**Introduction**

Within the constraints imposed by its design, an operation has to be run on an ongoing basis. ‘Planning and control’ is concerned with managing the ongoing activities of the operation so as to satisfy customer demand. All operations require plans and require controlling, although the degree of formality and detail may vary. This chapter introduces and provides an overview of some of the principles and methods of planning and control. We also examine information technology (IT), in the form of ERP (enterprise resources planning) systems. The different aspects of planning and control can be viewed as representing the reconciliation of supply with demand. Figure 10.1 shows where this chapter fits into the overall operations model.

**Key questions**

➤ What is planning and control?
➤ How do supply and demand affect planning and control?
➤ What are the activities of planning and control?
➤ How can enterprise resource planning (ERP) help planning and control?

*Figure 10.1 This chapter examines planning and control*

Check and improve your understanding of this chapter using self-assessment questions and a personalized study plan, audio and video downloads, and an eBook – all at www.myomlab.com.
Joanne Cheung is the Senior Service Adviser at a premier BMW dealership. She and her team act as the interface between customers who want their cars serviced and repaired, and the 16 technicians who carry out the work in their state-of-the-art workshop.

‘There are three types of work that we have to organize’, says Joanne. ‘The first is performing repairs on customers’ vehicles. They usually want this doing as soon as possible. The second type of job is routine servicing. It is usually not urgent so customers are generally willing to negotiate a time for this. The remainder of our work involves working on the pre-owned cars which our buyer has bought-in to sell on to customers. Before any of these cars can be sold they have to undergo extensive checks. To some extent we treat these categories of work slightly differently. We have to give good service to our internal car buyers, but there is some flexibility in planning these jobs. At the other extreme, emergency repair work for customers has to be fitted into our schedule as quickly as possible. If someone is desperate to have their car repaired at very short notice, we sometimes ask them to drop their car in as early as they can and pick it up as late as possible. This gives us the maximum amount of time to fit it into the schedule.

‘There are a number of service options open to customers. We can book short jobs in for a fixed time and do it while they wait. Most commonly, we ask the customer to leave the car with us and collect it later. To help customers we have ten loan cars which are booked out on a first-come first-served basis. Alternatively, the vehicle can be collected from the customer’s home and delivered back there when it is ready. Our four drivers who do this are able to cope with up to twelve jobs a day.

‘Most days we deal with fifty to eighty jobs, taking from half-an-hour up to a whole day. To enter a job into our process all Service Advisers have access to the computer-based scheduling system. On-screen it shows the total capacity we have day-by-day, all the jobs that are booked in, the amount of free capacity still available, the number of loan cars available, and so on. We use this to see when we have the capacity to book a customer in, and then enter all the customer’s details. BMW have issued “standard times” for all the major jobs. However, you have to modify these standard times a bit to take account of circumstances. That is where the Service Adviser’s experience comes in.

‘We keep all the most commonly used parts in stock, but if a repair needs a part which is not in stock, we can usually get it from the BMW parts distributors within a day. Every evening our planning system prints out the jobs to be done the next day and the parts which are likely to be needed for each job. This allows the parts staff to pick out the parts for each job so that the technicians can collect them first thing the next morning without any delay.

‘Every day we have to cope with the unexpected. A technician may find that extra work is needed, customers may want extra work doing, and technicians are sometimes ill, which reduces our capacity. Occasionally parts may not be available so we have to arrange with the customer for the vehicle to be rebooked for a later time. Every day up to four or five customers just don’t turn up. Usually they have just forgotten to bring their car in so we have to rebook them in at a later time. We can cope with most of these uncertainties because our technicians are flexible in terms of the skills they have and also are willing to work overtime when needed. Also, it is important to manage customers’ expectations. If there is a chance that the vehicle may not be ready for them, it shouldn’t come as a surprise when they try and collect it.’
Planning and control is concerned with the reconciliation between what the market requires and what the operation’s resources can deliver. Planning and control activities provide the systems, procedures and decisions which bring different aspects of supply and demand together. The purpose is always the same – to make a connection between supply and demand that will ensure that the operation’s processes run effectively and efficiently and produce products and services as required by customers. Consider, for example, the way in which routine surgery is organized in a hospital. When a patient arrives and is admitted to the hospital, much of the planning for the surgery will already have happened. The operating theatre will have been reserved, and the doctors and nurses who staff the operating theatre will have been provided with all the information regarding the patient’s condition. Appropriate preoperative and postoperative care will have been organized. All this will involve staff and facilities in different parts of the hospital. All must be given the same information and their activities coordinated. Soon after the patient arrives, he or she will be checked to make sure that their condition is as expected. Blood, if required, will be cross-matched and reserved, and any medication will be made ready. Any last-minute changes may require some degree of replanning. For example, if the patient shows unexpected symptoms, observation may be necessary before the surgery can take place. Not only will this affect the patient’s own treatment, but other patients’ treatment may also have to be rescheduled. All these activities of scheduling, coordination and organization are concerned with the planning and control of the hospital.

The difference between planning and control

We have chosen to treat planning and control together. This is because the division between planning and control is not always clear. However, there are some general features that help to distinguish between the two. Planning is a formalization of what is intended to happen at some time in the future. But a plan does not guarantee that an event will actually happen. Customers change their minds about what they want and when they want it. Suppliers may not always deliver on time, machines may fail, or staff may be absent through illness. Control is the process of coping with changes. It may mean that plans need to be redrawn. It may also mean that an ‘intervention’ will need to be made in the operation to bring it back ‘on track’ – for example, finding a new supplier that can deliver quickly, repairing the machine which failed, or moving staff from another part of the operation to cover for the absentees. Control makes the adjustments which allow the operation to achieve the objectives that the plan has set, even when the assumptions on which the plan was based do not hold true.

Long-, medium- and short-term planning and control

The nature of planning and control activities changes over time. In the very long term, operations managers make plans concerning what they intend to do, what resources they need, and what objectives they hope to achieve. The emphasis is on planning rather than control, because there is little to control as such. They will use forecasts of likely demand which are described in aggregated terms. For example, a hospital will make plans for ‘2,000 patients’ without necessarily going into the details of the individual needs of those patients. Similarly, the hospital might plan to have 100 nurses and 20 doctors but again without deciding on the specific attributes of the staff. Operations managers will be concerned mainly to achieve financial targets. Budgets will be put in place which identify its costs and revenue targets.

