III	**Planning Resources and Controlling Material Flow:** Types of Planning Capacity Planning - Adjusting Capacity - Tactical Planning - Short-term Schedules- Material Requirements Planning -Extending the Role of MRP -Principles of Just-in-time -Achieving Just-in-time Operations -Extending JIT Along the Supply Chain	09

Planning Resources

- DISCUSS the role of planning in logistics
- MEASURE the capacity of a supply chain
- USE a standard approach to capacity planning
- DISCUSS some practical difficulties with capacity planning
- SEE how to design medium-term tactical plans
- EXPAND the tactical plans into short-term schedules

TYPES OF PLANNING

All activities have to be planned – which means that we design timetables to show when they will be done. Delivery plans, for example, might show the planned schedules for deliveries over the next month. If an organisation does not plan for the future, it can only work from hour-to-hour, without any continuity, and in constant danger of meeting unexpected circumstances that it cannot cope with. Planning lets us face the future with some confidence, rather than descending into chaos.

Planning the supply chain starts with the logistics strategy, which gives the overall aims. More details are added, and we get long-term plans which show how these aims will be achieved. These plans are, in turn, expanded with more details added. **The plans move down through the organisation, where they are continually expanded and described in more detail.**

You can see this approach to planning in **Capital Trains Corporation**. Their **business strategy gives a general description of their products,** which provide public transport around Washington. The logistics strategy shows how they run a network of train services for commuters. The **next level of planning forecasts demand for these services**, and then makes sure that there is enough capacity to meet this. In other words, they buy enough trains and hire enough staff to meet forecast demand. Then they move on to **more detailed plans, which give their timetable of services,** saying which routes their trains will serve and when they will arrive. Capital then expand these timetables into **detailed schedules** for individual trains and drivers, inspectors, materials, and any other resources they need.

As you can see, Capital Trains move down from strategic policies, through capacity plans, medium-term schedules of operations, and on to detailed timetables for all their resources. This is the usual approach to all planning (shown in Figure 6.1). People use different terms to describe these levels of planning, but the most common are:

- **Capacity plans,** which make sure there is enough capacity to meet long-term demand.
- **Aggregate plans,** which give summaries of the work done in related activities, typically by month at each location.
- **Master schedules**, which show a detailed timetable for all activities, typically by week.
- **Short-term schedules**, which show detailed timetables for jobs and resources, typically by day.

In this section, we look at each of these in turn.

