Equipment utilization
  - Customer satisfaction
  - Employment levels
  - Synchronization of flow throughout the supply chain

KEY TERMS

aggregate planning, 473
available-to-promise (ATP) inventory, 496
chase demand strategy, 481
level capacity strategy, 481
master production schedule (MPS), 493
rough-cut capacity planning (RCCP), 494
sales and operations planning, 473
simulation models, 491
time fences, 495
yield management, 492

SOLVED PROBLEMS

Problem 1

A manager is attempting to put together an aggregate plan for the coming nine months. She has obtained a forecast of expected demand for the planning horizon. The plan must deal with highly seasonal demand; demand is relatively high in periods 3 and 4 and again in period 8, as can be seen from the following forecasts:

Period	1	2	3	4	5	6	7	8	9	Total
Forecast	190	230	260	280	210	170	160	260	180	1,940

The department now has 20 full-time employees, each of whom can produce 10 units of output per period at a cost of $6 per unit. Inventory carrying cost is $5 per unit per period, and backlog cost is $10 per unit per period. The manager is considering a plan that would involve hiring two people to start working in period 1, one on a temporary basis who would work only through period 5. This would cost $500 in addition to unit production costs.

a. What is the rationale for this plan?

b. Determine the total cost of the plan, including production, inventory, and back-order costs.

Solution

a. With the current workforce of 20 people each producing 10 units per period, regular capacity is 1,800 units. That is 140 units less than expected demand. Adding one worker would increase regular capacity to 1,800 + 90 = 1,890 units. That would still be 50 units short, or just the amount one temporary worker could produce in five periods. Since one of the two seasonal peaks is quite early, it would make sense to start the temporary worker right away to avoid some of the back-order cost.

b. The production plan for this strategy is as follows:

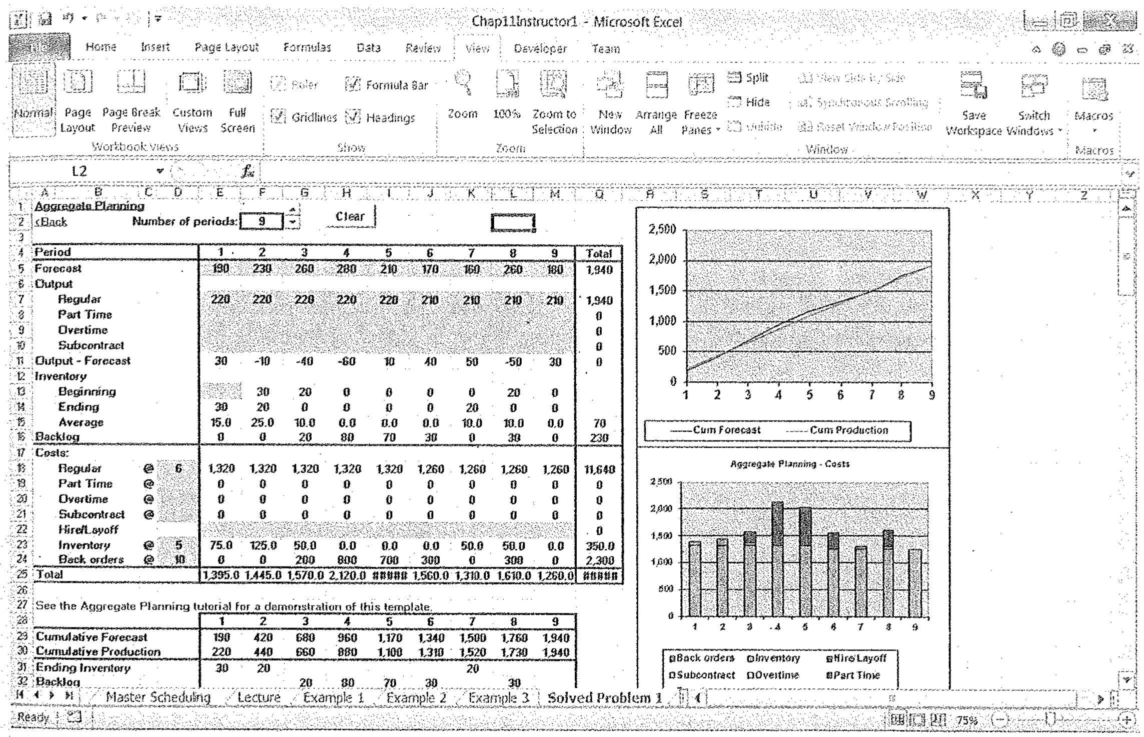
Period	1	2	3	4	5	6	7	8	9	Total
Forecast	190	230	260	280	210	170	160	260	180	1,940
Output										
Regular	220	220	220	220	220	210	210	210	210	1,940
Overtime	—	—	—	—	—	—	—	—	—	—
Subcontract	—	—	—	—	—	—	—	—	—	—
Output − Forecast	30	(10)	(40)	(60)	10	40	50	(50)	30	0
Inventory										
Beginning	0	30	20	0	0	0	0	20	0	
Ending	30	20	0	0	0	0	20	0	0	
Average	15	25	10	0	0	0	10	10	0	70
Backlog	0	0	20	80	70	30	0	30	0	230
Costs										
Output										
Regular @ $6	$1,320	1,320	1,320	1,320	1,320	1,260	1,260	1,260	1,260	$11,640
Overtime										
Subcontract										
Inventory @ $5	$ 75	125	50	0	0	0	50	50	0	$350
Back order @ $10	0	0	200	800	700	300	0	300	0	$ 2,300
Total	$1,395	1,445	1,570	2,120	2,020	1,560	1,310	1,610	1,260	$14,290