Medium-term planning and control is more detailed. It looks ahead to assess the overall demand which the operation must meet in a partially disaggregated manner. By this time, for example, the hospital must distinguish between different types of demand. The number of patients coming as accident and emergency cases will need to be distinguished from those requiring routine operations. Similarly, different categories of staff will have been identified.
and broad staffing levels in each category set. Just as important, contingencies will have been put in place which allow for slight deviations from the plans.

In short-term planning and control, many of the resources will have been set and it will be difficult to make large changes. However, short-term interventions are possible if things are not going to plan. By this time, demand will be assessed on a totally disaggregated basis, with all types of surgical procedures treated as individual activities. More importantly, individual patients will have been identified by name, and specific time slots booked for their treatment. In making short-term interventions and changes to the plan, operations managers will be attempting to balance the quality, speed, dependability, flexibility and costs of their operation on an ad hoc basis. It is unlikely that they will have the time to carry out detailed calculations of the effects of their short-term planning and control decisions on all these objectives, but a general understanding of priorities will form the background to their decision making. Figure 10.2 shows how the control aspects of planning and control increase in significance closer to the date of the event.

Supply and demand effects on planning and control

If planning and control is the process of reconciling demand with supply, then the nature of the decisions taken to plan and control an operation will depend on both the nature of demand and the nature of supply in that operation. In this section, we examine some differences in
Supply and demand effects on planning and control

Uncertainty in supply and demand

Uncertainty makes both planning and control more difficult. Local village carnivals, for example, rarely work to plan. Events take longer than expected, some of the acts scheduled in the programme may be delayed en route, and some traders may not arrive. The event requires a good compère to keep it moving, keep the crowd amused, and in effect control the event. Demand may also be unpredictable. A fast-food outlet inside a shopping centre does not know how many people will arrive, when they will arrive and what they will order. It may be possible to predict certain patterns, such as an increase in demand over the lunch and tea-time periods, but a sudden rainstorm that drives shoppers indoors into the centre could demand and supply which can affect the way in which operations managers plan and control their activities.

Short case Operations control at Air France

‘In many ways a major airline can be viewed as one large planning problem which is usually approached as many independent, smaller (but still difficult) planning problems. The list of things which need planning seems endless: crews, reservation agents, luggage, flights, through trips, maintenance, gates, inventory, equipment purchases. Each planning problem has its own considerations, its own complexities, its own set of time horizons, its own objectives, but all are interrelated.’

Air France has eighty flight planners working 24-hour shifts in their flight planning office at Roissy, Charles de Gaulle. Their job is to establish the optimum flight routes, anticipate any problems such as weather changes, and minimize fuel consumption. Overall the goals of the flight planning activity are first, and most important, safety followed by economy and passenger comfort. Increasingly powerful computer programs process the mountain of data necessary to plan the flights, but in the end many decisions still rely on human judgement. Even the most sophisticated expert systems only serve as support for the flight planners. Planning Air France’s schedule is a massive job. Just some of the considerations which need to be taken into account include the following.

- **Frequency** – for each airport how many separate services should the airline provide?
- **Fleet assignment** – which type of plane should be used on each leg of a flight?
- **Banks** – at any airline hub where passengers arrive and may transfer to other flights to continue their journey, airlines like to organize flights into ‘banks’ of several planes which arrive close together, pause to let passengers change planes, and all depart close together. So, how many banks should there be and when should they occur?

- **Block times** – a block time is the elapsed time between a plane leaving the departure gate at an airport and arriving at its gate in the arrival airport. The longer the allowed block time the more likely a plane will be to keep to schedule even if it suffers minor delays. However, longer block times also mean fewer flights can be scheduled.
- **Planned maintenance** – any schedule must allow time for planes to have time at a maintenance base.
- **Crew planning** – pilot and cabin crew must be scheduled to allocate pilots to fly planes on which they are licensed and to keep within maximum ‘on duty’ times for all staff.
- **Gate plotting** – if many planes are on the ground at the same time there may be problems in loading and unloading them simultaneously.
- **Recovery** – many things can cause deviations from any plan in the airline industry. Allowances must be built in to allow for recovery.

For flights within and between Air France’s 12 geographic zones, the planners construct a flight plan that will form the basis of the actual flight only a few hours later. All planning documents need to be ready for the flight crew who arrive two hours before the scheduled departure time. Being responsible for passenger safety and comfort, the captain always has the final say and, when satisfied, co-signs the flight plan together with the planning officer.

Source: Getty Images
significantly increase demand. Conversely, other operations are reasonably predictable, and the need for control is minimal. For example, cable TV services provide programmes to a schedule into subscribers’ homes. It is rare to change the programme plan. Demand may also be predictable. In a school, for example, once classes are fixed and the term or semester has started, a teacher knows how many pupils are in the class. A combination of uncertainty in the operation’s ability to supply, and in the demand for its products and services, is particularly difficult to plan and control.

**Dependent and independent demand**

Some operations can predict demand with more certainty than others. For example, consider an operation providing professional decorating and refurbishment services which has as its customers a number of large hotel chains. Most of these customers plan the refurbishment and decoration of their hotels months or even years in advance. Because of this, the decoration company can itself plan its activities in advance. Its own demand is dependent upon the relatively predictable activities of its customers. By contrast, a small painter and decorator serves the domestic and small business market. Some business also comes from house construction companies, but only when their own painters and decorators are fully occupied. In this case, demand on the painting and decorating company is relatively unpredictable. To some extent, there is a random element in demand which is virtually independent of any factors obvious to the company.