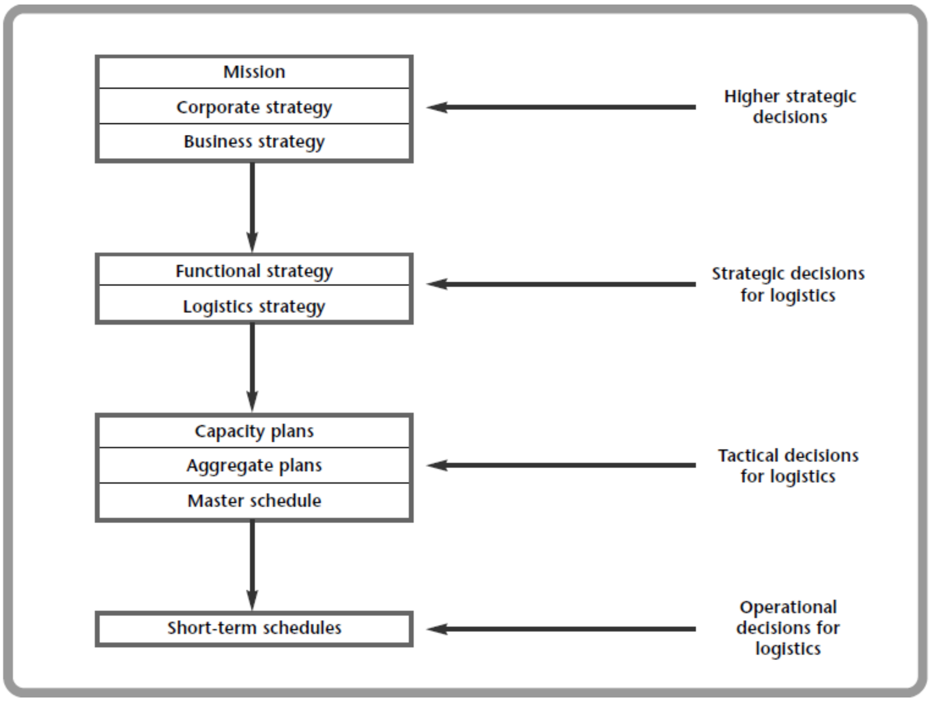


Figure 6.1 An approach to planning logistics

CAPACITY PLANNING

Definitions

The capacity of an operation is its maximum throughput in a specified time. All operations have some limit on their capacity: a factory has a maximum number of units it can make a week, a university has a maximum intake of students; an aeroplane has a maximum number of seats, and a lorry has a maximum weight it can carry. Sometime the stated capacity has an explicit reference to time, such as a maximum number of customers that can be served in a day. Even when it is not mentioned explicitly, every measure of capacity refers to time. The number of seats on an aeroplane sets the capacity as a maximum number of passengers on a particular flight; the number of rooms in a hotel sets the maximum number of guests who can stay each day.

Sometimes the capacity seems obvious – such as the number of seats on a bus or volume of a tanker. At other times the capacity is not so clear. How, for example, can you find the capacity of a supermarket, airport or train network? The usual answer has a surrogate measure, such as the maximum number of customers per square metre of floor space in a shopping mall, or the minimum distance between planes. Such measures come from discussion and agreement rather than any physical limit.

Capacity is an important concept for logistics, as it defines the maximum flow through the supply chain in a given time.

The **CAPACITY** of a supply chain sets the maximum amount of product that can be delivered to final customers in a given time.

Most organisations do not like to work at full capacity, as this puts pressure on resources and people. Instead they work at a lower level that they can sustain over time. We allow for this disparity by defining different kinds of capacity. If you imagine a supply chain that is working in ideal conditions with no disruptions or problems of any kind, then the maximum throughput is its **designed capacity**. In reality, you seldom find such ideal conditions, and a more realistic measure is the **effective capacity**. This is the maximum throughput that can be sustained under normal conditions, and allows for disruptions, variations in performance, breakdowns, maintenance periods, and so on.

DESIGNED CAPACITY is the maximum possible throughput in ideal conditions.

EFFECTIVE CAPACITY is the maximum realistic throughput in normal conditions.

ACTUAL THROUGHPUT is normally lower than effective capacity.

Bottlenecks

Not all parts of a supply chain have the same capacity. There must be some part that limits overall throughput, and this forms a bottleneck. If you want to move some bulky materials from Johannesburg to Amsterdam, you might find a bottleneck at the docks in Cape Town. This part of the supply chain is working at full capacity, but other parts have spare capacity that is not used. The bottlenecks in a supply chain limit its overall capacity (as shown in Figure 6.2).

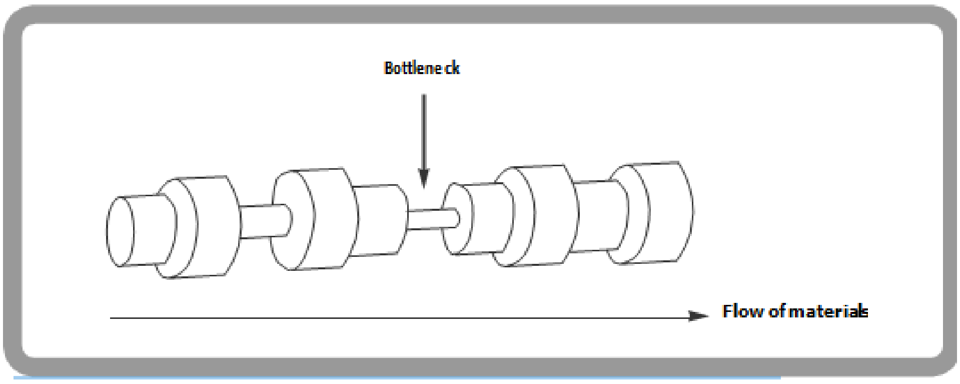


Figure 6.2 The bottleneck of a supply chain limits the capacity

It is obvious that you can only increase the capacity of a supply chain by adding more capacity at the bottleneck. Unfortunately, you often see cases where this is not done. Transport companies, for example, that recruit more managers to give leadership, when they are actually short of drivers; bus stations increase the size of waiting rooms, when congestion in the arrivals bay is limiting the number of buses; airlines using bigger aeroplanes when passenger terminals are already over-crowded. Identifying and overcoming bottlenecks is clearly not as easy as it seems.

