Source: Arup

Chapter 11

Capacity planning and control

Introduction

Providing the capability to satisfy current and future demand is a fundamental responsibility of operations management. Get the balance between capacity and demand right and the operation can satisfy its customers cost effectively. Get it wrong and it will fail to satisfy demand and have excessive costs. Capacity planning and control is also sometimes referred to as *aggregate* planning and control. This is because, at this level of the planning and control, demand and capacity calculations are usually performed on an aggregated basis which does not discriminate between the different products and services that an operation might produce. The essence of the task is to reconcile, at a general and aggregated level, the supply of capacity with the level of demand which it must satisfy (see Figure 11.1). This chapter also has a supplement that deals with analytical queuing models, one way of considering capacity planning and control, especially in some service operations.

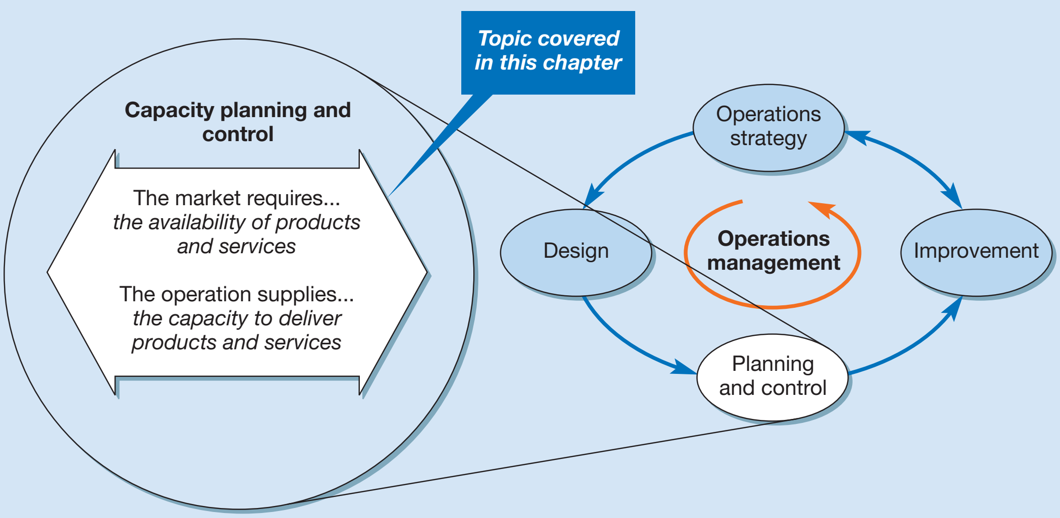


Figure 11.1 A definition of capacity planning and control

Key questions ???

- What is capacity planning and control?
- How is capacity measured?
- What are the ways of coping with demand fluctuation?
- How can operations plan their capacity level?
- How can operations control their capacity level?

Operations in practice

Britvic – delivering drinks to demand[1]

Britvic is among Europe's leading soft drink manufacturers, a major player in a market consuming nearly 10 billion litres a year. Annually, Britvic bottles, distributes and sells over 1 billion litres of ready-to-drink soft drinks in around 400 different flavours, shapes and sizes, including brands such as Pepsi, Tango, Robinsons, Aqua Libra, Purdey's and J2O. Every year, Britvic produces enough cans of soft drinks to stretch three times around the world, so it has to be a high-volume and high-speed business. Its six UK factories contain factory lines producing up to 1500 cans a minute, with distribution organized on a giant scale. At the centre of its distribution network is a National Distribution Centre (NDC) located at Lutterworth, UK. It is designed to operate 24 hours a day throughout the year, handling up to 620 truckloads of soft drinks daily and, together with a national network of 12 depots, it has to ensure that 250,000 outlets in the UK receive their orders on time. Designed and built in collaboration with Wincanton, a specialist supply chain solutions company, which now manages Britvic's NDC, it is capable of holding up to 140 million cans in its 50,000-pallet 'High Bay' warehouse. All information, from initial order to final delivery, is held electronically. Loads are scanned at Britvic factories and fed into the '*Business Planning and Control System*' that creates a schedule of receipts. This information is then fed to the *Warehouse Management System* and when hauliers arrive at the NDC, data is passed over to the *Movement Control System* that controls the retrieval of pallets from the High Bay.

Over the year Britvic distributes more than 100 million cases. However, the demand pattern for soft drinks is seasonal, with short-term changes caused by both weather and marketing campaigns. Furthermore, Britvic's service policy of responding whenever customers want deliveries has a dramatic impact on the NDC and its capacity planning. '*Our busiest periods are during the summer and in the run up to Christmas, where we expect over 200 trailers in and out each day – that equates to about 3 million cases per week. In the quiet periods, especially after Christmas, we have less than a million cases per week*' (Distribution Manager). Not only is demand on the NDC seasonal in a general sense, it can vary from 2000 pallets one day to 6000 the next as a result of short-term weather patterns and variable order patterns from large customers (supermarkets). Given the lack of space in the High Bay, it is not possible to simply stock up for the busy periods, so flexibility and efficiency are the keys to success.

Source: Wincanton

The NDC uses a number of methods to cope with demand fluctuation. Most important is the use and development of technology both within the NDC and out in Britvic's supply chain. High levels of throughput and the ability to respond quickly to demand fluctuations depend on the use of integrated information technology linked to automated High Bay handling technology. '*Without the automation this plant simply couldn't function. You realize how much you need this system when it breaks down! The* *other day, multiple errors in the system meant that in the space of six hours we went from being ahead to having 50 loads waiting to be processed. That equates to 1350 pallets or nearly 4 million cans.*'

Human resource management is also key in managing capacity. Every morning the shift manager receives orders for the day, although further orders can be placed at any time during the day. The order information allows the multi-skilled workforce to be allocated effectively. The daily meetings also allow any problems to be addressed and dealt with before they become critical. Finally, by outsourcing the NDC management to Wincanton, the site is able to second employees from other Wincanton-owned sites when demand is high. '*Our other sites around the country have different peaks and troughs throughout the year which helps us utilize employee numbers*.'

What is capacity?

Capacity
The maximum level of value-added activity that an operation, or process, or facility is capable of over a period of time.

The most common use of the word **capacity** is in the static, physical sense of the fixed *volume* of a container or the space in a building. This meaning of the word is also sometimes used by operations managers. For example, a pharmaceutical manufacturer may invest in new 1000-litre capacity reactor vessels, a property company purchases a 500-vehicle capacity city-centre car park, and a 'multiplex' cinema is built with ten screens and a total capacity of 2500 seats. Although these capacity measures describe the *scale* of these operations, they do not reflect the processing capacities of these investments. To do this we must incorporate a *time* dimension appropriate to the use of assets. So the pharmaceutical company will be concerned with the level of output that can be achieved using the 1000-litre reactor vessel. If a batch of standard products can be produced every hour, the planned processing capacity could be as high as 24,000 litres per day. If the reaction takes four hours and two hours are used for cleaning between batches, the vessel may produce only 4000 litres per day. Similarly, the car park may be fully occupied by office workers during the working day, 'processing' only 500 cars per day. Alternatively, it may be used for shoppers staying on average only one hour and theatre-goers occupying spaces for three hours in the evening. The processing capacity would then be up to 5000 cars per day. Thus the definition of the capacity of an operation is the *maximum level of value-added activity over a period of time* that the process can achieve under normal operating conditions.

Capacity constraints

Capacity constraint

Many organizations operate at below their maximum processing capacity, either because there is insufficient demand completely to 'fill' their capacity or as a deliberate policy, so that the operation can respond quickly to every new order. Often, though, organizations find themselves with some parts of their operation operating below their capacity while other parts are at their capacity 'ceiling'. It is the parts of the operation that are operating at their capacity 'ceiling' which are the **capacity constraint** for the whole operation. For example, a retail superstore might offer a gift-wrapping service which at normal times can cope with all requests for its services without delaying customers unduly. At Christmas, however, the demand for gift wrapping might increase proportionally far more than the overall increase in custom for the store as a whole. Unless extra resources are provided to increase the capacity of this micro operation, it could constrain the capacity of the whole store.

Planning and controlling capacity

Capacity planning and control is the task of setting the effective capacity of the operation so that it can respond to the demands placed upon it. This usually means deciding how the operation should react to fluctuations in demand. We have faced this issue before in Chapter 6 where we examined long-term changes in demand and the alternative capacity strategies for dealing with the changes. These strategies were concerned with introducing (or deleting) major increments of physical capacity. We called this task **long-term capacity strategy**. In this chapter we are treating the shorter time scale where capacity decisions are being made largely within the constraints of the physical capacity limits set by the operation's long-term capacity strategy.

Long-term capacity strategy

Medium- and short-term capacity

Having established long-term capacity, operations managers must decide how to adjust the capacity of the operation in the **medium term**. This usually involves an assessment of the demand forecasts over a period of 2–18 months ahead, during which time planned output can be varied, for example by changing the number of hours the equipment is used. In practice, however, few forecasts are accurate and most operations also need to respond to changes in demand which occur over a shorter time scale. Hotels and restaurants have unexpected and apparently random changes in demand from night to night, but also know from experience that certain days are on average busier than others. So operations managers also have to make **short-term capacity** adjustments, which enable them to flex output for a short period, either on a predicted basis (for example, bank checkouts are always busy at lunchtimes) or at short notice (for example, a sunny warm day at a theme park).

Medium-term capacity planning and control

Short-term capacity planning and control

Aggregate demand and capacity

The important characteristic of capacity planning and control, as we are treating it here, is that it is concerned with setting capacity levels over the medium and short terms in **aggregated** terms. That is, it is making overall, broad capacity decisions, but is not concerned with all of the detail of the individual products and services offered. This is what 'aggregated' means – different products and services are bundled together in order to get a broad view of demand and capacity. This may mean some degree of approximation, especially if the mix of products or services being produced varies significantly (as we shall see later in this chapter). Nevertheless, as a first step in planning and control, aggregation is necessary. For example, a hotel might think of demand and capacity in terms of 'room nights per month'. This ignores the number of guests in each room and their individual requirements, but it is a good first approximation. A woollen knitwear factory might measure demand and capacity in the number of units (garments) it is capable of making per month, ignoring size, colour or style variations. Aluminium producers could use tonnes per month, ignoring types of alloy, gauge and batch size variation. The ultimate aggregation measure is money. For example, retail stores, which sell an exceptionally wide variety of products, use revenue per month, ignoring variation in spend, number of items bought, the gross margin of each item and the number of items per customer transaction. If all this seems very approximate, remember that most operations have sufficient experience of dealing with aggregated data to find it useful.

Aggregated planning and control
A term used to indicate medium-term capacity planning that aggregates different products and services together in order to get a broad view of demand and capacity.

The objectives of capacity planning and control

The decisions operations managers taken in devising their capacity plans will affect several different aspects of performance:

- *Costs* will be affected by the balance between capacity and demand (or output level if that is different). Capacity levels in excess of demand could mean under-utilization of capacity and therefore high units cost.

- *Revenues* will also be affected by the balance between capacity and demand, but in the opposite way. Capacity levels equal to or higher than demand at any point in time will ensure that all demand is satisfied and no revenue lost.
- *Working capital* will be affected if an operation decides to build up finished goods inventory prior to demand. This might allow demand to be satisfied, but the organization will have to fund the inventory until it can be sold.
- *Quality* of goods or services might be affected by a capacity plan which involved large fluctuations in capacity levels, by hiring temporary staff for example. The new staff and the disruption to the operation's routine working could increase the probability of errors being made.
- *Speed* of response to customer demand could be enhanced, either by the build-up of inventories (allowing customers to be satisfied directly from the inventory rather than having to wait for items to be manufactured) or by the deliberate provision of surplus capacity to avoid queuing.
- *Dependability* of supply will also be affected by how close demand levels are to capacity. The closer demand gets to the operation's capacity ceiling, the less able it is to cope with any unexpected disruptions and the less dependable its deliveries of goods and services could be.
- *Flexibility*, especially volume flexibility, will be enhanced by surplus capacity. If demand and capacity are in balance, the operation will not be able to respond to any unexpected increase in demand.

The steps of capacity planning and control

The sequence of capacity planning and control decisions which need to be taken by operations managers is illustrated in Figure 11.2. Typically, operations managers are faced with a forecast of demand which is unlikely to be either certain or constant. They will also have some idea of their ability to meet this demand. Nevertheless, before any further decisions are taken, they must have quantitative data on both capacity and demand. So the first step will be to *measure the aggregate demand and capacity* levels for the planning period. The second step will be to *identify the alternative capacity plans* which could be adopted in response to the demand fluctuations. The third step will be to *choose the most appropriate capacity plan* for their circumstances.

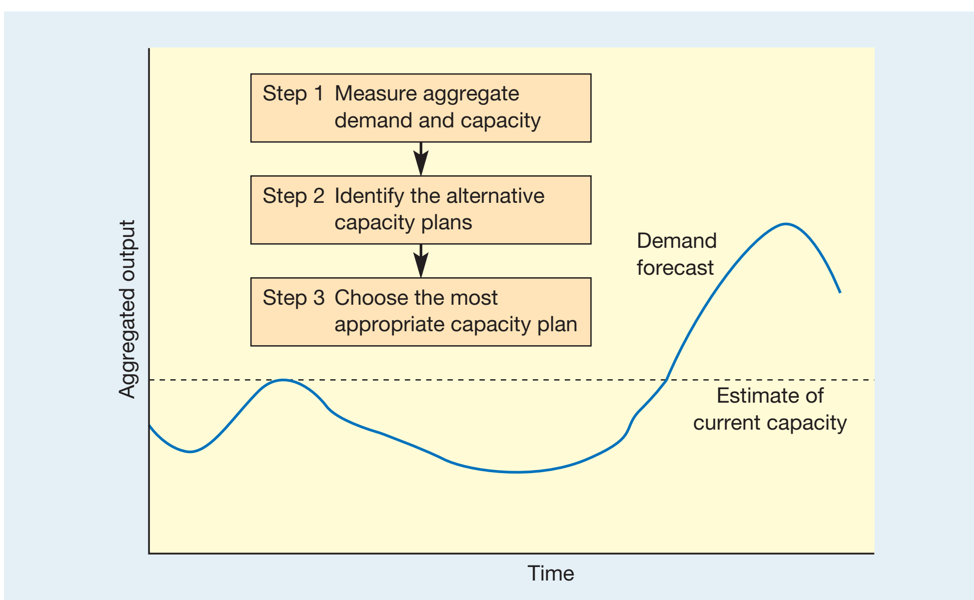


Figure 11.2 The steps in capacity planning and control

Measuring demand and capacity

Forecasting demand fluctuations

Forecasting is a key input to capacity planning and control

Although demand forecasting is usually the responsibility of the sales and/or marketing functions, it is a very important input into the capacity planning and control decision and so is of interest to operations managers. After all, without an estimate of future demand it is not possible to plan effectively for future events, only to react to them. It is therefore important to understand the basis and rationale for these demand forecasts. (See the supplement on forecasting after Chapter 6.) As far as capacity planning and control is concerned, there are three requirements from a demand forecast.