**Dependent demand**, then, is demand which is relatively predictable because it is dependent upon some factor which is known. For example, the manager who is in charge of ensuring that there are sufficient tyres in an automobile factory will not treat the demand for tyres as a totally random variable. He or she will not be totally surprised by the exact quantity of tyres which are required by the plant every day. The process of demand forecasting is relatively straightforward. It will consist of examining the manufacturing schedules in the car plant and deriving the demand for tyres from these. If 200 cars are to be manufactured on a particular day, then it is simple to calculate that 1,000 tyres will be demanded by the car plant (each car has five tyres) – demand is dependent on a known factor, the number of cars to be manufactured. Because of this, the tyres can be ordered from the tyre manufacturer to a delivery schedule which is closely in line with the demand for tyres from the plant (as in Figure 10.3). In fact, the demand for every part of the car plant will be derived from the assembly schedule for the finished cars. Manufacturing instructions and purchasing requests will all be dependent upon this figure.

**Independent demand**. They will supply demand without having any firm forward visibility of customer orders. For example, customers do not have to inform a supermarket when they are arriving and what they will buy. The supermarket takes its planning and control decisions based on its experience and understanding of the market, independent of what may actually happen. They run the risk of being out of stock of items when demand does not match their expectations. For example, the Ace Tyre Company, which operates a drive-in tyre replacement service, will need to manage a stock of tyres. In that sense it is exactly the same task that faced the manager of tyre stocks in the car plant. However, demand is very different for Ace Tyre. It cannot predict either the volume or the specific needs of customers. It must make decisions on how many and what type of tyres to stock, based on demand forecasts and in the light of the risks it is prepared to run of being out of stock. This is the nature of independent demand planning and control. It makes ‘best guesses’ concerning future demand, attempts to put the resources in place which can satisfy this demand, and attempts to respond quickly if actual demand does not match the forecast.

**Responding to demand**

In conditions of dependent demand, an operation will only start the process of producing goods or services when it needs to. Each order triggers the planning and control activities to
organize their production. For example, a specialist housebuilder might only start the process of planning and controlling the construction of a house when requested to do so by the customer. The builder might not even have the resources to start building before the order is received. The material that will be necessary to build the house will be purchased only when the timing and nature of the house are certain. The staff and the construction equipment might also be ‘purchased’ only when the nature of demand is clear. In a similar way, a specialist conference organizer will start planning for an event only when specifically requested to do so by the clients. A venue will be booked, speakers organized, meals arranged and the delegates contacted only when the nature of the service is clear. The planning and control necessary for this kind of operation can be called resource-to-order planning and control.

Other operations might be sufficiently confident of the nature of demand, if not its volume and timing, to keep ‘in stock’ most of the resources it requires to satisfy its customers. Certainly it will keep its transforming resources, if not its transformed resources. However, it would still make the actual product or service only to a firm customer order. For example, a house builder who has standard designs might choose to build each house only when a customer places a firm order. Because the design of the house is relatively standard, suppliers of materials will have been identified, even if the building operation does not keep the items in stock itself. The equivalent in the conference business would be a conference centre which has its own ‘stored’ permanent resources (the building, staff, etc.) but only starts planning a conference when it has a firm booking. In both cases, the operations would need create-to-order or make-to-order planning and control.

Some operations produce services or products ahead of any firm orders ‘to stock’. For example, some builders will construct pre-designed standard houses or apartments ahead of any firm demand for them. This will be done either because it is less expensive to do so or because it is difficult to create the goods or services on a one-off basis (it is difficult to make each apartment only when a customer chooses to buy one). If demand is high, customers may place requests for houses before they are started or during their construction. In this case, the customer will form a backlog of demand and must wait. The builder is also taking the risk, however, of holding a stock of unsold houses if buyers do not come along before they are finished. In fact, it is difficult for small builders to operate in this way, but less so for

Figure 10.3 Dependent demand is derived from the demand for something else; independent demand is more random
(say) a bottled cola manufacturer or other mass producer. The equivalent in the conference market would be a conference centre which schedules a series of events and conferences, programmed in advance and open to individual customers to book into or even turn up on the day. Cinemas and theatres usually work in this manner. Their performances are produced and supplied irrespective of the level of actual demand. Operations of this type will require make-to-stock planning and control.

**P:D ratios**

Another way of characterizing the graduation between resource-to-order and make-to-stock is by using a P:D ratio. This contrasts the total length of time customers have to wait between asking for the service and receiving it, demand time, $D$, and the total throughput time, $P$. Throughput time is how long the operation takes to obtain the resources, and produce and deliver the service.

**P and D times depend on the operation**

Make-to-stock operations produce their services and products in advance of any demand. For example, in an operation making consumer durables, demand time, $D$, is the sum of the times for transmitting the order to the company’s warehouse or stock point, picking and packing the order and physically transporting it to the customer. Behind this visible order cycle, however, lie other cycles. Reduction in the finished goods stock will eventually trigger the decision to manufacture a replenishment batch. This ‘produce’ cycle involves scheduling work in the manufacturing process. Behind the ‘produce’ cycle lies the ‘obtain resources’ cycle – the time for obtaining the input stocks. So, for this type of operation, the ‘demand’ time which the customer sees is very short compared with the total ‘throughput’ cycle. Contrast this with a resource-to-order operation. Here, $D$ is the same as $P$. Both include the ‘obtain resources’, ‘produce’ and ‘delivery’ cycles. The produce-to-order operation lies in between these two (see Figure 10.4).

![Figure 10.4 P and D for the different types of planning and control](image-url)
P:D ratios indicate the degree of speculation

Reducing total throughput time $P$ will have varying effects on the time the customer has to wait for demand to be filled. In resource-to-order operations, $P$ and $D$ are the same. Speeding up any part of $P$ will reduce customer’s waiting time, $D$. On the other hand, in ‘produce-to-stock’ operations, customers would only see reduced $D$ time if the ‘deliver’ part of $P$ were reduced. Also, in Figure 10.4, $D$ is always shown as being smaller than $P$, which is the case for most companies. How much smaller $D$ is than $P$ is important because it indicates the proportion of the operation’s activities which are speculative, that is, carried out on the expectation of eventually receiving a firm order for its efforts. The larger $P$ is compared with $D$, the higher the proportion of speculative activity in the operation and the greater the risk the operation carries. The speculative element in the operation is there because demand cannot be forecast perfectly. With exact or close to exact forecasts, risk would be non-existent or very low, no matter how much bigger $P$ was than $D$. Expressed another way: when $P$ and $D$ are equal, no matter how inaccurate the forecasts are, speculation is eliminated because everything is resourced and made to a firm order (although bad forecasting will lead to other problems). Reducing the $P:D$ ratio becomes, in effect, a way of taking some of the risk out of operations planning and control.