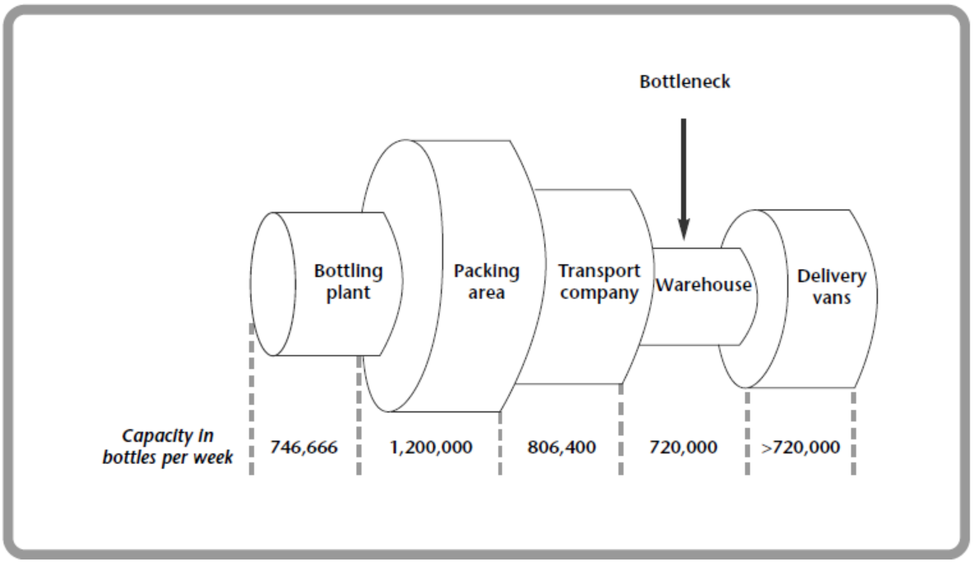


Figure 6.3 Capacity of distribution at J&R Softdrinks

Matching capacity and demand

The aim of capacity planning is to match the available capacity of facilities to the demands put on them. Any mismatch can be expensive. If capacity is less than demand, bottlenecks restrict the movement of materials, and customer service declines; if capacity is greater than demand, the organisation can move all its materials but it has spare capacity and underused resources.

You can see these effects in shops. When you go into some shops there are not enough people serving and you have to wait. The capacity of the shop is less than demand, and you probably go to a competitor where the queues are shorter. In other shops there are many people waiting to serve customers – so there are no queues, but the cost of paying these underused people is added to your bill.

Thankfully, there is a standard approach to capacity planning that we can illustrate in the following worked example.

The **main steps in capacity planning** find the resources needed, compare these with the resources available, and then look at alternative plans for overcoming any differences. To be more specific, we:

1. examine forecast demand and translate this into a capacity needed
2. find the capacity available in present facilities
3. identify mismatches between capacity needed and that available
4. suggest alternative plans for overcoming any mismatch
5. compare these plans and find the best
6. implement the best and monitor performance.

This is a standard approach to all kinds of planning, which is sometimes called **resource requirement planning.** Unfortunately, taking the steps in this straightforward sequence does not usually work. There can be a huge number of potential plans to consider, and it is impossible to look at them all in detail. It is also difficult to compare the alternatives, as there may be competing objectives and non-quantifiable factors. A more realistic view replaces the single procedure with an iterative one. This designs a plan and sees how close it gets to achieving its objectives; if it performs badly, the plan is modified to find improvements. In effect, steps 4 and 5 are repeated until they give a reasonable solution. This iterative procedure recognizes that it is rarely possible to find the single 'best' plan, and we are really looking for one that is generally accepted.

ADJUSTING CAPACITY

Problems with capacity planning

There are **several practical problems with capacity planning**. For example, where demand comes in small quantities and can take almost any value, while capacity comes in large discrete amounts. Typically, capacity can be increased by opening another shop, employing another person, using another vehicle, building another warehouse, and so on.

Suppose that the throughput of a supply chain rises steadily over time. Capacity should be increased at some point, but the increase will come as a discrete step. There is no way of exactly matching the discrete capacity to a continuous demand, so we have to use one of three basic strategies (as shown in Figure 6.4).

(a) more or less match capacity to demand, so that there is sometimes excess capacity and sometimes a shortage
(b) make capacity at least equal to demand by early expansion, which needs more investment in facilities and gives lower utilisation

(c) only add capacity when the additional facilities would be fully used, which has lower investment and high utilisation, but restricts throughput.