The total cost for this plan is $14,290, plus the $500 cost for hiring and for the layoff, giving a total of $14,790. This plan may or may not be good. The manager would need information on other costs and options before settling on one plan.

Although the calculations are relatively straightforward, the backlogs can sometimes seem difficult to obtain. Consider these rules for computing the backlog:

1. Start with the Output − Forecast value. If this is positive and there was a backlog in the preceding period, reduce the backlog by this amount. If the amount exceeds the backlog, the difference becomes the ending inventory for the period. If they are exactly equal, the backlog and the ending inventory will both be equal to zero.
2. If Output − Forecast is negative, subtract it from the beginning inventory. If this produces a negative value, that value becomes the backlog for that period.

You also can use the appropriate Excel template to obtain the solution:



Aggregate Planning

Number of periods: 9

Period		1	2	3	4	5	6	7	8	9	Total
Forecast		190	230	260	280	210	170	160	260	180	1,940
Output											
Regular		220	220	220	220	220	210	210	210	210	1,940
Part Time											0
Overtime											0
Subcontract											0
Output - Forecast		30	-10	-40	-60	10	40	50	-50	30	0
Inventory											
Beginning			30	20	0	0	0	0	20	0	
Ending		30	20	0	0	0	0	20	0	0	
Average		15.0	25.0	10.0	0.0	0.0	0.0	10.0	10.0	0.0	70
Backlog		0	0	20	80	70	30	0	30	0	230
Costs:											
Regular	@ 6	1,320	1,320	1,320	1,320	1,320	1,260	1,260	1,260	1,260	11,640
Part Time	@	0	0	0	0	0	0	0	0	0	0
Overtime	@	0	0	0	0	0	0	0	0	0	0
Subcontract	@	0	0	0	0	0	0	0	0	0	0
Hire/Layoff											0
Inventory	@ 5	75.0	125.0	50.0	0.0	0.0	0.0	50.0	50.0	0.0	350.0
Back orders	@ 10	0	0	200	800	700	300	0	300	0	2,300
Total		1,395.0	1,445.0	1,570.0	2,120.0	#####	1,560.0	1,310.0	1,610.0	1,260.0	#####

See the Aggregate Planning tutorial for a demonstration of this template.

	1	2	3	4	5	6	7	8	9
Cumulative Forecast	190	420	680	960	1,170	1,340	1,500	1,760	1,940
Cumulative Production	220	440	660	880	1,100	1,310	1,520	1,730	1,940
Ending Inventory	30	20					20		
Backlog			20	80	70	30		30	

Problem 2

Spring and Summer Fashions, a clothing producer, has generated a forecast for the next eight weeks. Demand is expected to be fairly steady, except for periods 3 and 4, which have higher demands:

Period	1	2	3	4	5	6	7	8	Total
Forecast	1,200	1,200	1,400	3,000	1,200	1,200	1,200	1,200	11,600

The company typically hires seasonal workers to handle the extra workload in periods 3 and 4. The cost for hiring and training a seasonal worker is $50 per worker, and the company plans to hire two additional workers and train them in period 3, for work in period 4, and then lay them off (no cost for layoff). Develop an aggregate plan that uses steady output from regular workers with added output from the two seasonal workers in period 4. The output rate for the seasonal workers is slightly less than that of regular workers, so their cost per unit is higher. The cost per unit for regular workers is $4 per hour, while cost per unit for the seasonal workers is $5 per unit. Backlog cost is $1 per unit per period.