It is expressed in terms which are useful for capacity planning and control

If forecasts are expressed only in money terms and give no indication of the demands that will be placed on an operation's capacity, they will need to be translated into realistic expectations of demand, expressed in the same units as the capacity (for example, machine hours per year, operatives required, space, etc.).

It is as accurate as possible

In capacity planning and control, the accuracy of a forecast is important because, whereas demand can change instantaneously, there is a lag between deciding to change capacity and the change taking effect. Thus many operations managers are faced with a dilemma. In order to attempt to meet demand, they must often decide output in advance, based on a forecast which might change before the demand occurs, or worse, prove not to reflect actual demand at all.

It gives an indication of relative uncertainty

Decisions to operate extra hours and recruit extra staff are usually based on forecast levels of demand, which could in practice differ considerably from actual demand, leading to unnecessary costs or unsatisfactory customer service. A forecast of demand levels in a supermarket may show initially slow business that builds up to a lunchtime rush. After this, demand slows, only to build up again for the early evening rush before it falls again at the end of trading. The supermarket manager can use this forecast to adjust (say) checkout capacity throughout the day. But although this may be an accurate average demand forecast, no single day will exactly conform to this pattern. Of equal importance is an estimate of how much actual demand could differ from the average. This can be found by examining demand statistics to build up a distribution of demand at each point in the day. The importance of this is that the manager now has an understanding of when it will be important to have reserve staff, perhaps filling shelves, but on call to staff the checkouts should demand warrant it. Generally, the advantage of probabilistic forecasts such as this is that it allows operations managers to make a judgement between possible plans that would virtually guarantee the operation's ability to meet actual demand and plans that minimize costs. Ideally, this judgement should be influenced by the nature of the way the business wins orders: price-sensitive markets may require a risk-avoiding cost minimization plan that does not always satisfy peak demand, whereas markets that value responsiveness and service quality may justify a more generous provision of operational capacity.

Seasonality of demand

Demand seasonality

Supply seasonality

In many organizations, capacity planning and control is concerned largely with coping with seasonal demand fluctuations. Almost all products and services have some demand seasonality and some also have supply seasonality, usually where the inputs are seasonal agricultural products – for example, in processing frozen vegetables. These fluctuations in demand or supply may be reasonably forecastable, but some are usually also affected by unexpected variations in the weather and by changing economic conditions. Figure 11.3 gives some examples of seasonality, while the short case 'Producing while the sun shines' discusses the sometimes unexpected link between weather conditions and demand levels.

Figure 11.3 **Many types of operation have to cope with seasonal demand**

GO TO WEB! 11A

Consider the four different types of operation described previously: a wool knitwear factory, a city hotel, a supermarket and an aluminium producer. Their demand patterns are shown in Figure 11.4. The woollen knitwear business and the city hotel both have seasonal sales demand patterns, but for different reasons: the woollen knitwear business because of climatic patterns (cold winters, warm summers) and the hotel because of demand from business people, who take vacations from work at Christmas and in the summer. The retail supermarket is a little less seasonal, but is affected by pre-vacation peaks and reduced sales during vacation periods. The aluminium producer shows virtually no seasonality, but is showing a steady growth in sales over the forecast period.

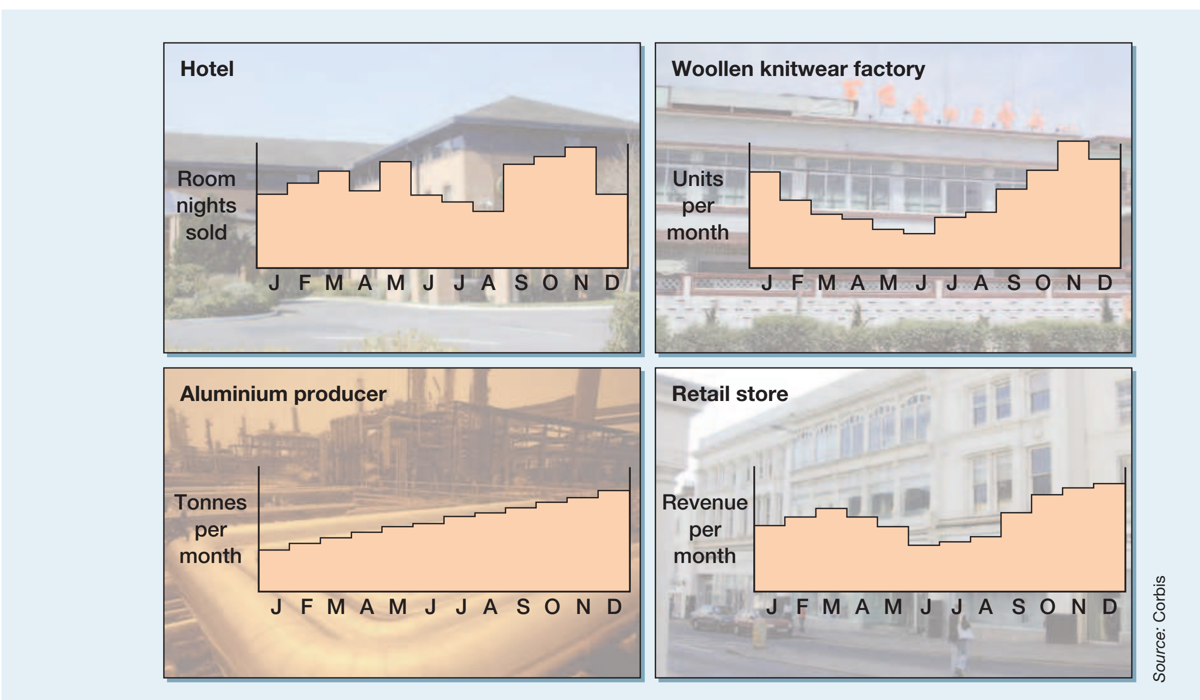


Figure 11.4 **Aggregate demand fluctuations for four organizations**

Weekly and daily demand fluctuations

Seasonality of demand occurs over a year, but similar predictable variations in demand can also occur for some products and services on a shorter cycle. The daily and weekly demand patterns of a supermarket will fluctuate, with some degree of predictability. Demand might be low in the morning, higher in the afternoon, with peaks at lunchtime and after work in the evening. Demand might be low on Monday and Tuesday, build up during the latter part of the week and reach a peak on Friday and Saturday. Banks, public offices, telephone sales organizations and electricity utilities all have weekly and daily, or even hourly, demand patterns which require capacity adjustment. The extent to which an operation will have to cope with very short-term demand fluctuations is partly determined by how long its customers are prepared to wait for their products or services. An operation whose customers are incapable of, or unwilling to, wait will have to plan for very short-term demand fluctuations. Emergency services, for example, will need to understand the hourly variation in the demand for their services and plan capacity accordingly.

Short case **Producing while the sun shines**[2]

The sales of some products are profoundly affected by the weather. Sunglasses, sunscreen, waterproof clothing and ice-cream are all obvious examples. Yet the range of operations interested in weather forecasting has expanded significantly. Energy utilities, soft drink producers and fresh food producers and retailers are all keen to purchase the latest weather forecasts. But so are operations such as banking call centres and mobile phone operators. It would appear that the demand for telephone banking falls dramatically when the sun shines, as does the use of mobile phones. A motorway catering group was surprised to find that its sales of hot meals fell predictably by €110,000 per day for each degree temperature rise above 20°C. Similarly, insurance companies have found it wise to sell their products when the weather is poor and likely customers are trapped indoors rather than relaxing outside in the sun, refusing to worry about the future. In the not-for-profit sector new understanding is being developed on the link between various illnesses and temperature. Here temperature is often used as a predictor of demand. So, for example, coronary thrombosis cases peak two days after a drop in temperature, for strokes the delay is around five days, while deaths from respiratory infections peak twelve days from a temperature drop. Knowing this, hospital managers can plan for changes in their demand.

Because of this, meteorological services around the world now sell increasingly sophisticated forecasts to a wide range of companies. In the UK, the Meteorological Office offers an internet-based service for its customers. It is also used to help insurance specialists price insurance policies to provide compensation against weather-related risk. Complex financial products called 'weather derivates' are available to compensate for weather-related

Source: Alamy/Medical-on-line

uncertainty. So, for example, an energy company could buy a financial option before winter where the seller pays the company a guaranteed sum of money if the temperature rises above a certain level. If the weather is mild and energy sales are low, the company gets compensation. If the weather is cold, the company loses the premium it has paid to the seller but makes up for it by selling more power at higher prices. However, as meteorologists point out, it is up to the individual businesses to use the information wisely. Only they have the experience to assess the full impact of weather on their operation. So, for example, supermarkets know that a rise in temperature will impact on the sales of cottage cheese (whereas, unaccountably, the sales of cottage cheese with pineapple chunks are not affected).

Question

1 How should a business work out what it is prepared to pay for these increasingly sophisticated weather forecasts?

Measuring capacity

The main problem with measuring capacity is the complexity of most operations. Only when the operation is highly standardized and repetitive is capacity easy to define unambiguously. So if a television factory produces only one basic model, the weekly capacity could be described as 2000 Model A televisions. A government office may have the capacity to print and post 500,000 tax forms per week. A fast ride at a theme park might be designed to process batches of 60 people every three minutes – a capacity to convey 1200 people per hour. In each case, an **output capacity measure** is the most appropriate measure because the output from the operation does not vary in its nature. For many operations, however, the definition of capacity is not so obvious. When a much wider range of outputs places varying demands on the process, output measures of capacity are less useful. Here **input capacity measures** are frequently used to define capacity. Almost every type of operation could use a mixture of both input and output measures, but in practice most choose to use one or the other (see Table 11.1).

Output capacity measure

Input capacity measures

Capacity depends on activity mix

The hospital measures its capacity in terms of its resources, partly because there is not a clear relationship between the number of beds it has and the number of patients it treats. If all its patients required relatively minor treatment with only short stays in hospital, it could treat many people per week. If most of its patients required long periods of observation or recuperation, it could treat far fewer. Output depends on the mix of activities in which the hospital is engaged and, because most hospitals perform many different types of activities, output is difficult to predict. Certainly it is difficult to compare directly the capacity of hospitals which have very different activities.

Table 11.1 Input and output capacity measures for different operations

Operation	*Input measure of capacity*	*Output measure of capacity*
Air-conditioner plant	Machine hours available	**Number of units per week**
Hospital	**Beds available**	Number of patients treated per week
Theatre	**Number of seats**	Number of customers entertained per week
University	**Number of students**	Students graduated per year
Retail store	**Sales floor area**	Number of items sold per day
Airline	**Number of seats available on the sector**	Number of passengers per week
Electricity company	Generator size	**Megawatts of electricity generated**
Brewery	Volume of fermentation tanks	**Litres per week**

(Note: The most commonly used measure is shown in bold.)

Worked example

Suppose an air-conditioner factory produces three different models of air-conditioner unit: the deluxe, the standard and the economy. The deluxe model can be assembled in 1.5 hours, the standard in 1 hour and the economy in 0.75 hours. The assembly area in the factory has 800 staff hours of assembly time available each week.

If demand for deluxe, standard and economy units is in the ratio 2:3:2, the time needed to assemble 2 + 3 + 2 = 7 units is:

$$(2 \times 1.5) + (3 \times 1) + (2 \times 0.75) = 7.5 \text{ hours}$$

The number of units produced per week is:

$$\frac{800}{7.5} \times 7 = 746.7 \text{ units}$$

If demand changes to a ratio of deluxe, economy, standard units of 1:2:4, the time needed to assemble 1 + 2 + 4 = 7 units is:

$$(1 \times 1.5) + (2 \times 1) + (4 \times 0.75) = 6.5 \text{ hours}$$

Now the number of units produced per week is:

$$\frac{800}{6.5} \times 7 = 861.5 \text{ units}$$

Design capacity and effective capacity

Design capacity
The capacity of a process or facility as it is designed to be, often greater than effective capacity.

Effective capacity
The useful capacity of a process or operation after maintenance, changeover and other stoppages and loading has been accounted for.

Utilization
The ratio of the actual output from a process or facility to its design capacity.

Efficiency

The theoretical capacity of an operation – the capacity which its technical designers had in mind when they commissioned the operation – cannot always be achieved in practice. For example, a company coating photographic paper will have several coating lines which deposit thin layers of chemicals onto rolls of paper at high speed. Each line will be capable of running at a particular speed. Multiplying the maximum coating speed by the operating time of the plant gives the theoretical **design capacity** of the line. But in reality the line cannot be run continuously at its maximum rate. Different products will have different coating requirements, so the line will need to be stopped while it is changed over. Maintenance will need to be performed on the line, which will take out further productive time. Technical scheduling difficulties might mean more lost time. Not all of these losses are the operations manager's fault; they have occurred because of the market and technical demands on the operation. The actual capacity which remains, after such losses are accounted for, is called the **effective capacity** of operation. Not that these causes of reduction in capacity will be the only losses in the operation. Such factors as quality problems, machine breakdowns, absenteeism and other avoidable problems will all take their toll. This means that the *actual output* of the line will be even lower than the effective capacity. The ratio of the output actually achieved by an operation to its design capacity and the ratio of output to effective capacity are called, respectively, the **utilization** and the **efficiency** of the plant:

$$\textbf{Utilization} = \frac{\textbf{actual output}}{\textbf{design capacity}}$$

$$\textbf{Efficiency} = \frac{\textbf{actual output}}{\textbf{effective capacity}}$$

Worked example

Suppose the photographic paper manufacturer has a coating line with a design capacity of 200 square metres per minute and the line is operated on a 24-hour day, 7 days per week (168 hours per week) basis.

Design capacity is $200 \times 60 \times 24 \times 7 = 2.016$ million square metres per week. The records for a week's production show the following lost production time:

1	Product changeovers (set-ups)	20 hrs
2	Regular preventative maintenance	16 hrs
3	No work scheduled	8 hrs
4	Quality sampling checks	8 hrs
5	Shift change times	7 hrs
6	Maintenance breakdown	18 hrs
7	Quality failure investigation	20 hrs
8	Coating material stockouts	8 hrs
9	Labour shortages	6 hrs
10	Waiting for paper rolls	6 hrs

→

During this week the actual output was only 582,000 square metres.