**Planning and control activities**

There are four overlapping activities: loading, sequencing, scheduling, and monitoring and control that together form the planning and control task (see Figure 10.5). Some caution is needed when using these terms. Different organizations may use them in different ways, and even textbooks in the area adopt different definitions. For example, some authorities describe what we have called ‘planning and control’ as ‘operations scheduling’. However, the terminology of planning and control is less important than understanding the basic ideas.

**Loading**

Loading is the amount of work that is allocated to a part of an operation. For example, a machine on the shop floor of a manufacturing business is available, in theory, 168 hours
a week. However, this does not necessarily mean that 168 hours of work can be loaded onto that machine. For some periods the machine cannot be worked; for example, it may not be available on statutory holidays and weekends. Therefore, the load put onto the machine must take this into account. Of the time that the machine is available for work, other losses further reduce the available time. For example, time may be lost while changing over from making one component to another. If the machine breaks down, it will not be available. If there is machine reliability data available, this must also be taken into account. Sometimes the machine may be waiting for parts to arrive or be 'idling' for some other reason. Other losses could include an allowance for the machine being run below its optimum speed (for example, because it has not been maintained properly) and an allowance for the 'quality losses' or defects which the machine may produce. Likewise, in a service-dominant operation it may not be appropriate to schedule workers for 8 hours per day. Loading will need to take into account rest breaks, idle time, changing from one task to another, and boredom reducing actual time available, for example. Of course, many of these losses should be small or non-existent in a well-managed operation. However, the valuable operating time available for productive working, even in the best operations, can be significantly below the maximum time available.

**Sequencing**

When work arrives at any part of an operation decisions must be taken on the order in which the work will be tackled. This activity is termed sequencing. The priorities given to work in an operation are often determined by some predefined set of rules, some of which are summarized below.

**Customer priority**

Operations will sometimes use customer priority sequencing, which allows an important or aggrieved customer (or item) to be 'processed' prior to others, irrespective of the order of arrival. This approach is typically used by operations whose customer base is skewed, containing a mass of small customers and a few large, very important customers. Some banks, for example, give priority to important customers. The emergency services often have to use their judgement in prioritizing the urgency of requests for service. For example, in the priority system used by police forces the operators receiving emergency and other calls are trained to grade the calls into priority categories. The response by the police is then organized to match the level of priority. The triage system in hospitals operates in a similar way (see short case). However, customer priority sequencing, although giving a high level of service to some customers, may erode the service given to many others. This may lower the overall performance of the operation if work flows are disrupted to accommodate important customers.

**Physical constraints**

The physical nature of the materials being processed may determine the priority of work. For example, in an operation using paints or dyes, lighter shades will be sequenced before darker shades. On completion of each batch, the colour is slightly darkened for the next batch. This is because darkness of colour can only be added to and not removed from the colour mix.

**Due date (DD)**

Prioritizing by due date means that work is sequenced according to when it is 'due' for delivery, irrespective of the size of each job or the importance of each customer. For example, a support service in an office block, such as a reprographic unit, will often ask when copies are required, and then sequence the work according to that due date. Due date sequencing usually improves the delivery reliability of an operation and improves average delivery speed. However, it may not provide optimal productivity, as a more efficient sequencing of work may reduce total costs.
Planning and control activities

**Short case**

*The hospital triage system*

One of the hospital environments that is most difficult to sequence is the Accident and Emergency department, where patients arrive at random, without any prior warning, throughout the day. It is up to the hospital’s reception and the medical staff to devise very rapidly a schedule which meets most of the necessary criteria. In particular, patients who arrive having had very serious accidents, or presenting symptoms of a serious illness, need to be attended to urgently. Therefore, the hospital will sequence these cases first. Less urgent cases – perhaps patients who are in some discomfort, but whose injuries or illnesses are not life-threatening – will have to wait until the urgent cases are treated. Routine non-urgent cases will have the lowest priority of all. In many circumstances, these patients will have to wait for the longest time, which may be many hours, especially if the hospital is busy. Sometimes these non-urgent cases may even be turned away if the hospital is too busy with more important cases. In situations where hospitals expect sudden influxes of patients, they have developed what is known as a triage system, whereby medical staff hurriedly sort through the patients who have arrived to determine which category of urgency each patient fits into. In this way a suitable schedule for the various treatments can be devised in a short period of time.

**Last-in first-out (LIFO)**

Last-in first-out (LIFO) is a method of sequencing usually selected for practical reasons. For example, unloading an elevator is more convenient on a LIFO basis, as there is only one entrance and exit. However, it is not an equitable approach. Patients at hospital clinics may be infuriated if they see newly arrived patients examined first.

**First-in first-out (FIFO)**

Some operations serve customers in exactly the sequence they arrive in. This is called first-in first-out sequencing (FIFO), or sometimes ‘first come, first served’ (FCFS). For example, passport offices receive mail, and sort it according to the day when it arrived. They work through the mail, opening it in sequence, and process the passport applications in order of arrival.

**Longest operation time (LOT)**

Operations may feel obliged to sequence their longest jobs first in the system called longest operation time sequencing. This has the advantage of occupying work centres for long periods. By contrast, relatively small jobs progressing through an operation will take up time at each work centre because of the need to change over from one job to the next. However, although longest operation time sequencing keeps utilization high, this rule does not take into account delivery speed, reliability or flexibility.

**Shortest operation time first (SOT)**

Most operations at some stage become cash-constrained. Larger jobs that take more time will not enable the business to invoice as quickly. In these situations, the sequencing rules may be adjusted to tackle short jobs first in the system, called shortest operation time sequencing. These jobs can then be invoiced and payment received to ease cash-flow problems. This has an effect of improving delivery performance, if the unit of measurement is delivery of jobs. However, it may adversely affect total productivity and can damage service to larger customers.
Judging sequencing rules

All five performance objectives, or some variant of them, could be used to judge the effectiveness of sequencing rules. However, the objectives of dependability, speed and cost are particularly important. So, for example, the following performance objectives are often used:

- Meeting ‘due date’ promised to customer (dependability);
- Minimizing the time the job spends in the process, also known as ‘flow time’ (speed);
- Minimizing work-in-progress inventory (an element of cost);
- Minimizing idle time of work centres (another element of cost).