Solution

Period			1	2	3	4	5	6	7	8	Total
Forecast			1,200	1,200	1,400	3,000	1,200	1,200	1,200	1,200	11,600
Output											
Regular			1,200	1,200	1,200	1,200	1,200	1,200	1,200	1,200	9,600
Part Time						2,000					2,000
Overtime											0
Subcontract											0
Output - Forecast			0	0	−200	200	0	0	0	0	0
Inventory											
Beginning			0	0	0	0	0	0	0	0	
Ending			0	0	0	0	0	0	0	0	
Average			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Backlog			0	0	200	0	0	0	0	0	200
Costs :											
Regular	@	4	4,800	4,800	4,800	4,800	4,800	4,800	4,800	4,800	38,400
Part Time	@	5	0	0	0	10,000	0	0	0	0	10,000
OverTime	@		0	0	0	0	0	0	0	0	0
Subcontract	@		0	0	0	0	0	0	0	0	0
Hire/Layoff		50			100						100
Inventory	@		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Back orders	@	1	0	0	200	0	0	0	0	0	200
Total			4,800.0	4,800.0	5,100.0	14,800	4,800.0	4,800.0	4,800.0	4,800.0	48,700.0

Problem 3

Prepare a schedule like that shown in Figure 11.11 for the following situation. The forecast for each period is 70 units. The starting inventory is zero. The MPS rule is to schedule production if the projected inventory on hand is negative. The production lot size is 100 units. The following table shows committed orders.

Period	Customer Orders
1	80
2	50
3	30
4	10

Solution

Period	(A) Inventory from Previous Period	(B) Requirements*	(C = A − B) Net Inventory before MPS	MPS	(MPS + C) Projected Inventory
1	0	80	(80)	100	20
2	20	70	(50)	100	50
3	50	70	(20)	100	80
4	80	70	10	0	10

*Requirements equal the larger of forecast and customer orders in each period.

Starting Inv. = 0	1	2	3	4
Forecast	70	70	70	70
Customer orders	80	50	30	10
Projected on-hand inventory	20	50	80	10
MPS	100	100	100	0
ATP	20	50	60	0

DISCUSSION AND REVIEW QUESTIONS

1. What three levels of planning involve operations managers? What kinds of decisions are made at the various levels?
2. What are the three phases of intermediate planning?
3. What is aggregate planning? What is its purpose?

4. Why is there a need for aggregate planning?
5. What are the most common decision variables for aggregate planning in a manufacturing setting? In a service setting?
6. What aggregate planning difficulty that might confront an organization offering a variety of products and/or services would not confront an organization offering one or a few similar products or services?
7. Briefly discuss the advantages and disadvantages of each of these planning strategies:
   a. Maintain a level rate of output and let inventories absorb fluctuations in demand.
   b. Vary the size of the workforce to correspond to predicted changes in demand requirements.
   c. Maintain a constant workforce size, but vary hours worked to correspond to predicted demand requirements.
8. What are the primary advantages and limitations of informal graphic and charting techniques for aggregate planning?
9. Briefly describe the planning techniques listed below, and give an advantage and disadvantage for each:
   a. Spreadsheet
   b. Linear programming
   c. Simulation
10. What are the inputs to master scheduling? What are the outputs?
11. Explain the managerial significance of aggregate planning.

TAKING STOCK

1. What general trade-offs are involved in master scheduling in terms of the frozen portion of the schedule?
2. Who needs to interface with the master schedule and why?
3. How has technology had an impact on master scheduling?

CRITICAL THINKING EXERCISES

1. Service operations often face more difficulty in planning than their manufacturing counterparts. However, service does have certain advantages that manufacturing often does not. Explain service planning difficulty, and the advantages and disadvantages.
2. Name several behaviors related to aggregate planning or master scheduling that you believe would be unethical, and the ethical principle that would be violated for each.

PROBLEMS

1. Refer to Example 1. The president of the firm has decided to shut down the plant for vacation and installation of new equipment in period 4. After installation, the cost per unit will remain the same, but the output rate for regular time will be 450. Regular output is the same as in Example 1 for periods 1, 2, and 3; 0 for period 4; and 450 for each of the remaining periods. Note, though, that the forecast of 400 units in period 4 must be dealt with. Prepare the aggregate plan, and compute its total cost.