The first five categories of lost production occur as a consequence of reasonably unavoidable, planned occurrences and amount to a total of 59 hours. The last five categories are unplanned, and avoidable, losses and amount to 58 hours.

$$\text{Design capacity} = 168 \text{ hours per week}$$

$$\text{Effective capacity} = 168 - 59 = 109 \text{ hrs}$$

$$\text{Actual output} = 168 - 59 - 58 = 51 \text{ hrs}$$

$$\text{Utilization} = \frac{\text{actual output}}{\text{design capacity}} = \frac{51 \text{ hrs}}{168\text{hrs}} = 0.304\ (30\%)$$

$$\text{Efficiency} = \frac{\text{actual output}}{\text{effective capacity}} = \frac{51 \text{ hrs}}{109 \text{ hrs}} = 0.468\ (47\%)$$

Critical commentary

For such an important topic, there is surprisingly little standardization in how capacity is measured. Not only is a reasonably accurate measure of capacity needed for operations planning and control, it is also needed to decide whether it is worth investing in extra physical capacity such as machines. Yet not all practitioners would agree with the way in which design and effective capacity have been defined or measured in the previous worked example. Some would argue that the first five categories do *not* occur as 'a consequence of reasonably unavoidable, planned occurrences'. Product changeover set-ups can be reduced, allocating work in a different manner between processes could reduce the amount of time when no work is scheduled, even re-examining preventative maintenance schedules could lead to a reduction in lost time. One school of thought is that whatever capacity efficiency measures are used, they should be useful as diagnostic measures which can highlight the root causes of inefficient use of capacity. The idea of overall equipment effectiveness described next is often put forward as a useful way of measuring capacity efficiencies.

Overall equipment effectiveness[3]

Overall equipment effectiveness (OEE)
A method of judging the effectiveness of how operations equipment is used.

The **overall equipment effectiveness (OEE)** measure is an increasingly popular method of judging the effectiveness of operations equipment. It is based on three aspects of performance:

- *the time* that equipment is available to operate;
- *the quality* of the product or service it produces;
- *the speed*, or throughput rate, of the equipment.

GO TO WEB! 11B

Overall equipment effectiveness is calculated by multiplying an availability rate by a performance (or speed) rate multiplied by a quality rate. Some of the reduction in available capacity of a piece of equipment (or any process) is caused by time losses such as set-up and changeover losses (when the equipment or process is being prepared for its next activity), and breakdown failures when the machine is being repaired. Some capacity is lost through speed losses such as when equipment is idling (for example when it is temporarily waiting for work from another process) and when equipment is being run below its optimum work rate. Finally, not everything processed by a piece of equipment will be error free. So some capacity is lost through quality losses.

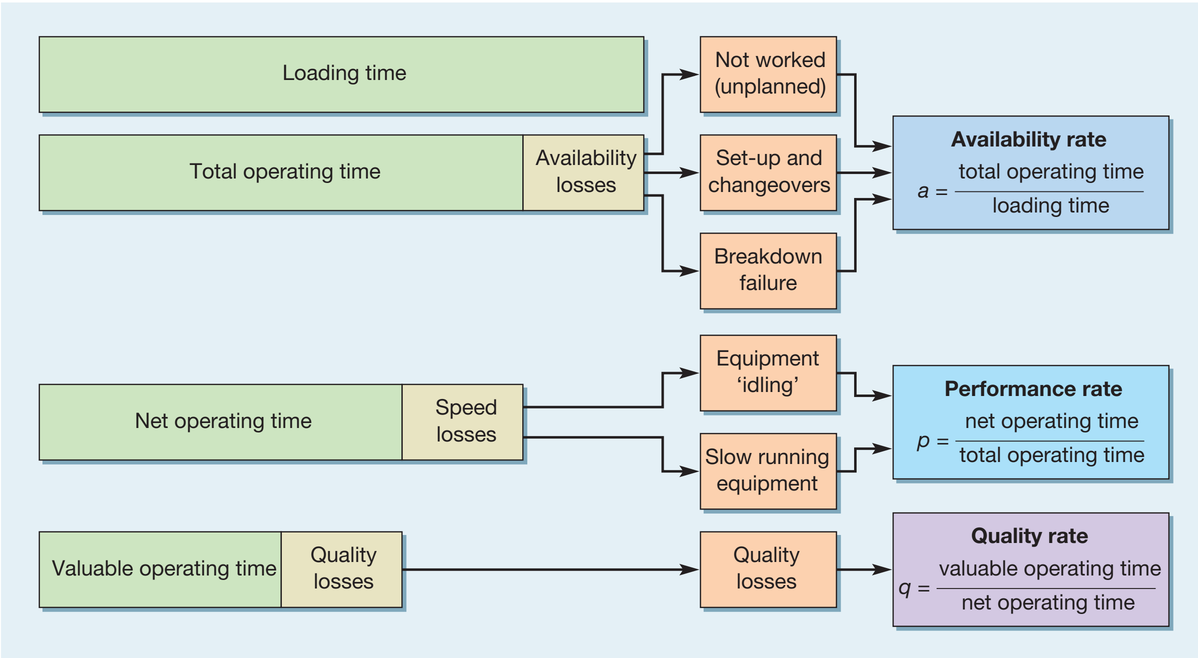


Figure 11.5 Operating equipment effectiveness

Taking the notation in Figure 11.5,

$$\text{OEE} = a \times p \times q$$

For equipment to operate effectively, it needs to achieve high levels of performance against all three of these dimensions. Viewed in isolation, these individual metrics are important indicators of plant performance, but they do not give a complete picture of the machine's *overall* effectiveness. This can be understood only by looking at the combined effect of the three measures, calculated by multiplying the three individual metrics together. All these losses to the OEE performance can be expressed in terms of units of time – the design cycle time to produce one good part. So, a reject of one part has an equivalent time loss. In effect, this means that an OEE represents the valuable operating time as a percentage of the design capacity.

Short case **British Airways London Eye**

GO TO WEB! 11C

The British Airways London Eye is the world's largest observation wheel and one of the UK's most spectacular tourist attractions. Since opening to 2006, they have welcomed over 21 million visitors. The 32 fully air conditioned passenger capsules, fixed on the perimeter of the 135 metre diameter rim, each hold up to 25 people. The wheel rotates continuously, so entry requires customers to step into the capsules which are moving at 0.26 metres per second, which is a quarter of normal walking speed. One complete 360-degree rotation takes 30 minutes, at the end of which the doors open and passengers disembark. Boarding and disembarkation are separated on the specially designed platform which is built out over the river. The attraction has a 'timed admissions booking system' (TABS) for both individual and group bookings. This allocates requests for 'flights' on the basis of half-hour time

Source: British Airways London Eye

slots. At the time of writing, the London Eye is open every day except Christmas Day. The first flight of the day departs at 10.00 am. In summer (June–September) the last flight is at 9.00 pm and the rest of the year at 8.00 pm. The British Airways London Eye forecasts anticipated that 2.2 million passengers would fly the London Eye in 2000, excluding January, which was reserved for final testing and admission of invited guests only. An early press release told journalists that the London Eye would rotate an average of 6,000 revolutions per year.

Questions

1 Calculate the hourly, weekly and annual design capacity of the London Eye, based on the planned operating time. How does this compare with the maximum theoretical design capacity if it operated 24 hours a day? How accurate is the annual number of revolutions mentioned in the press release?

2 Based on passenger numbers, what is the anticipated capacity utilization in the first year of operation? Explain why this is less than 100 per cent?

Worked example

In a typical seven-day period, the planning department programs a particular machine to work for 150 hours – its loading time. Changeovers and set-ups take an average of 10 hours and breakdown failures average 5 hours every seven days. The time when the machine cannot work because it is waiting for material to be delivered from other parts of the process is 5 hours on average and during the period when the machine is running, it averages 90 per cent of its rated speed. Subsequently 3 per cent of the parts processed by the machine are found to be defective in some way.

Maximum time available = 7 × 24 hours
= 168 hours

Loading time = 150 hours

Availability losses = 10 hours (set-ups) + 5 hrs (breakdowns)
= 15 hours

So, total operating time = loading time – availability
= 150 hours – 15 hours
= 135 hours

Speed losses = 5 hours (idling) + ((135–5) × 0.1)(10% of remaining time)
= 18 hours

So, net operating time = total operating time – speed losses
= 135 – 18
= 117 hours

Quality losses = 117 (net operating time) × 0.03 (error rate)
= 3.51 hours

So, valuable operating time = net operating time – quality losses
= 117 – 3.51
= 113.49 hours

$$\text{Therefore, availability rate} = a = \frac{\text{total operating time}}{\text{loading time}} = \frac{135}{150} = 90\%$$

$$\text{and, performance rate} = p = \frac{\text{net operating time}}{\text{total operating time}} = \frac{117}{135} = 86.67\%$$

$$\text{and quality rate} = q = \frac{\text{valuable operating time}}{\text{net operating time}} = \frac{113.49}{117} = 97\%$$

$$\text{OEE } (a \times p \times q) = 75.6\%$$

The alternative capacity plans

Level capacity plan
An approach to medium-term capacity management that attempts to keep output from an operation or its capacity, constant, irrespective of demand.

Chase demand plan
An approach to medium-term capacity management that attempts to adjust output and/or capacity to reflect fluctuations in demand.

Demand management
An approach to medium-term capacity management that attempts to change or influence demand to fit available capacity.

With an understanding of both demand and capacity, the next step is to consider the alternative methods of responding to demand fluctuations. There are three 'pure' options available for coping with such variation:

- ignore the fluctuations and keep activity levels constant (**level capacity plan**);
- adjust capacity to reflect the fluctuations in demand (**chase demand plan**);
- attempt to change demand to fit capacity availability (**demand management**).

In practice, most organizations will use a mixture of all of these 'pure' plans, although often one plan might dominate. The short case 'Seasonal salads' describes how one operation uses some of these options.

Level capacity plan

In a level capacity plan, the processing capacity is set at a uniform level throughout the planning period, regardless of the fluctuations in forecast demand. This means that the same number of staff operates the same processes and should therefore be capable of producing the same aggregate output in each period. Where non-perishable materials are processed, but not immediately sold, they can be transferred to finished goods inventory in anticipation of sales at a later time. Thus this plan is feasible (but not necessarily desirable) for our examples of the woollen knitwear company and the aluminium producer (see Figure 11.7).

Short case **Seasonal salads**

GO TO WEB! 11D

Lettuce is an all-year-round ingredient for most salads, but both the harvesting of the crop and its demand are seasonal. Lettuces are perishable and must be kept in cold stores and transported in refrigerated vehicles. Even then the product stays fresh for a maximum of only a week. In most north European countries, demand continues throughout the winter at around half the summer levels, but outdoor crops cannot be grown during the winter months. Glasshouse cultivation is possible but expensive.

One of Europe's largest lettuce growers is G's Fresh Salads, based in the UK. Its supermarket customers require fresh produce to be delivered 364 days a year, but because of the limitations of the English growing season, the company has developed other sources of supply in Europe. It acquired a farm and packhouse in the Murcia region of south-eastern Spain, which provides the bulk of salad crops during the winter, transported daily to the UK by a fleet of refrigerated trucks. Further top-up produce is imported by air from around the world.

Sales forecasts are agreed with the individual supermarkets well in advance, allowing the planting and growing programmes to be matched to the anticipated level of sales. However, the programme is only a rough guide. The supermarkets may change their orders right up to the afternoon of the preceding day. Weather is a

Source: Corbis/Photocuisine

dominant factor. First, it determines supply – how well the crop grows and how easy it is to harvest. Second, it influences sales – cold, wet periods during the summer discourage the eating of salads, whereas hot spells boost demand greatly.

Figure 11.6 illustrates this. The iceberg lettuce sales programme is shown and compared with the actual English-grown and Spanish-grown sales. The fluctuating nature of the actual sales is the result of a combination of weather-related availability and supermarket demand. These do not always match. When demand is higher than expected, the picking rigs and their crews continue to work into the middle of night, under floodlights. Another capacity problem is the operation's staffing levels. It relies on temporary seasonal harvesting and packing staff to supplement the full-time employees for both the English and Spanish seasons. Since most of the crop is transported to the UK in bulk, a large permanent staff is maintained for packing and distribution in the UK. The majority of the Spanish workforce is temporary, with only a small number retained during the extremely hot summer to grow and harvest other crops such as melons.

The specialist lettuce harvesting machines (the 'rigs') are shipped over to Spain every year at the end of the English season, so that the company can achieve maximum utilization from all this expensive capital equipment. These rigs not only enable very high productivity of the pickers but also ensure the best possible conditions for quality packing and rapid transportation to the cold stores.

Questions

1 What approach(es) does the company seem to take to its capacity management?

2 What are the consequences of getting its planting and harvesting programmes wrong?

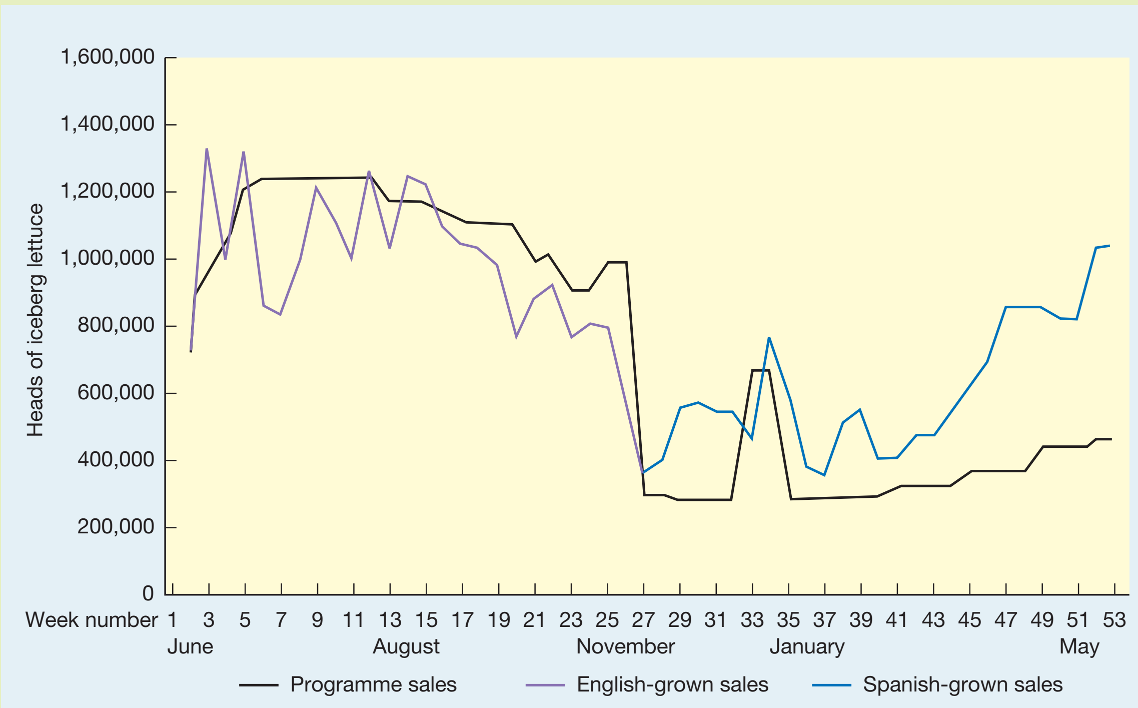


Figure 11.6 Typical year's iceberg lettuce sales

GO TO WEB! 11E

Level capacity plans of this type can achieve the objectives of stable employment patterns, high process utilization and usually also high productivity with low unit costs. Unfortunately, they can also create considerable inventory which has to be financed and stored. Perhaps the biggest problem, however, is that decisions have to be taken as to what to produce for inventory rather than for immediate sale. Will green woollen sweaters knitted in July still be fashionable in October? Could a particular aluminium alloy in a specific sectional shape still be sold months after it has been produced? Most firms operating this plan, therefore, give priority to creating inventory only where future sales are relatively certain and unlikely to be affected by changes in fashion or design. Clearly, such plans are not suitable for 'perishable' products, such as foods and some pharmaceuticals, for products where fash-