Scheduling

Having determined the sequence that work is to be tackled in, some operations require a detailed timetable showing at what time or date jobs should start and when they should end – this is scheduling. Schedules are familiar statements of volume and timing in many consumer environments. For example, a bus schedule shows that more buses are put on routes at more frequent intervals during rush-hour periods. The bus schedule shows the time each bus is due to arrive at each stage of the route. Schedules of work are used in operations where some planning is required to ensure that customer demand is met. Other operations, such as rapid-response service operations where customers arrive in an unplanned way, cannot schedule the operation in a short-term sense. They can only respond at the time demand is placed upon them.

The complexity of scheduling

The scheduling activity is one of the most complex tasks in operations management. Firstly, schedulers must deal with several different types of resource simultaneously. Machines will have different capabilities and capacities; staff will have different skills. More importantly, the number of possible schedules increases rapidly as the number of activities and processes increases. For example, suppose one machine has five different jobs to process. Any of the five jobs could be processed first and, following that, any one of the remaining four jobs, and so on. This means that there are:

\[ 5 \times 4 \times 3 \times 2 = 120 \text{ different schedules possible} \]

More generally, for \( n \) jobs there are \( n! \) (factorial \( n \)) different ways of scheduling the jobs through a single process. We can now consider what impact there would be if, in the same situation, there was more than one type of machine. If we were trying to minimize the number of set-ups on two machines, there is no reason why the sequence on machine 1 would be the same as the sequence on machine 2. If we consider the two sequencing tasks to be independent of each other, for two machines there would be:

\[ 120 \times 120 = 14,400 \text{ possible schedules of the two machines and five jobs.} \]

A general formula can be devised to calculate the number of possible schedules in any given situation, as follows:

\[ \text{Number of possible schedules} = (n!)^m \]

where \( n \) is the number of jobs and \( m \) is the number of machines. In practical terms, this means that there are often many millions of feasible schedules, even for relatively small operations. This is why scheduling rarely attempts to provide an ‘optimal’ solution but rather satisfies itself with an ‘acceptable’ feasible one.

Forward and backward scheduling

Forward scheduling involves starting work as soon as it arrives. Backward scheduling involves starting jobs at the last possible moment to prevent them from being late. For example, assume that it takes six hours for a contract laundry to wash, dry and press a batch of overalls. If
the work is collected at 8.00 am and is due to be picked up at 4.00 pm, there are more than six hours available to do it. Table 10.1 shows the different start times of each job, depending on whether they are forward- or backward-scheduled.

**Table 10.1** The effects of forward and backward scheduling

<table>
<thead>
<tr>
<th>Task</th>
<th>Duration</th>
<th>Start time (backwards)</th>
<th>Start time (forwards)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Press</td>
<td>1 hour</td>
<td>3.00 pm</td>
<td>1.00 pm</td>
</tr>
<tr>
<td>Dry</td>
<td>2 hours</td>
<td>1.00 pm</td>
<td>11.00 am</td>
</tr>
<tr>
<td>Wash</td>
<td>3 hours</td>
<td>10.00 am</td>
<td>8.00 am</td>
</tr>
</tbody>
</table>

The choice of backward or forward scheduling depends largely upon the circumstances. Table 10.2 lists some advantages and disadvantages of the two approaches.

**Table 10.2** Advantages of forward and backward scheduling

<table>
<thead>
<tr>
<th>Advantages of forward scheduling</th>
<th>Advantages of backward scheduling</th>
</tr>
</thead>
<tbody>
<tr>
<td>High labour utilization – workers always start work to keep busy</td>
<td>Lower material costs – materials are not used until they have to be, therefore delaying added value until the last moment</td>
</tr>
<tr>
<td>Flexible – the time slack in the system allows unexpected work to be loaded</td>
<td>Less exposed to risk in case of schedule change by the customer</td>
</tr>
<tr>
<td>Tends to focus the operation on customer due dates</td>
<td></td>
</tr>
</tbody>
</table>

**Gantt charts**

The most common method of scheduling is by use of the Gantt chart. This is a simple device which represents time as a bar, or channel, on a chart. The start and finish times for activities can be indicated on the chart and sometimes the actual progress of the job is also indicated. The advantages of Gantt charts are that they provide a simple visual representation both of what should be happening and of what actually is happening in the operation. Furthermore, they can be used to ‘test out’ alternative schedules. It is a relatively simple task to represent alternative schedules (even if it is a far from simple task to find a schedule which fits all the resources satisfactorily). Figure 10.6 illustrates a Gantt chart for a specialist software developer. It indicates the progress of several jobs as they are expected to progress through five stages of the process. Gantt charts are not an optimizing tool, they merely facilitate the development of alternative schedules by communicating them effectively.

**Figure 10.6** Gantt chart showing the schedule for jobs at each process stage
Short case
The life and times of a chicken salad sandwich

Pre-packed sandwiches are a growth product around the world as consumers put convenience and speed above relaxation and cost. But if you have recently consumed a pre-packed sandwich, think about the schedule of events which has gone into its making. For example, take a chicken salad sandwich. Less than 5 days ago, the chicken was on the farm unaware that it would never see another weekend. The Gantt chart schedule shown in Figure 10.7 tells the story of the sandwich, and (posthumously), of the chicken.