2. Refer to Example 1. Suppose that the regular output rate will drop to 290 units per period due to an expected change in production requirements. Costs will not change. Prepare an aggregate plan and compute its total cost for each of these alternatives:
   a. Use overtime at a fixed rate of 20 units per period as needed. Plan for an ending inventory of zero for period 6. Backlogs cannot exceed 90 units per period.
   b. Use subcontracting at a maximum rate of 50 units per period; the usage need not be the same in every period. Have an ending inventory of zero in the last period. Again backlogs cannot exceed 90 units in any period. Compare these two plans.

3. Refer to Example 2. Suppose you can use a combination of overtime and subcontracting, but you cannot use subcontracting in more than two periods. Up to 50 units of subcontracting and either 0 or 40 units of overtime are allowed per period. Subcontracting is $6 per unit, and overtime is $3 per unit. (*Hint:* Use subcontracting only when overtime units are not sufficient to decrease backlogs to 80 units or less.) Plan for an ending inventory balance of 0 for period 6. Prepare a plan that will minimize total cost.

4. Refer to Example 2. Determine whether a plan to use subcontracting at a maximum rate of 50 units per period as needed with no overtime would achieve a lower total cost than the plan shown in Example 2. Again, plan for a zero inventory balance at the end of period 6.

5. Manager T. C. Downs of Plum Engines, a producer of lawn mowers and leaf blowers, must develop an aggregate plan given the forecast for engine demand shown in the table. The department has a normal capacity of 130 engines per month. Normal output has a cost of $60 per engine. The beginning inventory is zero engines. Overtime has a cost of $90 per engine.

a. Develop a chase plan that matches the forecast and compute the total cost of your plan.
b. Compare the costs to a level plan that uses inventory to absorb fluctuations. Inventory carrying cost is $2 per engine per month. Backlog cost is $90 per engine per month.

	Month								
	1	2	3	4	5	6	7	8	Total
Forecast	120	135	140	120	125	125	140	135	1,040

6. Manager Chris Channing of Fabric Mills, Inc., has developed the forecast shown in the table for bolts of cloth. The figures are in hundreds of bolts. The department has a normal capacity of 275(00) bolts per month, except for the seventh month, when capacity will be 250(00) bolts. Normal output has a cost of $40 per hundred bolts. Workers can be assigned to other jobs if production is less than normal. The beginning inventory is zero bolts.
   a. Develop a chase plan that matches the forecast and compute the total cost of your plan. Overtime is $60 per hundred bolts.
   b. Would the total cost be less with regular production with no overtime, but using a subcontractor to handle the excess above normal capacity at a cost of $50 per hundred bolts? Backlogs are not allowed. The inventory carrying cost is $2 per hundred bolts.

Month	1	2	3	4	5	6	7	Total
Forecast	250	300	250	300	280	275	270	1,925

7. SummerFun, Inc., produces a variety of recreation and leisure products. The production manager has developed an aggregate forecast:

Month	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
Forecast	50	44	55	60	50	40	51	350

Use the following information to develop aggregate plans.

Regular production cost	$80 per unit	Back-order cost	$20 per unit
Overtime production cost	$120 per unit	Beginning inventory	0 units
Regular capacity	40 units per month		
Overtime capacity	8 units per month		
Subcontracting cost	$140 per unit		
Subcontracting capacity	12 units per month		
Holding cost	$10 per unit per month		

Develop an aggregate plan using each of the following guidelines and compute the total cost for each plan. Which plan has the lowest total cost?
   a. Use regular production. Supplement using inventory, overtime, and subcontracting as needed. No backlogs allowed.
   b. Use a level strategy. Use a combination of backlogs, subcontracting, and inventory to handle variations in demand.

8. Nowjuice, Inc., produces Shakewell® fruit juice. A planner has developed an aggregate forecast for demand (in cases) for the next six months.

Month	May	Jun	Jul	Aug	Sep	Oct
Forecast	4,000	4,800	5,600	7,200	6,400	5,000

Use the following information to develop aggregate plans.