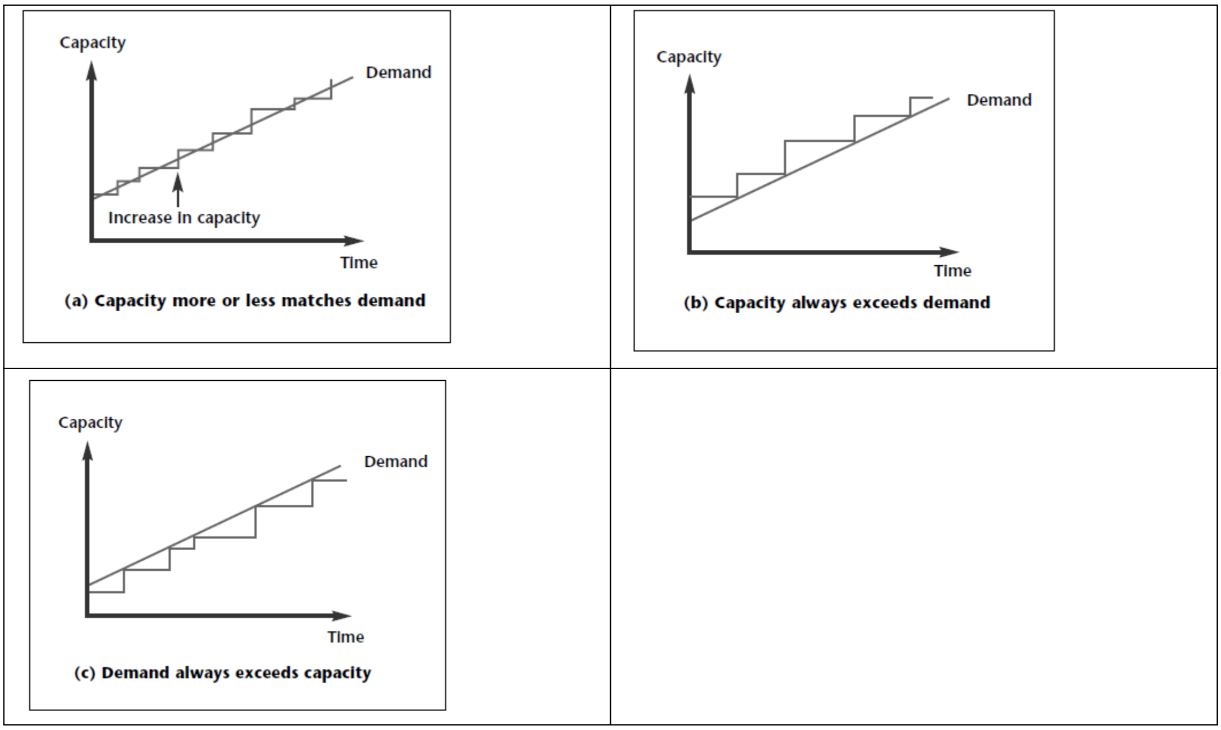


Figure 6.4 Alternative timing of capacity expansion

Each of these strategies is best in different circumstances. Factors that encourage an **early increase in capacity** include high cost of shortages, widely variable demand, varying efficiency, and low cost of spare capacity. The capacity of a large furniture shop, such as MFI, is largely set by the number of sales people. The nature of demand and relative costs, mean that the shop is likely to increase capacity early and make sure that there are always enough staff to serve customers. The main **factor that encourages a delay before increasing capacity** is the capital cost. New motorways are expensive and controversial, so expansions are delayed for as long as possible, and they are crowded as soon as they open.

A related question about changing capacity concerns the size of any changes. If you want to hire four new people over the next few months, should you recruit them all in one big campaign, or is it better to add them in smaller steps. Any change in capacity is likely to cause some disruption, so it might be better to have a few large increases rather than more smaller ones (as shown in Figure 6.5).

The benefits of large increases include longer periods without disruptions, less risk of not meeting unexpected demand, and the expansion might give economies of scale. On the other hand, there is not such a close match to demand, disruptions may be more serious, capital costs are higher, utilisation is low, and there are risks if demand changes.