From the forecast, orders for non-perishable items are placed for goods to arrive up to a week in advance of their use. Orders for perishable items will be placed daily, a day or two before the items are required. Tomatoes, cucumbers and lettuces have a three-day shelf life so may be received up to three days before production. Stock is held on a strict first-in-first-out (FIFO) basis. If today is Wednesday, vegetables are processed that have been received during the last three days. This morning the bread arrived from a local bakery and the chicken arrived fresh, cooked and in strips ready to be placed directly in the sandwich during assembly. Yesterday (Tuesday) it had been killed, cooked, prepared and sent on its journey to the factory. By midday orders for tonight’s production will have been received on the Internet. From 2.00 pm until 10.00 pm the production lines are closed down for maintenance and a very thorough cleaning. During this time the production planning team is busy planning the night’s production run. Production for delivery to customers furthest away from the factory will have to be scheduled first. By 10 pm production is ready to start. Sandwiches are made on production lines. The bread is loaded onto a conveyor belt by hand and butter is spread automatically by a machine. Next the various fillings are applied at each stage according to the specified sandwich ‘design’, see Figure 10.8. After the filling has been assembled the top slice of bread is placed on the sandwich and machine-chopped into two triangles, packed and sealed by machine. It is now early Thursday morning and by 2.00 am the first refrigerated lorries are already departing on their journeys to various customers. Production continues through until 2.00 pm on the Thursday, after which once again the maintenance and cleaning teams move in. The last sandwiches are dispatched by 4.00 pm on the Thursday. There is no finished goods stock.

Pre-packed sandwiches are a growth product around the world as consumers put convenience and speed above relaxation and cost. But if you have recently consumed a pre-packed sandwich, think about the schedule of events which has gone into its making. For example, take a chicken salad sandwich. Less than 5 days ago, the chicken was on the farm unaware that it would never see another weekend. The Gantt chart schedule shown in Figure 10.7 tells the story of the sandwich, and (posthumously), of the chicken.

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Figure 10.7 Simplified schedule for the manufacture and delivery of a chicken salad sandwich

<table>
<thead>
<tr>
<th>ID</th>
<th>Task name</th>
<th>Tuesday</th>
<th>Wednesday</th>
<th>Thursday</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Orders for tomorrow’s fresh deliveries</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>2</td>
<td>Packaging for tonight’s production arrives</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>3</td>
<td>Tomatoes arrive – whole</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>4</td>
<td>Cucumbers arrive – whole</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Lettuces arrive – whole</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>6</td>
<td>Preparation (slice/wash/dry/portion)</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>7</td>
<td>Chickens killed</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>8</td>
<td>Prepared chicken meat despatched</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>Prepared chicken arrives 9–12 am</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>10</td>
<td>Bread arrives 9–12 am</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>11</td>
<td>EDI customer orders received</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>12</td>
<td>Production line shutdown and clean 2–10 pm</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>13</td>
<td>Start first production (assembly) 10 pm–2 am</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>14</td>
<td>First sandwich orders despatched 2 am</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>15</td>
<td>First sandwich order travels to distant depots</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>16</td>
<td>Start subsequent production runs (assembly) 2 am</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>17</td>
<td>Subsequent production sandwiches despatched 8 am–4 pm</td>
<td>0</td>
<td>4</td>
<td>8</td>
</tr>
</tbody>
</table>

Outline schedule for chicken salad sandwich

Figure 10.7 Simplified schedule for the manufacture and delivery of a chicken salad sandwich
Planning and control activities

Where the dominant resource in an operation is its staff, then the schedule of work times effectively determines the capacity of the operation itself. The main task of scheduling, therefore, is to make sure that sufficient numbers of people are working at any point in time to provide a capacity appropriate for the level of demand at that point in time. This is often called staff rostering. Operations such as call centres, postal delivery, policing, holiday couriers, retail shops and hospitals will all need to schedule the working hours of their staff with demand in mind. This is a direct consequence of these operations having relatively high ‘visibility’. Such operations cannot store their outputs in inventories and so must respond directly to customer demand. For example, Figure 10.9 shows the scheduling of shifts for a small technical ‘hot line’ support service for a small software company. It gives advice to customers on their technical problems. Its service times are 04.00 hrs to 20.00 hrs on Monday, 04.00 hrs to 22.00 hrs Tuesday to Friday, 06.00 hrs to 22.00 hrs on Saturday, and 10.00 hrs to 20.00 hrs on Sunday. Demand is heaviest Tuesday to Thursday, starts to decrease on Friday, is low over the weekend and starts to increase again on Monday.

The scheduling task for this kind of problem can be considered over different timescales, two of which are shown in Figure 10.9. During the day, working hours need to be agreed with individual staff members. During the week, days off need to be agreed. During the year, vacations, training periods and other blocks of time where staff are unavailable need to be agreed. All this has to be scheduled such that:

- capacity matches demand;
- the length of each shift is neither excessively long nor too short to be attractive to staff;

![Shift scheduling in a home-banking enquiry service](image)
● working at unsocial hours is minimized;
● days off match agreed staff conditions (for example) in this example – staff prefer two
  consecutive days off every week;
● vacation and other ‘time-off’ blocks are accommodated;
● sufficient flexibility is built into the schedule to cover for unexpected changes in supply
  (staff illness) and demand (surge in customer calls).

Scheduling staff times is one of the most complex of scheduling problems. In the relatively
simple example shown in Figure 10.9 we have assumed that all staff have the same level
and type of skill. In very large operations with many types of skill to schedule and uncertain
demand (for example a large hospital) the scheduling problem becomes extremely complex.
Some mathematical techniques are available but most scheduling of this type is, in practice,
solved using heuristics (rules of thumb), some of which are incorporated into commercially
available software packages.

Monitoring and controlling the operation

Having created a plan for the operation through loading, sequencing and scheduling, each
part of the operation has to be monitored to ensure that planned activities are indeed
happening. Any deviation from the plans can then be rectified through some kind of inter-
vention in the operation, which itself will probably involve some replanning. Figure 10.10
illustrates a simple view of control. The output from a work centre is monitored and
compared with the plan which indicates what the work centre is supposed to be doing.
Deviations from this plan are taken into account through a replanning activity and the
necessary interventions made to the work centre which will ensure that the new plan is
carried out. Eventually, some further deviation from planned activity will be detected and
the cycle is repeated.