Regular production cost	$10 per case
Regular production capacity	5,000 cases
Overtime production cost	$16 per case
Subcontracting cost	$20 per case
Holding cost	$1 per case per month
Beginning inventory	0

Develop an aggregate plan using each of the following guidelines and compute the total cost for each plan. Which plan has the lowest total cost?
   a. Use level production. Supplement using overtime as needed.

b. Use a combination of overtime (500 cases per period maximum), inventory, and subcontracting (500 cases per period maximum) to handle variations in demand.
c. Use overtime up to 750 cases per period and inventory to handle variations in demand.

9. Wormwood, Ltd., produces a variety of furniture products. The planning committee wants to prepare an aggregate plan for the next six months using the following information:

	MONTH					
	1	2	3	4	5	6
Demand	160	150	160	180	170	140
Capacity						
Regular	150	150	150	150	160	160
Overtime	10	10	0	10	10	10

Cost Per Unit	
Regular time	$50
Overtime	75
Subcontract	80
Inventory, per period	4

Subcontracting can handle a maximum of 10 units per month. Beginning inventory is zero. Develop a plan that minimizes total cost. No back orders are allowed.

10. Refer to Solved Problem 1. Prepare two additional aggregate plans. Call the one in the solved problem plan A. For plan B, hire one more worker at a cost of $200. Make up any shortfall using subcontracting at $8 per unit, with a maximum of 20 units per period (i.e., use subcontracting to reduce back orders when the forecast exceeds regular output). Note that the ending inventory in period 9 should be zero. Therefore, Total forecast − Total output = Quantity subcontracted. An additional constraint is that back orders cannot exceed 80 units in any period. For plan C, assume no workers are hired (so regular output is 200 units per period instead of 210 as in plan B). Use subcontracting as needed, but no more than 20 units per period. Compute the total cost of each plan. Which plan has the lowest cost?

11. Refer to Solved Problem 1. Suppose another option is to use part-time workers to assist during seasonal peaks. The cost per unit, including hiring and training, is $11. The output rate is 10 units per worker per period for all workers. A maximum of 10 part-time workers can be used, and the same number of part-time workers must be used in all periods that have part-time workers. The ending inventory in period 9 should be 10 units. The limit on backlogs is 20 units per period. Try to make up backlogs as soon as possible. Compute the total cost for this plan, and compare it to the cost of the plan used in the solved problem. Assume 20 full-time workers.

12. Refer to Solved Problem 1. Prepare an aggregate plan that uses overtime ($9 per unit, maximum output 25 units per period) and inventory variation. Try to minimize backlogs. The ending inventory in period 9 should be zero, and the limit on backlogs is 60 units per period. Note that Total output = Total regular output + Overtime quantity. Compute the total cost of your plan, and compare it to the total cost of the plan used in the solved problem. Assume 20 full-time workers.

13. Refer to Solved Problem 1. Prepare an aggregate plan that uses some combination of laying off ($100 per worker), subcontracting ($8 per unit, maximum of 20 units per period, must use for three consecutive periods), and overtime ($9 per unit, maximum of 25 per period, maximum of 60 for the planning horizon). Compute the total cost, and compare it with any of the other plans you have developed. Which plan has the lowest total cost? Assume you start with 21 workers.

14. Verify the transportation solution shown in Example 3.

15. Refer to Example 3. Suppose that an increase in warehousing costs and other costs brings inventory carrying costs to $2 per unit per month. All other costs and quantities remain the same. Determine a revised solution to this transportation problem.

16. Refer to Example 3. Suppose that regular-time capacity will be reduced to 440 units in period 3 to accommodate a companywide safety inspection of equipment. What will the additional cost of the optimal plan be as compared to the one shown in Example 3? Assume all costs and quantities are the same as given in Example 3 except for the regular-time output in period 3.

17. Solve Problem 16 using an inventory carrying cost of $2 per unit per period.

18. Dundas Bike Components Inc. of Wheelville, Illinois, manufactures bicycle wheels in two different sizes for the Big Bike Co. assembly plant located across town. David Dundas, the firm's owner-manager, has just received Big Bike's order for the next six months.

	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
20-Inch Wheels	1,000 units	900	600	700	1,100	1,100
24-Inch Wheels	500 units	500	300	500	400	600

a. Under what circumstances will it be possible for David to develop just one aggregate plan rather than two (one for each size wheel)? Explain in two to three sentences without calculations.

b. Currently Dundas employs 28 full-time, highly skilled employees, each of whom can produce 50 wheels per month. Because skilled labor is in short supply in the Wheelville area, David would like to develop a pure level-output plan. There is no inventory of finished wheels on hand at present, but David would like to have 300 on hand at the end of April. Big Bike will tolerate back orders of up to 200 units per month. Show your level plan in tabular form.

c. Calculate the total annual cost of your plan using these costs:

Regular	$5.00	Hiring	$300
Overtime	$7.50	Layoff	$400
Part-time	NA	Inventory	$1.00
Subcontract	NA	Back order	$6.00

19. Prepare a master production schedule for industrial pumps in the manner of Figure 11.11 in the chapter. Use the same inputs as the example, but change the MPS rule from "schedule production when the projected on-hand inventory would be negative without production" to "schedule production when the projected on-hand inventory would be less than 10 without production."