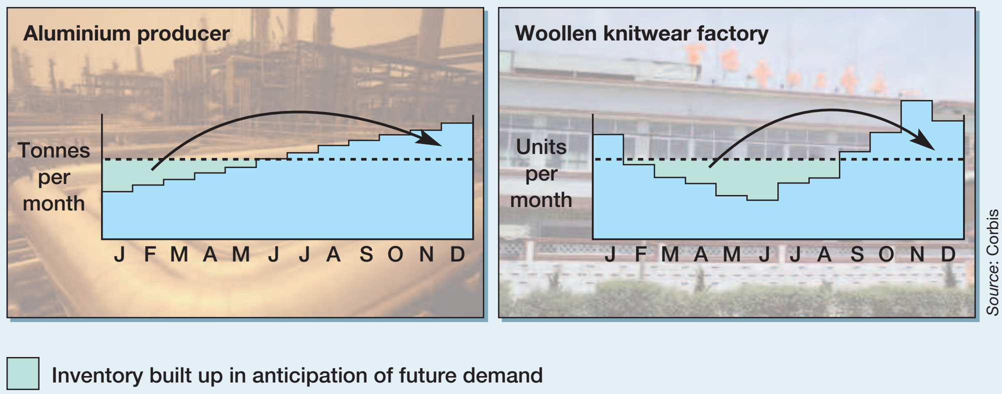


Figure 11.7 Level capacity plans which use anticipation inventory to supply future demand

ion changes rapidly and unpredictably (popular music CDs, fashion garments) or for customized products.

A level capacity plan could also be used by the hotel and supermarket, although this would not be the usual approach of such organizations because it generally results in a waste of staff resources, reflected in low productivity. Because service cannot be stored as inventory, a level capacity plan would involve running the operation at a uniformly high level of capacity availability. The hotel would employ sufficient staff to service all the rooms, to run a full restaurant and to staff the reception even in months when demand was expected to be well below capacity. Similarly, the supermarket would plan to staff all the checkouts, warehousing operations and so on even in quiet periods (see Figure 11.8).

Low utilization can make level capacity plans prohibitively expensive in many service operation, but may be considered appropriate where the opportunity costs of individual lost sales are very high, for example in the high-margin retailing of jewellery and in (real) estate agents. It is also possible to set the capacity somewhat below the forecast peak demand level in order to reduce the degree of under-utilization. However, in the periods where demand is expected to exceed planned capacity, customer service may deteriorate. Customers may have to queue for long periods or may be 'processed' faster and less sensitively. While this is obviously far from ideal, the benefits to the organization of stability and productivity may outweigh the disadvantages of upsetting some customers.

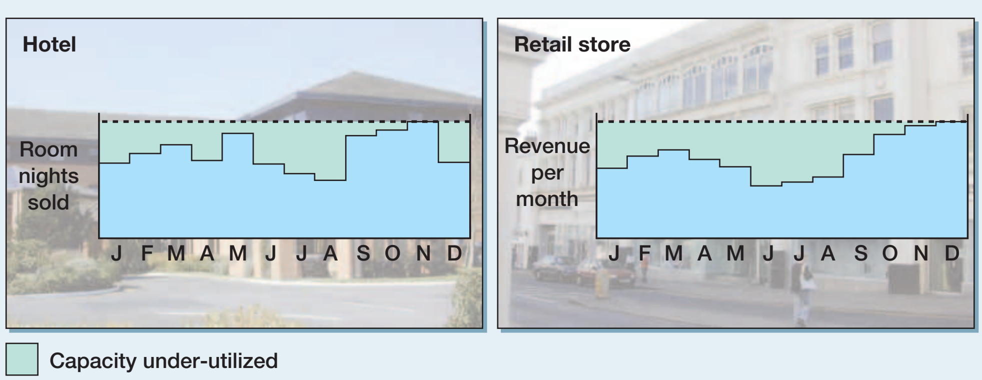


Figure 11.8 Level capacity plans with under-utilization of capacity

Chase demand plan

The opposite of a level capacity plan is one which attempts to match capacity closely to the varying levels of forecast demand. This is much more difficult to achieve than a level capacity plan, as different numbers of staff, different working hours and even different amounts of equipment may be necessary in each period. For this reason, pure chase demand plans are unlikely to appeal to operations which manufacture standard, non-perishable products. Also, where manufacturing operations are particularly capital-intensive, the chase demand policy would require a level of physical capacity, all of which would be used only occasionally. It is for this reason that such a plan is less likely to be appropriate for the aluminium producer than for the woollen garment manufacturer (see Figure 11.9). A pure chase demand plan is more usually adopted by operations which cannot store their output, such as customer-processing operations or manufacturers of perishable products. It avoids the wasteful provision of excess staff that occurs with a level capacity plan and yet should satisfy customer demand throughout the planned period. Where output can be stored, the chase demand policy might be adopted in order to minimize or eliminate finished goods inventory.

GO TO WEB! 11F

Sometimes it is difficult to achieve very large variations in capacity from period to period. If the changes in forecast demand are as large as those in the hotel example (see Figure 11.10), significantly different levels of staffing will be required throughout the year. This would mean employing part-time and temporary staff, requiring permanent employees to work longer hours or even bringing in contract labour. The operations managers will then have the difficult task of ensuring that quality standards and safety procedures are still adhered to and that customer service levels are maintained.

Methods of adjusting capacity

The chase demand approach requires that capacity is adjusted by some means. There are a number of different methods for achieving this, although they may not all be feasible for all types of operation. Some of these methods are listed below.

Overtime and idle time

Often the quickest and most convenient method of adjusting capacity is by varying the number of productive hours worked by the staff in the operation. When demand is higher than nominal capacity, **overtime** is worked, and when demand is lower than nominal capacity, the amount of time spent by staff on productive work can be reduced. In the latter case, it may be possible for staff to engage in some other activity such as cleaning or maintenance. This method is useful only if the timing of the extra productive capacity matches that of the

Overtime

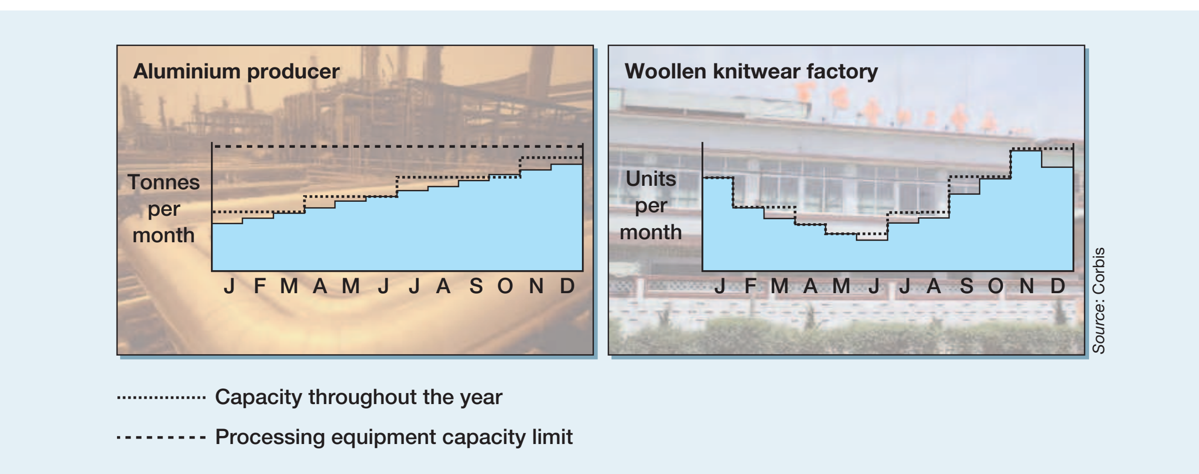


Figure 11.9 **Chase demand capacity plans with changes in capacity which reflect changes in demand**

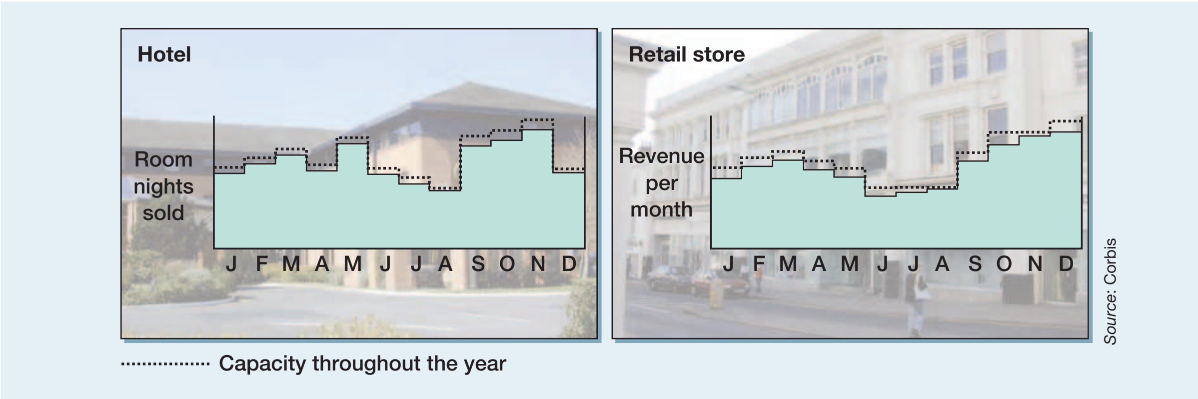


Figure 11.10 Chase demand capacity plans with changes in capacity which reflect changes in demand

demand. For example, there is little to be gained in asking a retail operation's staff to work extra hours in the evening if all the extra demand is occurring during their normal working period. The costs associated with this method are either the extra payment which is normally necessary to secure the agreement of staff to work overtime, or in the case of **idle time**, the costs of paying staff who are not engaged in direct productive work. Further, there might be costs associated with the fixed costs of keeping the operation heated, lit and secure over the extra period staff are working. There is also a limit to the amount of extra working time which any workforce can deliver before productivity levels decrease. **Annualized hours** approaches, as described in the short case 'Working by the year', are one way of flexing working hours without excessive extra costs.

Idle time

Annualized hours

Varying the size of the workforce

If capacity is largely governed by workforce size, one way to adjust it is to adjust the size of the workforce. This is done by hiring extra staff during periods of high demand and laying them off as demand falls, or **hire and fire**. However, there are cost and ethical implications to be taken into account before adopting such a method. The costs of hiring extra staff include those associated with recruitment, as well as the costs of low productivity while new staff go through the learning curve. The costs of lay-off may include possible severance payments, but might also include the loss of morale in the operation and loss of goodwill in the local labour market. At a micro operation level, one method of coping with peaks in demand in one area of an operation is to build sufficient flexibility into job design and job demarcation so that staff can transfer across from less busy parts of the operation. The French hotel chain Novotel has trained some of its kitchen staff to escort customers from the reception area up to their rooms. The peak times for registering new customers coincide with the least busy times in the kitchen and restaurant areas.

Hire and fire
A (usually pejorative) term used in medium-term capacity management to indicate varying the size of the workforce through employment policy.

Using part-time staff

A variation on the previous strategy is to recruit **part-time staff**, that is, for less than the normal working day. This method is extensively used in service operations such as supermarkets and fast-food restaurants but is also used by some manufacturers to staff an evening shift after the normal working day. However, if the fixed costs of employment for each employee, irrespective of how long he or she works, are high, then using this method may not be worthwhile.

Part-time staff

Sub-contracting

In periods of high demand, an operation might buy capacity from other organizations, called **sub-contracting**. This might enable the operation to meet its own demand without the extra expense of investing in capacity which will not be needed after the peak in demand has passed. Again, there are costs associated with this method. The most obvious one is that

Sub-contracting
When used in medium-term capacity management, it indicates the temporary use of other operations to perform some tasks, or even produce whole products or services, during times of high demand.

sub-contracting can be very expensive. The sub-contractor will also want to make sufficient margin out of the business. A sub-contractor may not be as motivated to deliver on time or to the desired levels of quality. Finally, there is the risk that the sub-contractors might decide to enter the same market.

Critical commentary

To many, the idea of fluctuating the workforce to match demand, either by using part-time staff or by hiring and firing, is more than just controversial, it is regarded as unethical. It is any business's responsibility, they argue, to engage in a set of activities which is capable of sustaining employment at a steady level. Hiring and firing merely for seasonal fluctuations, which can be predicted in advance, is treating human beings in a totally unacceptable manner. Even hiring people on a short-term contract in practice leads to them being offered poorer conditions of service and leads to a state of permanent anxiety as to whether they will keep their jobs. On a more practical note, it is pointed out that, in an increasingly global business world where companies may have sites in different countries, those countries that allow hiring and firing are more likely to have their plants 'downsized' than those where legislation makes this difficult.

Manage demand plan

Demand management An approach to medium-term capacity management that attempts to change or influence demand to fit available capacity.

Change demand

The most obvious mechanism of **demand management** is to **change demand** through price. Although this is probably the most widely applied approach in demand management, it is less common for products than for services. Some city hotels offer low-cost 'city break' vacation packages in the months when fewer business visitors are expected. Skiing and camping holidays are cheapest at the beginning and end of the season and are particularly expensive during school vacations. Discounts are given by photo-processing firms during winter periods but never around summer holidays. Ice-cream is 'on offer' in many supermarkets during the winter. The objective is invariably to stimulate off-peak demand and to constrain peak demand in order to smooth demand as much as possible. Organizations can also attempt to increase demand in low periods by appropriate advertising. For example, turkey growers in the UK and the USA make vigorous attempts to promote their products at times other than Christmas and Thanksgiving.