Push and pull control

One element of control is periodic intervention into the activities of the operation. An
important decision is how this intervention takes place. The key distinction is between
intervention signals which push work through the processes within the operation and those
which pull work only when it is required. In a push system of control, activities are scheduled
by means of a central system and completed in line with central instructions, such as an
ERP system (see later). Each work centre pushes out work without considering whether the
succeeding work centre can make use of it. Work centres are coordinated by means of the

![Figure 10.10 A simple model of control](image-url)
Planning and control activities

central operations planning and control system. In practice, however, there are many reasons why actual conditions differ from those planned. As a consequence, idle time, queues and inventory often characterize push systems. By contrast, in a pull system of control, the pace and specification of what is done are set by the ‘customer’ workstation, which ‘pulls’ work from the preceding (supplier) workstation. The customer acts as the only ‘trigger’ for movement. If a request is not passed back from the customer to the supplier, the supplier cannot do anything. A request from a customer not only triggers activity at the supplying stage, but also prompts the supplying stage to request a further delivery from its own suppliers. In this way, demand is transmitted back through the stages from the original point of demand by the original customer.

Understanding the differing principles of push and pull is important because they have different effects in terms of their propensities to accumulate inventory in the operation. Pull systems are far less likely to result in inventory build-up and are therefore favoured by lean operations (see Chapter 11).

**Drum, buffer, rope**

The drum, buffer, rope concept comes from the theory of constraints (TOC) originally described by Eli Goldratt in his novel *The Goal*. It is an idea that helps to decide exactly where in a process control should occur. Most operations do not have the same amount of work loaded onto each separate work centre (that is, they are not perfectly balanced). This means there is likely to be a part of the process which is acting as a bottleneck on the work flowing through the process. Goldratt argued that the bottleneck in the process should be the control point of the whole process. It is called the drum because it sets the ‘beat’ for the rest of the process to follow. Because it does not have sufficient capacity, a bottleneck is (or should be) working all the time. Therefore, it is sensible to keep a buffer of inventory in front of it to make sure that it always has something to work on. Because it constrains the output of the whole process, any time lost at the bottleneck will affect the output from the whole process. Therefore, it is not worthwhile for the parts of the process before the bottleneck to work to their full capacity. All they would do is produce work which
would accumulate further along in the process up to the point where the bottleneck is constraining the flow. Therefore, some form of communication between the bottleneck and the input to the process is needed to make sure that activities before the bottleneck do not overproduce. This is called the rope (see Figure 10.12).

**Critical commentary**

Most of the perspectives on control taken in this chapter are simplifications of a far more messy reality. They are based on models used to understand mechanical systems such as car engines. But anyone who has worked in real organizations knows that organizations are not machines. They are social systems, full of complex and ambiguous interactions. Simple models such as these assume that operations objectives are always clear and agreed, yet organizations are political entities where different and often conflicting objectives compete. Local government operations, for example, are overtly political. Furthermore, the outputs from operations are not always easily measured. A university may be able to measure the number and qualifications of its students, for example, but it cannot measure the full impact of its education on their future happiness. Also, even if it is possible to work out an appropriate intervention to bring an operation back into ‘control’, most operations cannot perfectly predict what effect the intervention will have. Even the largest burger bar chain does not know exactly how a new shift allocation system will affect performance. Also, some operations never do the same thing more than once anyway. Most of the work done by construction operations is one-offs. If every output is different, how can ‘controllers’ ever know what is supposed to happen? Their plans themselves are mere speculation.

**Enterprise resource planning (ERP)**

One of the most important issues in planning and controlling operations is managing the sometimes vast amounts of information generated by the activity. It is not just the operations function that is the author and recipient of this information – almost every other function of a business will be involved. So, it is important that all relevant information that is spread throughout the organization is brought together. Then it can inform planning and control decisions such as when activities should take place, where they should happen, who should be doing them, how much capacity will be needed, and so on. This is what enterprise resource planning (ERP) does.
What is ERP?

An easy way of thinking about enterprise resource planning (ERP) is to imagine that you have decided to hold a party in two weeks’ time and expect about 40 people to attend. As well as drinks, you decide to provide sandwiches and snacks. You will probably do some simple calculations, estimating guests’ preferences and how much people are likely to drink and eat. You may already have some food and drink in the house which you will use, so you will take that into account when making your shopping list. If any of the food is to be cooked from a recipe, you may have to multiply up the ingredients to cater for 40 people. Also, you may also wish to take into account the fact that you will prepare some of the food the week before and freeze it, while you will leave the rest to either the day before or the day of the party. So, you will need to decide when each item is required so that you can shop in time. In fact, planning a party requires a series of interrelated decisions about the volume (quantity) and timing of the materials needed. This is the basis of the foundation concept for ERP called materials requirement planning (MRP). It is a process that helps companies make volume and timing calculations (similar to those in the party, but on a much larger scale, and with a greater degree of complexity). But your planning may extend beyond ‘materials’. You may want to hire in a sound system from a local supplier — you will have to plan for this. The party also has financial implications. You may have to agree a temporary increase to your credit card limit. Again, this requires some forward planning and calculations of how much it is going to cost, and how much extra credit you require. Both the equipment and financial implications may vary if you increase the number of guests. But, if you postpone the party for a month, these arrangements will change. Also, there are also other implications of organizing the party. You will need to give friends, who are helping with the organization, an idea of when they should come and for how long. This will depend on the timing of the various tasks to be done (making sandwiches etc.).

So, even for this relatively simple activity, the key to successful planning is how we generate, integrate and organize all the information on which planning and control depends. Of course, in business operations it is more complex than this. Companies usually sell many different services and products to many hundreds of customers with constantly changing demands. This is a bit like organizing 200 parties one week, 250 the next and 225 the following week, all for different groups of guests with different requirements who keep changing their minds about what they want to eat and drink. This is what ERP does, it helps companies ‘forward-plan’ these types of decisions and understand all the implications of any changes to the plan.

How did ERP develop?

Enterprise resource planning is the latest, and the most significant, development of the original materials requirements planning (MRP) philosophy. The large companies which have grown almost exclusively on the basis of providing ERP systems include SAP and Oracle. Yet to understand ERP, it is important to understand the various stages in its development, summarized in Figure 10.13. The original MRP became popular during the 1970s, although the planning and control logic that underlies it had, by then, been known for some time. What popularized MRP was the availability of computer power to drive the basic planning and control mathematics.