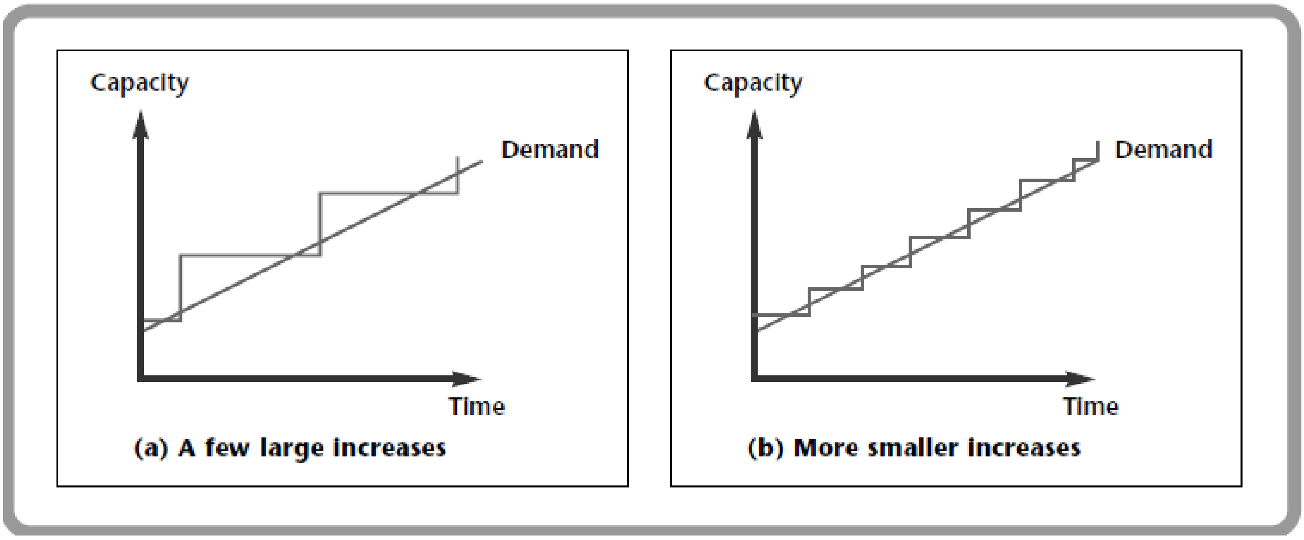


Figure 6.5 Alternative size of capacity expansion

Short-term adjustments to capacity

Capacity planning is largely a strategic function. **Organisations can increase the overall capacity** of a supply chain by opening a warehouse, designing a new process, opening new offices, or moving to a new location. They **can reduce excess capacity** by closing warehouses, shutting down a plant, or transferring facilities to other products. These are strategic decisions with long-term consequences. But **an organisation can also adjust capacity by leasing** extra space, working overtime, employing temporary staff, or sub-contracting parts of their work.

These are clearly tactical and operational decisions. It is fairer to say, then, that capacity plan- ning includes decisions at all levels; strategic plans give the overall picture, modified by shorter term adjustments.
There are two ways of making these short-term adjustments to capacity:

- **capacity management** adjusts capacity to match demand
- **demand management** adjusts demand to match available capacity.

Imagine a wholesaler that runs a 12,000 square metre warehouse. This sets the normal capacity. If there is a temporary increase in business because of orders from a nearby construc- tion site, the wholesaler can use capacity management and rent extra space for the duration of the construction project. Alternatively, there may be some reason why the wholesaler does not want to increase capacity, so it can **use demand management to increase prices and reduce demand to match the existing capacity.**

An obvious way of making short-term adjustments to capacity is to change the hours worked, by working overtime to increase capacity or undertime to reduce it.
Ways of adjusting capacity include:

- *changing the work pattern* to match demand
- *employing part-time staff* to cover peak demands
- *using outside contractors*
- *renting or leasing extra facilities*
- *adjusting the speed of working*
- *rescheduling maintenance periods*
- *making the customer do some work*, such as packing their own bags in supermarkets.

Such adjustments cannot be done too often or too severely, as they can have significant effects on employees, operations and customers. The alternative is to **adjust demand,** and the obvious way of doing this is to **change the price.** There is, however, only a certain amount of flexibility here. Prices must be high enough to cover costs, low enough to be competitive, and not change too many times to confuse customers.
Ways to adjust demand include:

- *vary the price*
- *limit the customers served*, by demanding specific 'qualifications'
- *change the marketing effort*
- *offer incentives to change demand patterns*, such as off-peak travel rates
- *change related products to encourage substitution*, such as holiday destinations
- *vary the lead time*
- *use a reservation or appointment system*
- *use stocks to cushion demand.*

Changing capacity over time

So far we have assumed that capacity is constant over time. In practice, the effective capacity of a supply chain can change quite markedly. Even if there are no changes to the operations, there are short-term variations due to staff illness, interruptions, breakdowns, weather, enthusiasm of employees, and so on. Imagine a group of people moving heavy materials about a warehouse. At the end of an eight-hour shift they will be tired and their effective capacity will be much lower than at the beginning of the shift, even though there has been no change to their work.