Alternative products and services

Alternative products

GO TO WEB! 11G

Sometimes a more radical approach is required to fill periods of low demand such as developing **alternative products** or services which can be produced on existing processes but have different demand patterns throughout the year. (See the short case 'Getting the message' for an example of this approach.) Most universities fill their accommodation and lecture theatres with conferences and company meetings during vacations. Ski resorts provide organized mountain activity holidays in the summer. Some garden tractor companies in the US now make snow movers in the autumn and winter. The apparent benefits of filling capacity in this way must be weighted against the risks of damaging the core product or service and the operation must be fully capable of serving both markets. Some universities have been criticized for providing sub-standard, badly decorated accommodation which met the needs of impecunious undergraduates but which failed to impress executives at a trade conference.

Mixed plans

Each of the three 'pure' plans is applied only where its advantages strongly outweigh its disadvantages. For many organizations, however, these 'pure' approaches do not match their required combination of competitive and operational objectives. Most operations managers are required simultaneously to reduce costs and inventory, to minimize capital investment and yet to provide a responsive and customer-oriented approach at all times. For this reason,

Short case **Working by the year**[4]

One method of fluctuating capacity as demand varies throughout the year without many of the costs associated with overtime or hiring temporary staff is called the annual hours work plan. This involves staff contracting to work a set number of hours per year rather than a set number of hours per week. The advantage of this is that the amount of staff time available to an organization can be varied throughout the year to reflect the real state of demand. Annual hours plans can also be useful when supply varies throughout the year. For example, a UK cheese factory of Express Foods, like all cheese factories, must cope with processing very different quantities of milk at different times of the year. In spring and during early summer, cows produce large quantities of milk, but in late summer and autumn the supply slows to a trickle. Before the introduction of annualized hours, the factory had relied on overtime and hiring temporary workers during the busy season. Now the staff are contracted to work a set number of hours a year, with rotas agreed more than a year in advance and after consultation with the union. This means that at the end of July staff broadly know what days and hours they will be working up to September of the following year. If an emergency should arise, the company can call in people from a group of 'super crew' who work more flexible hours in return for higher pay but can do any job in the factory.

However, not all experiments with annualized hours have been as successful as that at Express Foods. In cases where demand is very unpredictable, staff can be asked to come in to work at very short notice. This can cause considerable disruption to social and family life. At one news-broadcasting company, the scheme caused problems. Journalists and camera crew who went to cover a foreign crisis found that they had worked so many hours they were asked to take off the whole of one month to compensate. Since they had no holiday plans, many would have preferred to work.

Question

1 What do you see as being the major advantages and disadvantages to both the company and the staff of adopting the annual hours work plan?

most organizations choose to follow a mixture of the three approaches. This can be best illustrated by the woollen knitwear company example (see Figure 11.11). Here some of the peak demand has been brought forward by the company offering discounts to selected retail customers (manage demand plan). Capacity has also been adjusted at two points in the year

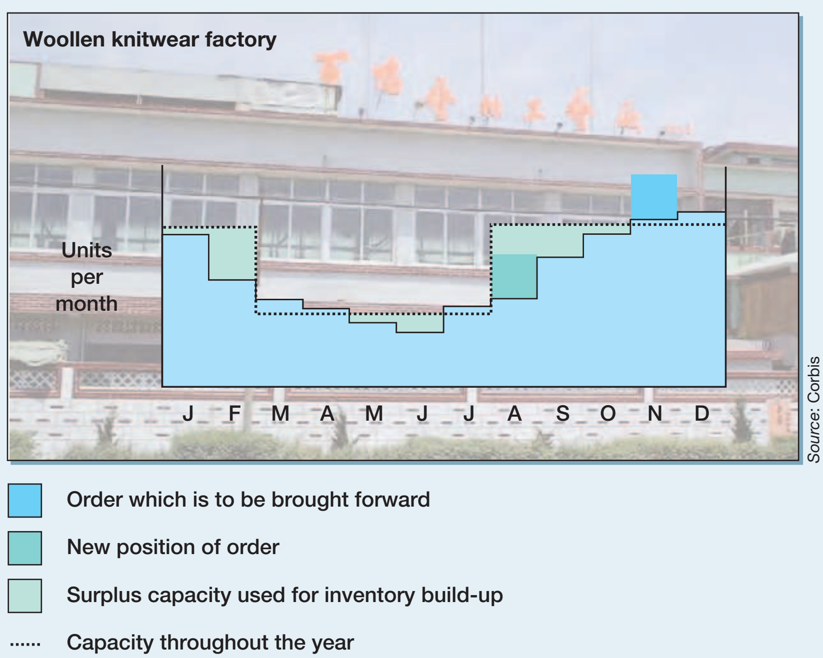


Figure 11.11 **A mixed capacity plan for the woollen knitwear factory**

to reflect the broad changes in demand (chase demand plan). Yet the adjustment in capacity is not sufficient to avoid totally the build-up of inventories (level capacity plan).

Yield management

Yield management
A collection of methods that can be used to ensure that an operation (usually with a fixed capacity) maximizes its potential to generate profit.

In operations which have relatively fixed capacities, such as airlines and hotels, it is important to use the capacity of the operation for generating revenue to its full potential. One approach such operations use is called **yield management**. This is really a collection of methods, some of which we have already discussed, which can be used to ensure that an operation maximizes its potential to generate profit. Yield management is especially useful where:

- capacity is relatively fixed;
- the market can be fairly clearly segmented;
- the service cannot be stored in any way;
- the services are sold in advance;
- the marginal cost of making a sale is relatively low.

Airlines fit all these criteria. They adopt a collection of methods to try to maximize the yield (i.e. profit) from their capacity. These include the following:

Short case **Getting the message**[5]

Companies which traditionally operate in seasonal markets can demonstrate some considerable ingenuity in their attempts to develop counter-seasonal products. One of the most successful industries in this respect has been the greetings card industry. Mother's Day, Father's Day, Halloween, Valentine's Day and other occasions have all been promoted as times to send (and buy) appropriately designed cards. Now, having run out of occasions to promote, greetings card manufacturers have moved on to 'non-occasion' cards, which can be sent at any time. These have the considerable advantage of being less seasonal, thus making the companies' seasonality less marked.

Hallmark Cards, the market leader in North America, has been the pioneer in developing non-occasion cards. Its cards include those intended to be sent from a parent to a child with messages such as 'Would a hug help?', 'Sorry I made you feel bad' and 'You're perfectly wonderful – it's your room that's a mess'. Other cards deal with more serious adult themes such as friendship ('You're more than a friend, you're just like family') or even alcoholism ('This is hard to say, but I think you're a much neater person when you're not drinking'). Now Hallmark Cards has founded a 'loyalty marketing group' that 'helps companies communicate with their customers at an emotional level'. It promotes the use of greetings cards for corporate use, to show that customers and employees are valued. Whatever else these products may be, they are not seasonal!

Source: Empics

Questions

1 What seem to be the advantages and disadvantages of the strategy adopted by Hallmark Cards?

2 What else could it do to cope with demand fluctuations?

- *Over-booking capacity.* Not every passenger who has booked a place on a flight will actually show up for the flight. If the airline did not fill this seat it would lose the revenue from it. Because of this, airlines regularly book more passengers onto flights than the capacity of the aircraft can cope with. If they over-book by the exact number of passengers who fail to show up, they have maximized their revenue under the circumstances. Of course, if more passengers show up than they expect, the airline will have a number of upset passengers to deal with (although they may be able to offer financial inducements for the passengers to take another flight). If they fail to over-book sufficiently, they will have empty seats. By studying past data on flight demand, airlines try to balance the risks of over-booking and under-booking.
- *Price discounting.* At quiet times, when demand is unlikely to fill capacity, airlines will also sell heavily discounted tickets to agents who then themselves take the risk of finding customers for them. In effect, this is using the price mechanism to affect demand.
- *Varying service types.* Discounting and other methods of affecting demand are also adjusted depending on the demand for particular types of service. The relative demand for first-, business- and economy-class seats varies throughout the year. There is no point discounting tickets in a class for which demand will be high. Yield management also tries to adjust the availability of the different classes of seat to reflect their demand. Airlines will also vary the number of seats available in each class by upgrading or even changing the configuration of seats.[6]

Choosing a capacity planning and control approach

Before an operation can decide which of the capacity plans to adopt, it must be aware of the consequences of adopting each plan in its own set of circumstances. Two methods are particularly useful in helping to assess the consequences of adopting particular capacity plans:

Cumulative representations

Queuing theory
A mathematical approach that models random arrival and processing activities in order to predict the behaviour of queuing systems (also called waiting line theory).

- **cumulative representations** of demand and capacity;
- **queuing theory**.

Cumulative representations

Figure 11.12 shows the forecast aggregated demand for a chocolate factory which makes confectionery products. Demand for its products in the shops is greatest at Christmas. To meet this demand and allow time for the products to work their way through the distribution system, the factory must supply a demand which peaks in September, as shown. One method of assessing whether a particular level of capacity can satisfy the demand would be to calculate the degree of over-capacity below the graph which represents the capacity levels (areas A and C) and the degree of under-capacity above the graph (area B). If the total over-capacity is greater than the total under-capacity for a particular level of capacity, that capacity could be regarded as adequate to satisfy demand fully, the assumption being that inventory has been accumulated in the periods of over-capacity. However, there are two problems with this approach. The first is that each month shown in Figure 11.12 may not have the same amount of productive time. Some months (August, for example) may contain vacation periods which reduce the availability of capacity. The second problem is that a capacity level which seems adequate may be able to supply products only *after* the demand for them has occurred. For example, if the period of under-capacity occurred at the beginning of the year, no inventory could have accumulated to meet demand. A far superior way of assessing capacity plans is first to plot demand on a *cumulative* basis. This is shown as the thicker line in Figure 11.12.

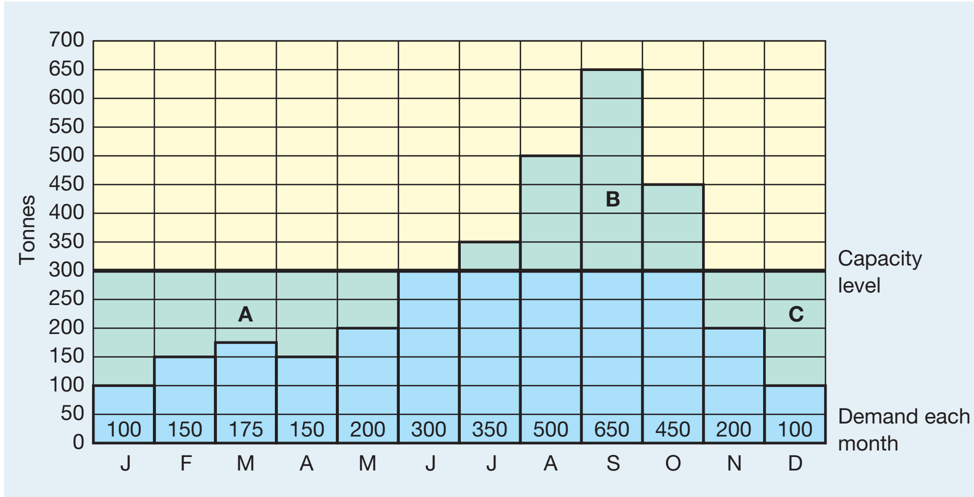


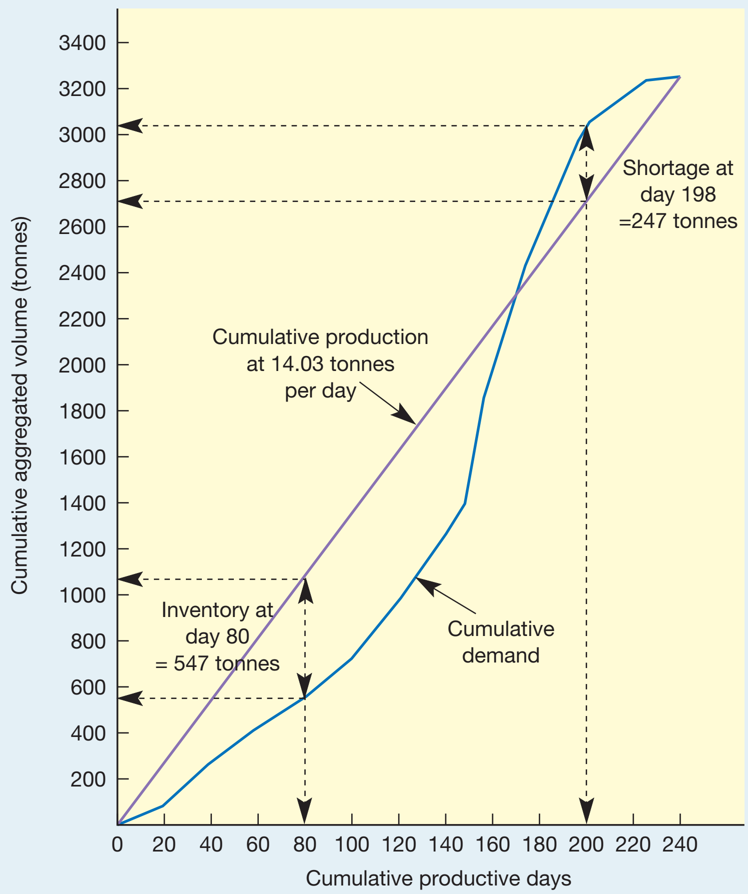
Figure 11.12 If the over-capacity areas (A+C) are greater than the under-capacity area (B), the capacity level seems adequate to meet demand. This may not necessarily be the case, however

The cumulative representation of demand immediately reveals more information. First, it shows that although total demand peaks in September because of the restricted number of available productive days, the peak demand per productive day occurs a month earlier in August. Second, it shows that the fluctuation in demand over the year is even greater than it seemed. The ratio of monthly peak demand to monthly lowest demand is 6.5:1, but the ratio of peak to lowest demand per productive day is 10:1. Demand per productive day is more relevant to operations managers because productive days represent the time element of capacity.

The most useful consequence of plotting demand on a cumulative basis is that by plotting capacity on the same graph, the feasibility and consequences of a capacity plan can be assessed. Figure 11.13 also shows a level capacity plan which produces at a rate of 14.03 tonnes per productive day. This meets cumulative demand by the end of the year. It would also pass our earlier test of total over-capacity being the same or greater than under-capacity.

However, if one of the aims of the plan is to supply demand when it occurs, the plan is inadequate. Up to around day 168, the line representing cumulative production is above that representing cumulative demand. This means that at any time during this period, more product has been produced by the factory than has been demanded from it. In fact, the vertical distance between the two lines is the level of inventory at that point in time. So by day 80, 1122 tonnes have been produced but only 575 tonnes have been demanded. The surplus of production above demand, or inventory, is therefore 547 tonnes. When the cumulative demand line lies above the cumulative production line, the reverse is true. The vertical distance between the two lines now indicates the shortage, or lack of supply. So by day 198, 3,025 tonnes have been demanded but only 2778 tonnes produced. The shortage is therefore 247 tonnes.