Manufacturing Resource Planning (MRP II) expanded out of MRP during the 1980s. Again, it was a technology innovation that allowed the development. Local-area networks (LANs), together with increasingly powerful desktop computers, allowed a much higher degree of processing power and communication between different parts of a business. Also MRP II’s extra sophistication allowed the forward modelling of ‘what-if’ scenarios. The strength of MRP and MRP II lay always in the fact that it could explore the consequences of any changes to what an operation was required to do. So, if demand changed, the MRP system would calculate all the ‘knock-on’ effects and issue instructions accordingly. This
same principle also applies to ERP, but on a much wider basis. Enterprise resource planning (ERP) has been defined as, ‘a complete enterprise wide business solution. The ERP system consists of software support modules such as: marketing and sales, field service, product design and development, production and inventory control, procurement, distribution, industrial facilities management, process design and development, manufacturing, quality, human resources, finance and accounting, and information services. Integration between the modules is stressed without the duplication of information.’

So, ERP systems allow decisions and databases from all parts of the organization to be integrated so that the consequences of decisions in one part of the organization are reflected in the planning and control systems of the rest of the organization (see Figure 10.14). ERP is the equivalent of the organization’s central nervous system, sensing information about the condition of different parts of the business and relaying the information to other parts of

**Figure 10.14** ERP integrates information from all parts of the organization
the business that need it. The information is updated in real time by those who use it and yet is always available to everyone connected to the ERP system.

Also, the potential of web-based communication has provided a further boost to ERP development. Many companies have suppliers, customers and other businesses with whom they collaborate who themselves have ERP-type systems. An obvious development is to allow these systems to communicate across supply networks. However, the technical, as well as organizational and strategic consequences of this can be formidable. Nevertheless, many authorities believe that the true value of ERP systems is only fully exploited when such web-integrated ERP (known by some people as 'collaborative commerce', or c-commerce) becomes widely implemented.

Summary answers to key questions

Check and improve your understanding of this chapter using self-assessment questions and a personalized study plan, audio and video downloads, and an eBook – all at www.myomlab.com.

➤ What is planning and control?

■ Planning and control is the reconciliation of the potential of the operation to supply services and products, with the demands of its customers on the operation. It is the set of day-to-day activities that run the operation.

■ A plan is a formalization of what is intended to happen at some time in the future. Control is the process of coping with changes to the plan and the operation to which it relates. Although planning and control are theoretically separable, they are usually treated together.

■ The balance between planning and control changes over time. Planning dominates in the long term and is usually done on an aggregated basis. At the other extreme, in the short term, control usually operates within the resource constraints of the operation but makes interventions into the operation in order to cope with short-term changes in circumstances.

➤ How do supply and demand affect planning and control?

■ The degree of uncertainty in demand affects the balance between planning and control. The greater the uncertainty, the more difficult it is to plan, and greater emphasis must be placed on control.

■ This idea of uncertainty is linked with the concepts of dependent and independent demand. Dependent demand is relatively predictable because it is dependent on some known factor. Independent demand is less predictable because it depends on the chances of the market or customer behaviour.

■ The different ways of responding to demand can be characterized by differences in the P:D ratio of the operation. The P:D ratio is the ratio of total throughput time of goods or services to demand time.

➤ What are the activities of planning and control?

■ In planning and controlling the volume and timing of activity in operations, four distinct activities are necessary:
  – loading, which dictates the amount of work that is allocated to each part of the operation;
  – sequencing, which decides the order in which work is tackled within the operation;
scheduling, which determines the detailed timetable of activities and when activities are started and finished;
• monitoring and control, which involve detecting what is happening in the operation, replanning if necessary, and intervening in order to impose new plans. Two important types are ‘pull’ and ‘push’ control. Pull control is a system whereby demand is triggered by requests from a work centre’s (internal) customer. Push control is a centralized system whereby decisions are issued to work centres which are then required to perform the task and supply the next workstation.

How can enterprise resource planning (ERP) help planning and control?

• ERP is an enterprise-wide information system that integrates all the information from many functions, that is needed for planning and controlling operations activities. This integration around a common database allows for transparency.
• ERP can be seen as the latest development from the original planning and control approach known as materials requirements planning (MRP).
• Although ERP is becoming increasingly competent at the integration of internal systems and databases, there is the even more significant potential of integration with other organizations’ ERP (and equivalent) systems.

Learning exercises

These problems and applications will help to improve your analysis of operations. You can find more practice problems as well as worked examples and guided solutions on MyOMLab at www.myomlab.com.

1. Re-read the ‘operations management in practice’ at the beginning of the chapter, ‘Joanne manages the schedule’, and also the short case on Air France. What are the differences and what are the similarities between the planning and control tasks in these two operations?

2. A specialist sandwich retailer must order sandwiches at least 8 hours before they are delivered. When they arrive in the shop, they are immediately displayed in a temperature-controlled cabinet. The average time that the sandwiches spend in the cabinet is 6 hours. What is the $P:D$ ratio for this retail operation?

3. Step 1 – Make a list of all the jobs you have to do in the next week. Include in this list jobs relating to your work and/or study, jobs relating to your domestic life, in fact all the things you have to do.
   Step 2 – Prioritize all these jobs on a ‘most important’ to ‘least important’ basis.
   Step 3 – Draw up an outline schedule of exactly when you will do each of these jobs.
   Step 4 – At the end of the week compare what your schedule said you would do with what you actually have done. If there is a discrepancy, why did it occur?
   Step 5 – Draw up your own list of planning and control rules from your experience in this exercise in personal planning and control.

4. From your own experience of making appointments at your general practitioner’s surgery, or by visiting whoever provides you with primary medical care, reflect on how patients are scheduled to see a doctor or nurse.
   (a) What do you think planning and control objectives are for a general practitioner’s surgery?
   (b) How could your own medical practice be improved?
Goldratt, E.Y. and Cox, J. (1984) *The Goal*, North River Press, Great Barrington, MA. Don’t read this if you like good novels but do read it if you want an enjoyable way of understanding some of the complexities of scheduling. It particularly applies to the drum, buffer, rope concept described in this chapter.


Want to know more?

**Useful websites**

www.bpic.co.uk/ Some useful information on general planning and control topics.

www.apics.org The American professional and education body that has its roots in planning and control activities.

www.opsman.org Lots of useful stuff.

Now that you have finished reading this chapter, why not visit MyOMLab at www.myomlab.com where you’ll find more learning resources to help you make the most of your studies and get a better grade.