20. Update the master schedule shown in Figure 11.11 given these updated inputs: It is now the end of week 1; customer orders are 25 for week 2, 16 for week 3, 11 for week 4, 8 for week 5, and 3 for week 6. Use the MPS rule of ordering production when projected on-hand inventory would be negative without production.

21. Prepare a master schedule like that shown in Figure 11.11 given this information: The forecast for each week of an eight-week schedule is 50 units. The MPS rule is to schedule production if the projected on-hand inventory would be negative without it. Customer orders (committed) are as follows:

Week	Customer Orders
1	52
2	35
3	20
4	12

Use a production lot size of 75 units and no beginning inventory.

22. Determine the available-to-promise (ATP) quantities for each period for Problem 21.

23. Prepare a schedule like that shown in Figure 11.12 for the following situation: The forecast is 80 units for each of the first two periods and 60 units for each of the next three periods. The starting inventory is 20 units. The company uses a chase strategy for determining the production lot size, except there is an upper limit on the lot size of 70 units. Also, the desired safety stock is 10 units. *Note:* The ATP quantities are based on maximum allowable production and do not include safety stock. Committed orders are as follows:

Period	Customer Orders
1	82
2	80
3	60
4	40
5	20

Eight Glasses a Day (EGAD)

CASE

The EGAD Bottling Company has decided to introduce a new line of premium bottled water that will include several "designer" flavors. Marketing manager Georgianna Mercer is predicting an upturn in demand based on the new offerings and the increased public awareness of the health benefits of drinking more water. She has prepared aggregate forecasts for the next six months, as shown in the following table (quantities are in tankloads):

Month	May	Jun	Jul	Aug	Sept	Oct	Total
Forecast	50	60	70	90	80	70	420

Production manager Mark Mercer (no relation to Georgianna) has developed the following information. (Costs are in thousands of dollars.)

Regular production cost	$1 per tankload
Regular production capacity	60 tankloads
Overtime production cost	$1.6 per tankload
Subcontracting cost	$1.8 per tankload
Holding cost	$2 per tankload per month
Back-ordering cost	$5 per month per tankload
Beginning inventory	0 tankloads

Among the strategies being considered are the following:

1. Level production supplemented by up to 10 tankloads a month from overtime.
2. A combination of overtime, inventory, and subcontracting.
3. Using overtime for up to 15 tankloads a month, along with inventory to handle variations.

Questions

1. The objective is to choose the plan that has the lowest cost. Which plan would you recommend?
2. Presumably, information about the new line has been shared with supply chain partners. Explain what information should be shared with various partners, and why sharing that information is important.

SELECTED BIBLIOGRAPHY AND FURTHER READINGS

Brandimarte, P., and A. Villa (Eds). *Modeling Manufacturing Systems: From Aggregate Planning to Real-Time Control.* New York: Springer, 1999.

Buxey, G. "Production Planning for Seasonal Demand." *International Journal of Operations and Production Management* 13, no. 7 (July 1993), pp. 4–21.

Hopp, Wallace J., and Mark L. Spearman. *Factory Physics.* 3rd ed. New York: Irwin/McGraw-Hill, 2007.

Jacobs, F. Robert, William L. Berry, D. Clay Whybark, and Thomas Vollman. *Manufacturing Planning and Control For Supply Chain Management.* 6th ed. Burr Ridge, IL: McGraw-Hill/Irwin, 2011.

Silver, E. A., D. F. Pyke, and R. Peterson. *Inventory Management and Production Planning and Scheduling.* New York: Wiley, 1998.

Sipper, Daniel, and Robert Bulfin Jr. *Production: Planning, Control, and Integration.* New York: McGraw-Hill, 1997.

Ware, Norman, and Donald Fogarty. "Master Schedule/Master Production Schedule: The Same or Different?" *Production and Inventory Management Journal,* First Quarter 1990, pp. 34–37.