For any capacity plan to meet demand as it occurs, its cumulative production line must always lie above the cumulative demand line. This makes it a straightforward task to judge the adequacy of a plan simply by looking at its cumulative representation. An impression of the inventory implications can also be gained from a cumulative representation by judging the area between the cumulative production and demand curves. This represents the amount of inventory carried over the period. Figure 11.14 illustrates an adequate level capacity plan for the chocolate manufacturer, together with the costs of carrying inventory. It is assumed that inventory costs £2 per tonne per day to keep in storage. The average inventory each month is taken to be the average of the beginning- and end-of-month inventory levels, and the inventory-carrying cost each month is the product of the average inventory, the inventory cost per day per tonne and the number of days in the month.

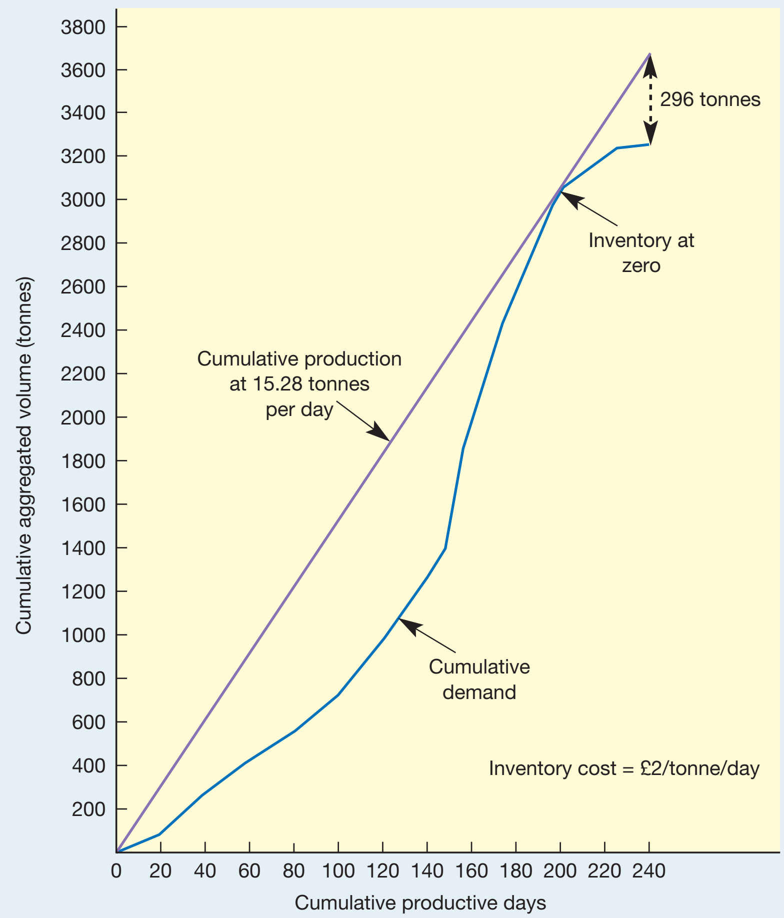


	J	F	M	A	M	J	J	A	S	O	N	D
Demand (tonnes/month)	100	150	175	150	200	300	350	500	650	450	200	100
Productive days	20	18	21	21	22	22	21	10	21	22	21	18
Demand (tonnes/day)	5	8.33	8.33	7.14	9.52	13.64	16.67	50	30.95	20.46	9.52	5.56
Cumulative days	20	38	59	80	102	124	145	155	176	198	219	237
Cumulative demand	100	250	425	575	775	1075	1425	1925	2575	3025	3225	3325
Cumulative production (tonnes)	281	533	828	1122	1431	1740	2023	2175	2469	2778	3073	3325
Ending inventory (tonnes)	181	283	403	547	656	715	609	250	(106)	(247)	(150)	0

Figure 11.13 A level capacity plan which produces shortages in spite of meeting demand at the end of the year

Comparing plans on a cumulative basis

Chase demand plans can also be illustrated on a cumulative representation. Rather than the cumulative production line having a constant gradient, it would have a varying gradient representing the production rate at any point in time. If a pure demand chase plan was adopted, the cumulative production line would match the cumulative demand line. The gap between the two lines would be zero and hence inventory would be zero. Although this would eliminate inventory-carrying costs, as we discussed earlier, there would be costs associated with changing capacity levels. Usually, the marginal cost of making a capacity change increases with the size of the change. For example, if the chocolate manufacturer wishes to increase capacity by 5 per cent, this can be achieved by requesting its staff to work overtime – a simple, fast and relatively inexpensive option. If the change is 15 per cent, overtime cannot



	J	F	M	A	M	J	J	A	S	O	N	D
Demand (tonnes/month)	100	150	175	150	200	300	350	500	650	450	200	100
Productive days	20	18	21	21	22	22	21	10	21	22	21	18
Demand (tonnes/day)	5	8.33	8.33	7.14	9.52	13.64	16.67	50	30.95	20.46	9.52	5.56
Cumulative days	20	38	59	80	102	124	145	155	176	198	219	237
Cumulative demand	100	250	425	575	775	1075	1425	1925	2575	3025	3225	3325
Cumulative production (tonnes)	306	581	902	1222	1559	1895	2216	2368	2689	3025	3346	3621
Ending inventory (tonnes)	206	331	477	647	784	820	791	443	114	0	121	296
Average inventory (tonnes)	103	270	404	562	716	802	806	617	279	57	61	209
Inventory cost for month (£)	4120	9720	16,968	23,604	31,504	35,288	33,852	12,340	11,718	2508	2562	7524

Total inventory cost for year = £191,608

Figure 11.14 A level capacity plan which meets demand at all times during the year

provide sufficient extra capacity and temporary staff will need to be employed – a more expensive solution which also would take more time. Increases in capacity of above 15 per cent might be achieved only by sub-contracting some work out. This would be even more expensive. The cost of the change will also be affected by the point from which the change is being made, as well as the direction of the change. Usually, it is less expensive to change capacity towards what is regarded as the ‘normal’ capacity level than away from it.

Worked example

Suppose the chocolate manufacturer, which has been operating the level capacity plan as shown in Figure 11.15, is unhappy with the inventory costs of this approach. It decides to explore two alternative plans, both involving some degree of demand chasing.

Plan 1

- Organize and staff the factory for a 'normal' capacity level of 8.7 tonnes per day.
- Produce at 8.7 tonnes per day for the first 124 days of the year, then increase capacity to 29 tonnes per day by heavy use of overtime, hiring temporary staff and some sub-contracting.
- Produce at 29 tonnes per day until day 194, then reduce capacity to 8.7 tonnes per day for the rest of the year.

The costs of changing capacity by such a large amount (the ratio of peak to normal capacity is 3.33:1) are calculated by the company as being:

Cost of changing from 8.7 tonnes/day to 29 tonnes/day = £110,000
Cost of changing from 29 tonnes/day to 8.7 tonnes/day = £60,000

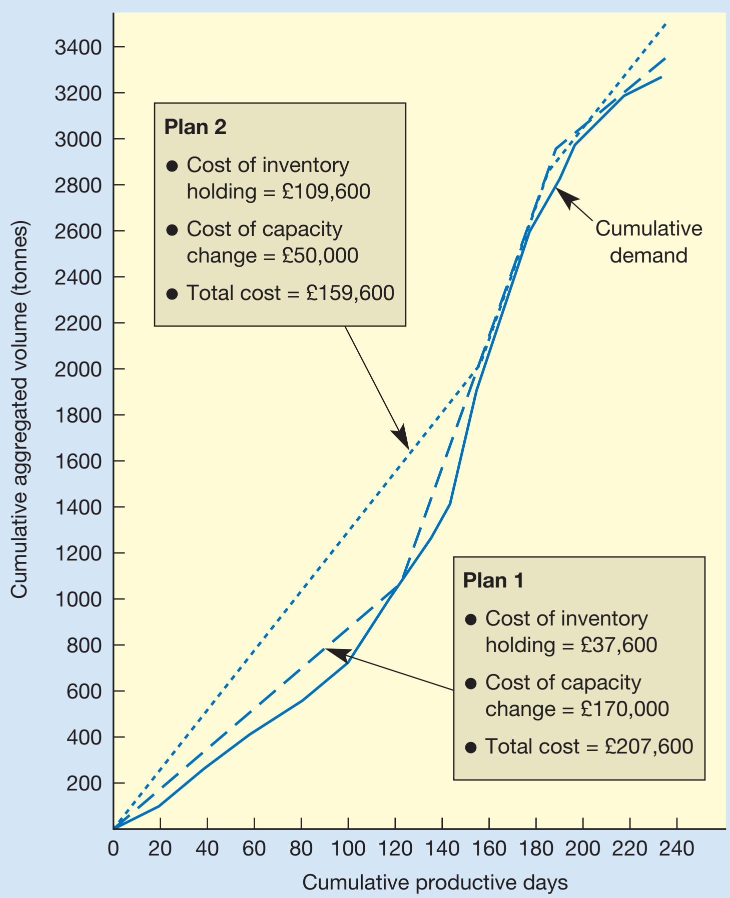


Figure 11.15 Comparing two alternative capacity plans

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Plan 2

- Organize and staff the factory for a 'normal' capacity level of 12.4 tonnes per day.
- Produce at 12.4 tonnes per day for the first 150 days of the year, then increase capacity to 29 tonnes per day by overtime and hiring some temporary staff.
- Produce at 29 tonnes/day until day 190, then reduce capacity to 12.4 tonnes per day for the rest of the year.

The costs of changing capacity in this plan are smaller because the degree of change is smaller (a peak to normal capacity ratio of 2.34:1) and they are calculated by the company as being:

Cost of changing from 12.4 tonnes/day to 29 tonnes/day = £35,000
Cost of changing from 29 tonnes/day to 12.4 tonnes/day = £15,000

Figure 11.15 illustrates both plans on a cumulative basis. Plan 1, which envisaged two drastic changes in capacity, has high capacity change costs but, because its production levels are close to demand levels, it has low inventory carrying costs. Plan 2 sacrifices some of the inventory cost advantage of Plan 1 but saves more in terms of capacity change costs.

Capacity planning as a queuing problem

Cumulative representations of capacity plans are useful where the operation has the ability to store its finished goods as inventory. However, for operations where it is not possible to produce products and services *before* demand for them has occurred, a cumulative representation would tell us relatively little. The cumulative 'production' could never be above the cumulative demand line. At best, it could show when an operation failed to meets its demand. So the vertical gap between the cumulative demand and production lines would indicate the amount of demand unsatisfied. Some of this demand would look elsewhere to be satisfied, but some would wait. This is why, for operations which, by their nature, cannot store their output, such as most service operations, capacity planning and control is best considered using waiting or **queuing theory**.

Queuing theory
A mathematical approach that models random arrival and processing activities in order to predict the behaviour of queuing systems (also called waiting line theory).

Queuing or 'waiting line' management

When we were illustrating the use of cumulative representations for capacity planning and control, our assumption was that, generally, any production plan should aim to meet demand at any point in time (the cumulative production line must be above the cumulative demand line). Looking at the issue as a queuing problem (in many parts of the world queuing concepts are referred to as 'waiting line' concepts) accepts that, while sometimes demand may be satisfied instantly, at other times customers may have to wait. This is particularly true when the arrival of individual demands on an operation are difficult to predict or the time to produce a product or service is uncertain, or both. These circumstances make providing adequate capacity at all points in time particularly difficult. Figure 11.16 shows the general form of this capacity issue. Customers arrive according to some probability distribution and wait to be processed (unless part of the operation is idle); when they have reached the front of the queue, they are processed by one of the *n* parallel 'servers' (their processing time also being described by a probability distribution), after which they leave the operation. There are many examples of this kind of system. Table 11.2 illustrates some of these. All of these examples can be described by a common set of elements that define their queuing behaviour.

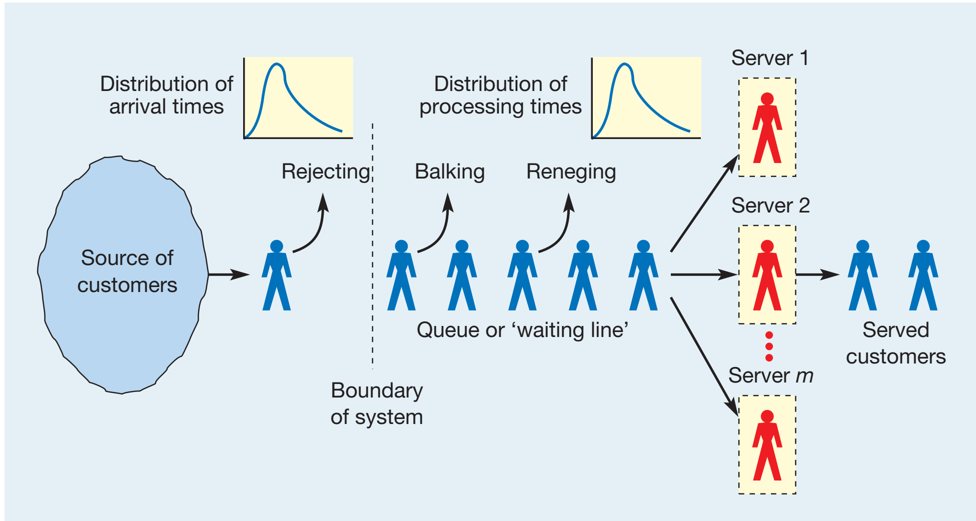


Figure 11.16 The general form of the capacity decision in queuing systems

Table 11.2 Examples of operations which have parallel processors

Operation	*Arrivals*	*Processing capacity*
Bank	Customers	Tellers
Supermarket	Shoppers	Checkouts
Hospital clinic	Patients	Doctors
Graphic artist	Commissions	Artists
Custom cake decorators	Orders	Cake decorators
Ambulance service	Emergencies	Ambulances with crews
Telephone switchboard	Calls	Telephonists
Maintenance department	Breakdowns	Maintenance staff

Calling population

The source of customers – sometimes called the **calling population**, is the source of supply of customers. In queue management 'customers' are not always human. 'Customers' could be trucks arriving at a weighbridge, orders arriving to be processed or machines waiting to be serviced, etc. The source of customers for a queuing system can be either *finite* or *infinite*. A finite source has a known number of possible customers. For example, if one maintenance person serves four assembly lines, the number of customers for the maintenance person is known, i.e. four. There will be a certain probability that one of the assembly lines will break down, and need repairing. However, if one line really does break down, the probability of another line needing repair is reduced because there are now only three lines to break down. So, with a finite source of customers the probability of a customer arriving depends on the number of customers already being serviced. By contrast, an infinite customer source assumes that there is a large number of potential customers so that it is always possible for another customer to arrive no matter how many are being serviced. Most queuing systems that deal with outside markets have infinite, or 'close-to-infinite', customer sources.