There are, however, other more systematic changes in capacity. One of the most obvious is the effect of a **learning curve**. The more often you repeat something, the easier it becomes and the faster you can do it (as shown in Figure 6.6). A common shape for a learning curve has the time taken to do an operation falling by a fixed proportion – typically around 10% – every time the number of repetitions is doubled. If you take 10 minutes to do a job for the first time, the second time takes only 90% of this, or 9 minutes; the fourth time takes 90% of the time for the second repetition, and so on. The following table shows the times for repetitions with this '90% learning curve'.

Number of repetitions	Time for the last (mins)
1	10.0
2	9.0
4	8.1
8	7.29
16	6.56
32	5.90
64	5.31
128	4.78

Another **reason for systematic changes** in capacity comes from **ageing equipment and facilities.** As equipment gets older its effective capacity declines as it breaks down more often, develops more faults, gives lower quality, slows down, and generally wears out. Sometimes the changes are slow – like the fuel consumption of a car, which rises steadily with age. Sometimes the change is very fast, like a bolt, which suddenly breaks.

This declining performance is by no means inevitable, and there are many things – ranging from mobile telephones to tea services – whose performance stays the same for long periods.

Even if performance does decline, there are ways of slowing its effects, such as **preventive maintenance** and rational **replacement policies**.

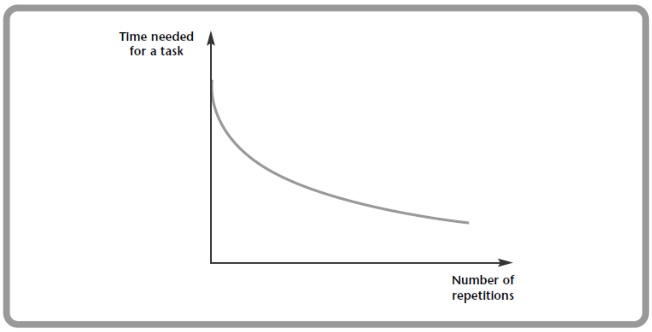


Figure 6.6 A typical learning curve

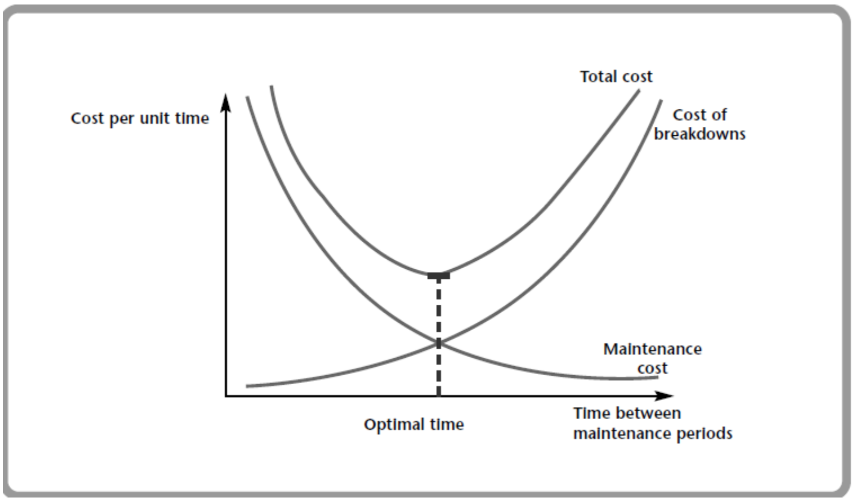


Figure 6.7 Cost of maintenance

With preventive maintenance, equipment is inspected and vulnerable parts are replaced after a certain period of use. By replacing bits that are worn – or are most likely to wear – the equipment is restored to give continuing, satisfactory performance. But how often should we do this maintenance? If it is done too often, the equipment runs efficiently but the mainte- nance costs are too high; if it is not done often enough, the maintenance costs are low but the equipment still breaks down. One way of finding the best compromise is to add together the costs of maintenance and expected failure. If we plot these against the frequency of mainte- nance, we get a U-shaped curve that has a distinct minimum. This minimum cost shows the best time between maintenance periods (as shown in Figure 6.7).

Even with regular maintenance there comes a point when repairs become too expensive and it is cheaper to buy new equipment. These replacement decisions can be expensive when building, say, a new logistic centre or shopping mall. There are many ways of tackling replace- ment decisions, but a common one extends the approach of preventive maintenance. In other words, we add the cost of operating equipment over a number of years and divide this by the age at replacement to give an average annual cost.

TACTICAL PLANNING

Aggregate plans

Tactical plans bridge the gap between longer term strategic plans and operational details. They show how the capacity will be used, and develop medium-term timetables for activities. Different names are used for this level of planning, but the most common are **aggregate plans** and **master schedules**.

Aggregate planning takes the forecast demand for logistics and uses this to design plans for each type of activity for, typically, each of the next few months. Suppose that Proctor Trans- port forecasts demand of 800 tonnes of materials to be delivered to Scandinavia over the next year. Capacity plans make sure that there are enough resources to deliver this. Then aggregate plans design an outline schedule for resources, perhaps planning deliveries of 100 tonnes in each of the first eight months. Aggregate plans only look at families of activities and are not concerned with details. They might show the number of cases moved through a logistics centre, but do not break this down into types of case or contents.

AGGREGATE PLANNING makes the tactical decisions that translate forecast demand and available capacity into schedules for families of activities.

Aggregate plans try to meet forecast demand, while using capacity as efficiently as possible. They typically aim at **low costs, high customer service, stable throughput, full utilisation of resources, or some other objectives.** To achieve this, they can adjust the values of several variables. They may, for example, change the number of people employed, the hours worked, the amounts of stock, the amount subcontracted, demand, and so on.

Essentially, aggregate planners are looking for answers to questions, like:

- Should we keep throughput at a constant level, or change it to meet varying demand?
- How should we use stocks to meet changing demand?
- Should we vary the size of the workforce with demand?
- Can we change work patterns to meet changing demand?
- Should we use subcontractors or outside organisations to cover peak demands?
- Can we allow shortages, perhaps with late delivery?
- Can we smooth the demand?

At the end of the aggregate planning, an organisation has schedules for its major types of activity, typically for each month, at each location. The next stage is to add more detail, and this is done in the **master schedules**.

A master schedule 'disaggregates' the aggregate plan and shows the planned

activities for, typically, each week over the next few weeks. The aggregate plan of Proctor Transport might show deliveries of 100 tonnes to Scandinavia next month. Then the master schedule gives more details, perhaps showing 2 deliveries of 9 tonnes to Denmark in week one, 3 deliveries of 7 tonnes to Sweden in week two, and so on.

> The **MASTER SCHEDULE** gives a timetable for activities, typically for each week. Its aim is to achieve the activities described in aggregate plans as efficiently as possible.

Overall approach of tactical planning

Master schedules are more detailed than aggregate plans, so they tend to be more complicated and messy. For both of them, however, we can use the general procedure that we described earlier as **resource requirement planning.** Remember that this has six steps:

Step 1 translate forecasts and other information into a demand for resources
Step 2 find the resources currently available
Step 3 identify mismatches between resources needed and available
Step 4 suggest alternative plans for overcoming any mismatches
Step 5 compare these plans and find the best
Step 6 implement the best plan and monitor performance.

We can use this approach (which is illustrated in Figure 6.8) for all types of planning. Remember that steps 4 and 5 are usually repeated until a reasonable solution is found. This iterative adjustment can be done many times, but it must stop at some point when the plans become final. At this point, the planners can move on to the next level of detail.