Arrival rate

The arrival rate – is the rate at which customers needing to be served arrive at the server or servers. Rarely do customers arrive at a steady and predictable rate; usually there is variability in their arrival rate. Because of this it is necessary to describe arrival rates in terms of probability distributions. The important issue here is that, in queuing systems, it is normal that at times no customers will arrive and at other times many will arrive relatively close together.

Queue

The queue – customers waiting to be served form the queue or waiting line itself. If there is relatively little limit on how many customers can queue at any time, we can assume that, for all practical purposes, an infinite queue is possible. Sometimes, however, there is a limit to how many customers can be in the queue at any one time.

Rejecting

Rejecting – if the number of customers in a queue is already at the maximum number allowed, the customer could be rejected by the system. For example, during periods of heavy demand some websites will not allow customers to access part of the site until the demand on its services has declined.

Balking

Balking – when a customer is a human being with free will (and the ability to get annoyed), he or she may refuse to join the queue and wait for service if it is judged to be too long. In queuing terms this is called balking.

Reneging

Reneging – this is similar to balking but here the customer has queued for a certain length of time and then (perhaps being dissatisfied with the rate of progress) leaves the queue and therefore the chance of being served.

Queue discipline

Queue discipline – this is the set of rules that determines the order in which customers waiting in the queue are served. Most simple queues, such as those in a shop, use a *first-come-first-served* queue discipline. The various sequencing rules described in Chapter 10 are examples of different queue disciplines.

Servers

Servers – a server is the facility that processes the customers in the queue. In any queuing system there may be any number of servers configured in different ways. In Figure 11.16 servers are configured in parallel, but some may have servers in a series arrangement. For example, on entering a self-service restaurant you may queue to collect a tray and cutlery, move on to the serving area where you queue again to order and collect a meal, move on to a drinks area where you queue once more to order and collect a drink and then finally queue to pay for the meal. In this case you have passed through four servers (even though the first one was not staffed) in a series arrangement. Of course, many queue systems are complex arrangements of series and parallel connections. There is also likely to be variation in how long it takes to process each customer. Even if customers do not have differing needs, human servers will vary in the time they take to perform repetitive serving tasks. Therefore processing time, like arrival time, is usually described by a probability distribution.

Balancing capacity and demand

The dilemma in managing the capacity of a queuing system is how many servers to have available at any point in time in order to avoid unacceptably long queuing times or unacceptably low utilization of the servers. Because of the probabilistic arrival and processing times, only rarely will the arrival of customers match the ability of the operation to cope with them. Sometimes, if several customers arrive in quick succession and require longer-than-average processing times, queues will build up in front of the operation. At other times, when customers arrive less frequently than average and also require shorter-than-average processing times, some of the servers in the system will be idle. So even when the average capacity (processing capability) of the operation matches the average demand (arrival rate) on the system, both queues and idle time will occur.

If the operation has too few servers (that is, capacity is set at too low a level), queues will build up to a level where customers become dissatisfied with the time they are having to wait, although the utilization level of the servers will be high. If too many servers are in place (that is, capacity is set at too high a level), the time which customers can expect to wait will not be long but the utilization of the servers will be low. This is why the capacity planning and control problem for this type of operation is often presented as a trade-off between customer waiting time and system utilization. What is certainly important in making capacity decisions is being able to predict both of these factors for a given queuing system. The supplement to this chapter details some of the more simple mathematical approaches to understanding queue behaviour.

Variability in demand or supply

Variability reduces effective capacity

The variability, either in demand or capacity, as discussed above, will reduce the ability of an operation to process its inputs. That is, it will **reduce its effective capacity**. This effect was explained in Chapter 4 when the consequences of variability in individual processes were

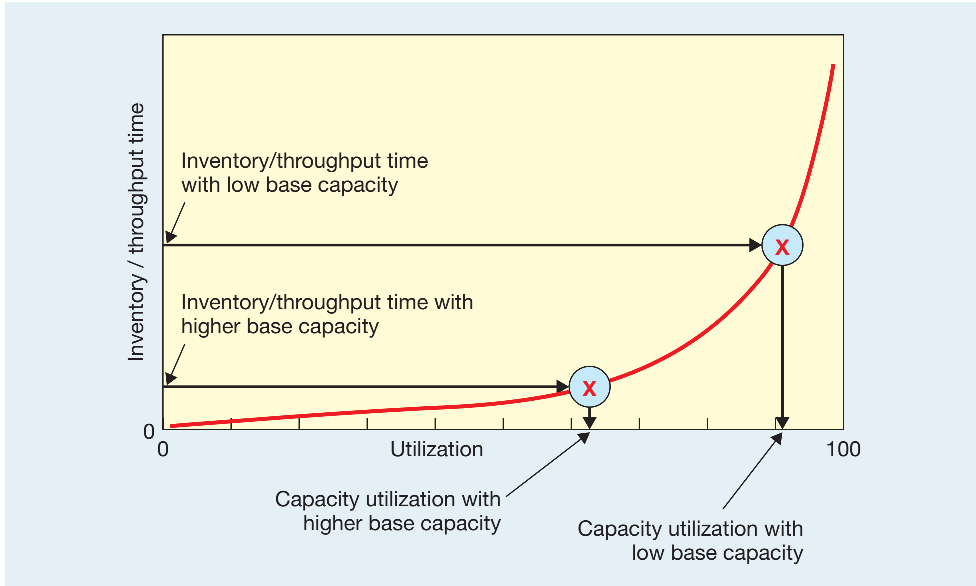


Figure 11.17 The effect of variability on the utilization of capacity

discussed. As a reminder, the greater the variability in arrival time or activity time at a process, the more the process will suffer both high throughput times and reduced utilization. This principle holds true for whole operations and because long throughput times mean that queues will build up in the operation, high variability also affects inventory levels. This is illustrated in Figure 11.17. The implication of this is that the greater the variability, the more extra capacity will need to be provided to compensate for the reduced utilization of available capacity. Therefore, operations with high levels of variability will tend to set their base level of capacity relatively high in order to provide this extra capacity.

Customer perceptions of queuing

If the 'customers' waiting in a queue are real human customers, an important aspect of how they judge the service they receive from a queuing system is how they perceive the time spent queuing. It is well known that if you are told you'll be waiting in a queue for 20 minutes and you are actually serviced in 10 minutes, your perception of the queuing experience will be more positive than if you were told that you would be waiting 10 minutes but the queue actually took 20 minutes. Because of this, the management of queuing systems usually involves attempting to manage customers' perceptions and expectations in some way (see the short case on Madame Tussaud's for an example of this). One expert in queuing has come up with a number of principles that influence how customers perceive waiting times.[7]

GO TO WEB! 11H

- Time spent idle is perceived as longer than time spent occupied.
- The wait before a service starts is perceived as more tedious than a wait within the service process.
- Anxiety and/or uncertainty heightens the perception that time spent waiting is long.
- A wait of unknown duration is perceived as more tedious than a wait whose duration is known.
- An unexplained wait is perceived as more tedious than a wait that is explained.
- The higher the value of the service for the customer, the longer the wait that will be tolerated.
- Waiting on one's own is more tedious than waiting in a group (unless you really don't like the others in the group).

Short case **Managing queues at Madame Tussaud's, Amsterdam**

A short holiday in Amsterdam would not be complete without a visit to Madame Tussaud's, located on four upper floors of the city's most prominent department store in Dam Square. With 600,000 visitors each year, this is the third most popular tourist attraction in Amsterdam, after the flower market and canal trips. On busy days in the summer, the centre can just manage to handle 5000 visitors. On a wet day in January, however, there may be only 300 visitors throughout the whole day. The centre is open for admission, seven days a week, from 10.00 am to 5.30 pm. In the streets outside, orderly queues of expectant tourists snake along the pavement, looking in at the displays in the store windows. In this public open space, Tussaud's can do little to entertain the visitors, but entrepreneurial buskers and street artists are quick to capitalize on a captive market.

On reaching the entrance lobby, individuals, families and groups purchase their admissions tickets. The lobby is in the shape of a large horseshoe, with the ticket sales booth in the centre. On winter days or at quiet spells, there will be only one sales assistant, but on busier days, visitors can pay at either side of the ticket booth, to speed up the process. Having paid, the visitors assemble in the lobby outside the two lifts. While waiting in this area, a photographer wanders around offering to take photos of the visitors standing next to life-sized wax figures of famous people. They may also be entertained by living look-alikes of famous personalities who act as guides to groups of visitors in batches of around 25 customers (the capacity of each of the two lifts which takes visitors up to the facility). The lifts arrive every four minutes and customers disembark simultaneously, forming one group of about 50 customers, who stay together throughout the section.

Source: Madame Tussaud's

Questions

1. Generally, what could Madame Tussaud's do to cope with its demand fluctuations?
2. What does the operation do to make queuing relatively painless? What else could it do?

The dynamics of capacity planning and control

Our emphasis so far has been on the planning aspects of capacity management. In practice, the management of capacity is a far more dynamic process which involves controlling and reacting to *actual* demand and *actual* capacity as they occur. The capacity control process can be seen as a sequence of partially reactive capacity decision processes, as shown in Figure 11.18. At the beginning of each period, operations management considers its forecasts of demand, its understanding of current capacity and, if appropriate, how much inventory has been carried forward from the previous period. Based on all this information, it makes plans for the following period's capacity. During the next period, demand might or might not be as forecast and the actual capacity of the operation might or might not turn out as planned. But whatever the actual conditions during that period, at the beginning of the next period the same types of decisions must be made, in the light of the new circumstances.

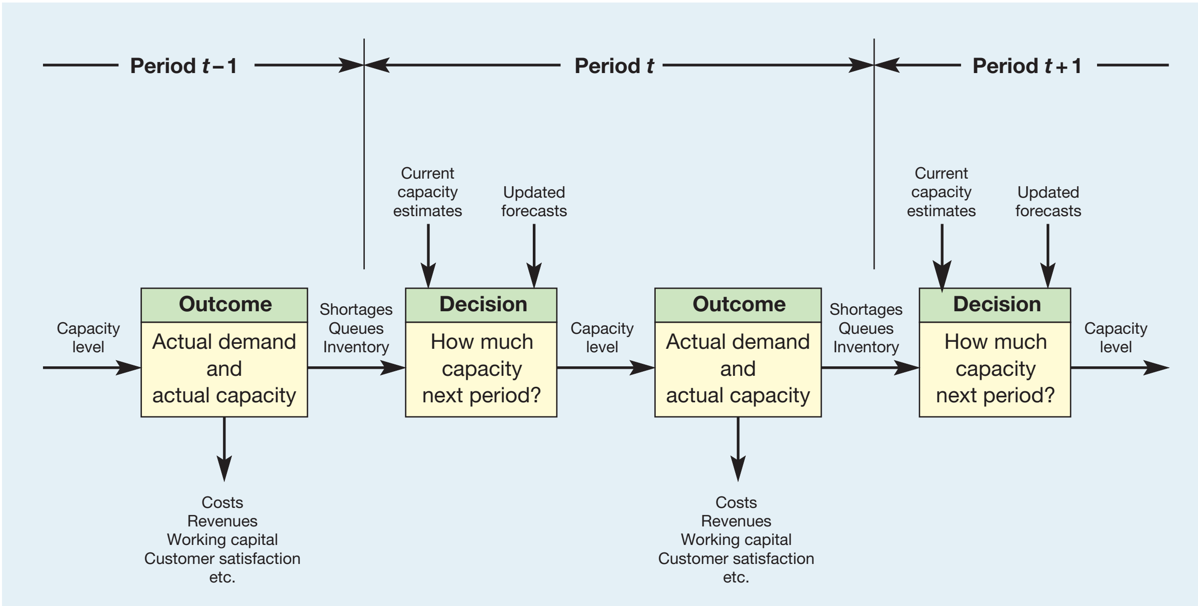


Figure 11.18 Capacity planning and control as a dynamic sequence of decisions

Summary answers to key questions

The Companion Website to the book – **www.pearsoned.co.uk/slack** *– also has a brief 'Study Guide' to each chapter.*

What is capacity planning and control?

- It is the way operations organize the level of value-added activity which they can achieve under normal operating conditions over a period of time.
- It is usual to distinguish between long-, medium- and short-term capacity decisions. Medium- and short-term capacity management where the capacity level of the organization is adjusted within the fixed physical limits which are set by long-term capacity decisions is sometimes called aggregate planning and control.
- Almost all operations have some kind of fluctuation in demand (or seasonality) caused by some combination of climatic, festive, behavioural, political, financial or social factors.

How is capacity measured?

- Either by the availability of its input resources or by the output which is produced. Which of these measures is used partly depends on how stable is the mix of outputs. If it is difficult to aggregate the different types of output from an operation, input measures are usually preferred.
- The usage of capacity is measured by the factors 'utilization' and 'efficiency'. A more recent measure is that of overall operations effectiveness (OEE).

What are the ways of coping with demand fluctuation?

- Output can be kept level, in effect ignoring demand fluctuations. This will result in under-utilization of capacity where outputs cannot be stored or the build-up of inventories where output can be stored.

- Output can chase demand by fluctuating the output level through some combination of overtime, varying the size of the workforce, using part-time staff and sub-contracting.
- Demand can be changed, either by influencing the market through such measures as advertising and promotion or by developing alternative products with a counter-seasonal demand pattern.
- Most operations use a mix of all these three 'pure' strategies.

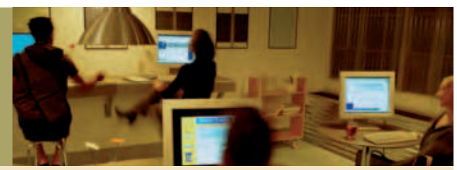
How can operations plan their capacity level?

- Representing demand and output in the form of cumulative representations allows the feasibility of alternative capacity plans to be assessed.
- In many operations, especially service operations, a queuing approach can be used to explore capacity strategies.

How can operations control their capacity level?

- By considering the capacity decision as a dynamic decision which periodically updates the decisions and assumptions upon which decisions are based.

Case study
Holly farm



In 2003, Charles and Gillian Giles decided to open up their farm to the paying public, in response to diminishing profits from their milk and cereals activities. They invested all their savings in building a 40-space car park and an area with spaces for six 40-seater buses, a safe viewing area for the milking parlour, special trailers for passengers to be transported around the farm on guided tours, a permanent exhibition of equipment, a 'rare breeds' paddock, a children's adventure playground, a picnic area and a farm shop. Behind the farm shop they built a small 'factory' making real dairy ice-cream, which also provided for public viewing. Ingredients for the ice-cream, pasteurized cream and eggs, sugar, flavourings, etc, were bought out, although this was not obvious to the viewing public.

Gillian took responsibility for all these new activities and Charles continued to run the commercial farming business. Through advertising, giving lectures to local schools and local organizations, the number of visitors to the farm increased steadily. By 2006 Gillian became so involved in running her business that she was unable to

Source: Wistow Maze, Leicestershire

Source: Sue Williams

A maize maze of the type Blackberry Hill Farm are considering give so much time to these promotional activities and the number of paying visitors levelled out to around 15,000 per year. Although the farm opened to the public at 11.00 am and closed at 7.00 pm after milking was finished, up to 90 per cent of visitors in cars or coaches would arrive later than 12.30 pm, picnic until around 2.00 pm and tour the farm until about 4.00 pm. By that time, around 20 per cent would have visited the farm shop and left, but the remainder would wait to view the milking, then visit the shop to purchase ice-cream and other produce, then depart.

Gillian opened the farm to the public each year from April to October inclusive. Demand would be too low outside this period, the conditions were often unsuitable for regular tractor rides and most of the animals had to be kept inside. Early experience had confirmed that midweek demand was too low to justify opening, but Friday through Monday was commercially viable, with almost exactly twice as many visitors on Saturdays and Sundays than on Fridays or Mondays. Gillian summed up the situation. '*I have decided to attempt to increase the number of farm visitors in 2007 by 50 per cent. This would not only improve our return on 'farm tours' assets, but also would help the farm shop to achieve its targets, and the extra sales of ice-cream would help to keep the 'factory' at full output. The real problem is whether to promote sales to coach firms or to intensify local advertising to attract more families in cars. We could also consider tie-ups with schools for educational visits, but I would not want to use my farm guides staff on any extra weekdays, as Charles needs them three days per week for 'real' farming work. However, most of the farm workers are glad of this extra work as it fits in well with their family life and helps them to save up for the luxuries most farm workers cannot afford*.'

The milking parlour

With 150 cows to milk, Charles invested in a 'carousel' parlour where cows are milked on a slow-moving turntable. Milking usually lasts from 4.30 pm to 7.00 pm, during which time visitors can view from a purpose-built gallery which has space and explanatory tape recordings, via headphones, for 12 people. Gillian has found that on average spectators like to watch for ten minutes, including five minutes for the explanatory tape. '*We're sometimes a bit busy on Saturdays and Sundays and a queue often develops before 4.00 pm as some people want to see the milking and then go home. Unfortunately, neither Charles nor the cows are prepared to start earlier. However, most people are patient and everybody gets their turn to see this bit of high technology. In a busy period, up to 80 people per hour pass through the gallery.*'

The ice-cream 'factory'

The factory is operated 48 weeks per year, four days per week, eight hours per day, throughout the year. The three employees, farm workers' wives, are expected to work in line with farm opening from April to October, but hours and days are by negotiation in other months. All output is in 1 litre plastic boxes, of which 350 are made every day, which is the maximum mixing and fast-freezing capacity. Although extra mixing hours would create more unfrozen ice-cream, the present equipment cannot safely and fully fast freeze more than 350 litres over a 24-hour period. Ice-cream that is not fully frozen cannot be transferred to the finished goods freezer, as slower freezing spoils the texture of the product. As it takes about one hour to clean out between flavours, only one of the four flavours is made on any day. The finished goods freezer holds a maximum of 10,000 litres, but to allow stock rotation, it cannot in practice be loaded to above 7000 litres. Ideally no ice-cream should be held more than 6 weeks at the factory, as the total recommended storage time is only 12 weeks prior to retail sale (there is no preservative used). Finished goods inventory at the end of December 2007 was 3600 litres.

Gillian's most recent figures indicated that all flavours cost about £2 per litre to produce (variable cost of materials, packaging and labour). The factory layout is by process with material preparation and weighing sections, mixing area, packing equipment and separate freezing equipment. It is operated as a batch process.

Ice-cream sales

The majority of output is sold through regional speciality shops and food sections of department stores. These outlets are given a standard discount of 25 per cent to allow a 33 per cent mark-up to the normal retail price of £4 per litre. Minimum order quantity is 100 litres and Gillian makes deliveries in the van on Tuesdays. Also, having been shown around the farm and 'factory', a large proportion of visitors buy ice-cream at the farm shop and take it away in well-insulated containers that keep it from melting for up to two hours in the summer. Gillian commented: '*These are virtually captive customers. We have analyzed this demand and found that on average one out of two coach customers buys a 1 litre box. On average, a car comes with four occupants and two 1 litre boxes are purchased. The farm shop retail price is £4 per box, which gives us a much better margin than for our sales to shops.*'

In addition, a separate, fenced, road entrance allows local customers to purchase goods at a separate counter of the farm shop without payment for, or access to, the other farm facilities. '*This is a surprisingly regular source of sales. We believe this is because householders make very infrequent visits to stock up their freezers almost regardless of the time of year or the weather. We also know that local hotels buy a lot this way and their use of ice-cream is year-round, with a peak only at Christmas when there are a larger number of banquets*.' All sales in this category are at the full retail price (£4). The finished product is sold to three categories of buyers. See Table 11.3. Note – (a) no separate record is kept of those sales to the paying farm visitors and those to the 'farm shop only', (b) the selling prices and discounts for 2008 will be as 2007, (c) Gillian

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Table 11.3 Analysis of annual sales of ice-cream (£000s) from 2003 to 2007 and forecast sales for 2008

	2003	*2004*	*2005*	*2006*	*2007*	*2008 forecast*
Retail shops	16	52	78	124	150	130
Farm shop total	20	32	40	50	54	80
Total	36	84	118	174	204	210

considered that 2007 was reasonably typical in terms of weather, although rainfall was a little higher than average during July and August.

Table 11.4 gives details of visitors to the farm and ice-cream sales in 2007. Gillian's concluding comments were: '*We have a long way to go to make this enterprise meet our expectations. We will probably make only a small return on capital employed in 2007, so must do all we can to increase our profitability. Neither of us wants to put more capital into the business, as we would have to borrow at interest rates of up to 15 per cent. We must make our investment work better. As a first step, I have decided to increase the number of natural flavours of our ice-cream to ten (currently only four) to try to defend the delicatessen trade against a competitor's aggressive marketing campaign. I don't expect that to fully halt the decline in our sales to these outlets and this is reflected in our sales forecast.*'

Questions

1 Evaluate Gillian's proposal to increase the number of farm visitors in 2008 by 50 per cent. (You may wish to consider: What are the main capacity constraints within these businesses? Should she promote coach company visits, even if this involves offering a discount on the admission charges? Should she pursue increasing visitors by car or school parties? In what other ways is Gillian able to manage capacity? What other information would help Gillian to take these decisions?)

2 What factors should Gillian consider when deciding to increase the number of flavours from four to ten? (Note: For any calculations, assume that each month consists of four weeks. The effects of statutory holidays should be ignored for the purpose of this initial analysis.)

Table 11.4 Records of farm visitors and ice-cream sales (£000s) in 2007

	Jan	*Feb*	*Mar*	*Apr*	*May*	*June*	*July*	*Aug*	*Sept*	*Oct*	*Nov*	*Dec*	*Total*
Total number of paying farm visitors	0	0	0	1200	1800	2800	3200	3400	1800	600	0	0	14,800
Monthly ice-cream sales	9	10.1	17.5	13.4	18	25.1	25.3	24.6	19.5	12.8	8.7	20	204

Other short cases and worked answers are included in the Companion Website to this book – **www.pearsoned.co.uk/slack**

Problems

1 The Dagenham Chow-Mein Pizza Company has a demand forecast for the next 12 months which is shown in Table 11.5.

Table 11.5 Pizza demand forecast

Months	*Demand (cases per month)*
January	600
February	800
March	1000
April	1500
May	2000
June	1700
July	1200
August	1100
September	900
October	2500
November	3200
December	900

The current workforce of 100 staff can produce 1000 cases of pizzas per month.

(**a**) Prepare a production plan which keeps the output level. How much warehouse space would the company need for this plan?

(**b**) Prepare a demand chase plan. What implications would this have for staffing levels, assuming that the maximum amount of overtime would result in production levels of only 10 per cent greater than normal working hours?

2 A local government office issues hunting licences. Demand for these licences is relatively slow in the first part of the year but then increases after the middle of the year before slowing down again towards the end of the year. The department works a 220-day year on a five-days-a-week basis. Between working days 0 and 100, demand is 25 per cent of demand during the peak period which lasts between day 100 and day 150. After day 150 demand reduces to about 12 per cent of the demand during the peak period. In total, the department processes 10,000 applications per year. The department has two permanent members of staff who are capable of processing 15 licence applications per day. If an untrained temporary member of staff can process only ten licences per day, how many temporary staff should the department recruit between days 100 and 150?

3 In the example above, if a new computer system is installed that allows experienced staff to increase their work rate to 20 applications per day and untrained staff to 15 applications per day, (**a**) does the department still need two permanent staff, and (**b**) how many temporary members of staff will be needed between days 100 and 150?

4 A field service organization repairs and maintains printing equipment for a large number of customers. It offers one level of service to all its customers and employs 30 staff. The operation's marketing vice president has decided that in future the company will offer three standards of service: platinum, gold and silver. It is estimated that platinum-service customers will require 50 per cent more time from the company's field service engineers than the current service. The current service is to be called 'the gold service'. The silver service is likely to require about 80 per cent of the time of the gold service. If future demand is estimated to be 20 per cent platinum, 70 per cent gold and 10 per cent silver service, how many staff will be needed to fulfil demand?

5 A specialist media company burns DVDs of movie clips to customers' specifications. The company's staff work a 35-hour week and do not expect to work any overtime. Although the company staffed the operation to produce 300 DVDs per week and demand has been slightly higher than this rate, it has been producing only 250 DVDs per week. A record of one week's activity shows that recording machine changeovers lost five hours of useful time maintenance lost three hours of useful time, quality checks lost two hours of time and coordination delays accounted for two hours lost per week. What is the utilization and the efficiency of the operation?

6 A professional institute outsources the marking of its examination papers but then employs specialists in its own offices to check the marking according to the marking scheme. Coordinating the flow of scripts from the (external) markers through to the (internal) checkers is always a problem and although the institute's ten checkers should inspect ten scripts an hour working a seven-hour day, last week only 500 scripts per day came through from the markers. In some ways it was a good thing that only 500 scripts arrived, even though 700 should have arrived, because two of the checkers were relatively new and working at only 80 per cent of the rate of the experienced checkers. Also, because of this, a total of 20 scripts per day needed rechecking by the supervisor. Calculate the OEE of the checking process.

Study activities

Some study activities can be answered by reading the chapter. Others will require some general knowledge of business activity and some might require an element of investigation. All have hints on how they can be answered on the Companion Website for this book that also contains more discussion questions – **www.pearsoned.co.uk.slack**

1 Look again at the principles which govern customers' perceptions of the queuing experience. For the following operations, apply the principles to minimize the perceived negative effects of queuing:

(**a**) A cinema.
(**b**) A doctor's surgery.
(**c**) Waiting to board an aircraft.

2 Consider how airlines cope with balancing capacity and demand. In particular, consider the role of yield management. Do this by visiting the website of a low-cost airline and for a number of flights price the fare being charged from tomorrow onwards. In other words, how much would it cost if you needed to fly tomorrow, how much if you needed to fly next week, how much if you needed to fly in two weeks, etc. Plot the results for different flights and debate the findings.

3 Calculate the OEE of the following facilities by investigating their use:

(**a**) A lecture theatre.
(**b**) A cinema.
(**c**) A coffee machine.

Discuss whether it is worth trying to increase the OEE of these facilities and, if it is, how you would go about it.

4 (**Advanced**) Read the supplement to this chapter on queuing theory. Visit an operation where queues form regularly and test out the validity of the queuing formulae used in the supplement to this chapter.

Notes on chapter

1 With thanks to Alistair Brandon-Jones of Warwick Business School and staff at Britvic National Distribution Centre.
2 Sources: Ashworth, J. (2002) 'Met Office Brings Sunshine to the Shops', *The Times*, 17 August. *The Economist* (2002) 'And Now Hear is the Health Forecast', 3 August. Jackson, H. (2002) 'Weather Derivates are Hot', *Wall Street Journal Europe*, 13 February.
3 With special thanks to Philip Godfrey and Cormac Campbell of OEE Consulting Ltd (www.oeeconsulting.com).
4 Sources: Lynch, P. (1991) 'Making Time for Productivity', *Personnel Management*, March; and Pickard, J. (1991) 'Annual Hours: A Year of Living Dangerously', *Personnel Management*, August.
5 Sources include Robinette, S. (2001) 'Get Emotional', *Harvard Business Review*, May.
6 Kimes, S. (1989) 'Yield Management: A Tool for Capacity-constrained Service Firms', *Journal of Operations Management*, Vol. 8, No. 4.
7 Maister, D. (1983) 'The Psychology of Waiting Lines', *Harvard Business Review*, January–February.

Selected further reading

Brandimarte, P. and Villa, A. (1999) *Modelling Manufacturing Systems: From aggregate planning to real time control*, Springer, New York. Very academic although it does contain some interesting pieces if you need to get 'under the skin' of the subject.

Buxey, G. (1993) 'Production Planning and Scheduling for Seasonal Demand', *International Journal of Operations and Production Management*, Vol. 13, No. 7. Another academic paper but one that takes an understandable and systematic approach.

Fisher, M.L., Hammond, J.H. and Obermeyer, W. (1994) 'Making Supply Meet Demand in an Uncertain World', *Harvard Business Review*, Vol. 72, No. 3, May–June.

Hopp, W.J. and Spearman, M.L. (2000) *Factory Physics* (2nd edn), McGraw-Hill, New York. Very mathematical indeed, but includes some interesting maths on queueing theory.

Vollmann, T.W., Berry, D.C., Whybark, F.R. and Jacobs, F.R. (2004) *Manufacturing Planning and Control Systems for Supply Chain Management: The Definitive Guide for Professionals*, McGraw-Hill Higher Education. The latest version of the 'bible' of manufacturing planning and control. It's exhaustive in its coverage of all aspects of planning and control including aggregate planning.

Useful websites

http://www.dti.gov.uk/er/index Website of the Employment Relations Directorate which has developed a framework for employers and employees which promotes a skilled and flexible labour market founded on principles of partnership.

http://www.worksmart.org.uk/index.php This site is from the Trades Union Congress. Its aim is 'to help today's working people get the best out of the world of work'.

http://www.eoc-law.org.uk/ This website aims to provide a resource for legal advisers and representatives who are conducting claims on behalf of applicants in sex discrimination and equal pay cases in England and Wales. The site covers employment-related sex discrimination only.

http://www.dol.gov/index.htm U.S. Department of Labor's site with information regarding using part-time employees.

http://www.downtimecentral.com/ Lots of information on operational equipment efficiency (OEE).

www.opsman.org Definitions, links and opinion on operations management.