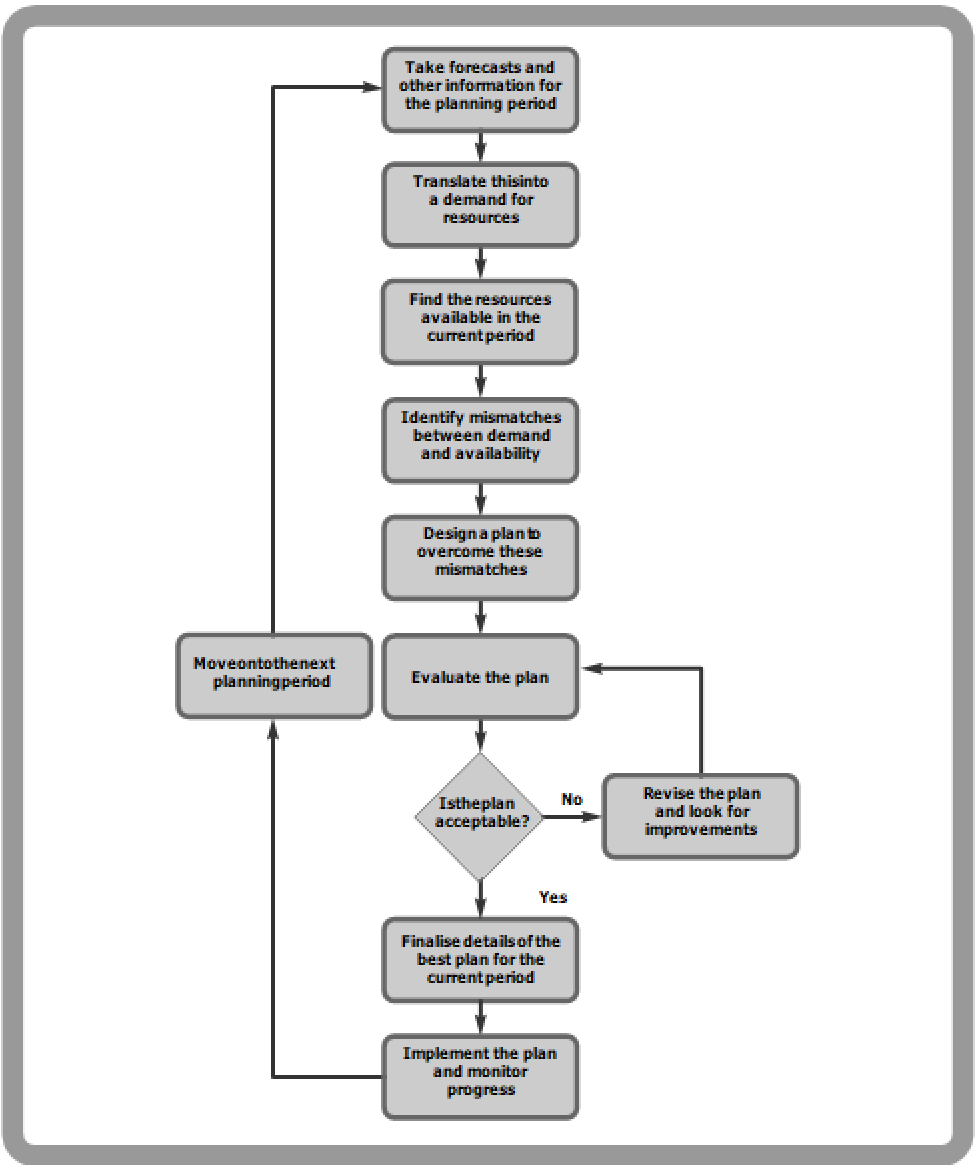


Figure 6.8 An iterative approach to planning

Generating alternative plans

The last worked example illustrates the general approach of planning, but you can see that there are many practical difficulties. One of the most important concerns the way that alter- native plans are generated and compared. There are usually so many possible plans that we cannot even list them all, let alone compare their merits. There are also so many competing objectives and non-quantifiable factors that it is difficult to find any plan that satisfies everyone, let alone identify the 'best'.

There are many ways of generating alternative plans, ranging from simple intuition

through to sophisticated mathematical models. The most appropriate depends on several factors, the most obvious being the balance between the cost of planning and the expected benefits. If you are moving huge quantities of oil in tankers and pipelines, costs are high and it is worth putting a lot of effort into a sophisticated model that guarantees good results. On the other hand, a small business is unlikely to have the resources for this, and will use a simple method that will give reasonable results with a lot less effort.

The following list shows the most common methods of generating plans.

1. *Negotiations:* Planning is so complicated that the best approach is often to negotiate a solution among the people most closely concerned. This may not give the best technical answer, but it should have the support of everyone concerned.

2. *Adjust previous plans:* Demands on logistics may not change much from one period to the next, so a useful approach is to take previous plans that worked successfully and update them in the light of current circumstances. This has the benefit of being relatively easy and giving stable operations. Unfortunately, the results can be of variable quality, they may take a long time to design, and they rely on the skills of the planner.
3. *Other intuitive methods:* These include a range of methods that rely on the skills, knowledge and experience of planners. They typically use a series of heuristic rules that have been successful in the past.

4. *Graphical methods:* Planners often find it easier to work with some kind of graphs or diagrams. A popular format uses a graph of cumulative demand over time, and the corresponding line of cumulative supply. The aim is to get the cumulative supply line nearly straight – giving constant throughput – and as close as possible to the cumulative demand line (as shown in Figure 6.9). There are many different formats for such diagrams.

5. *Spreadsheet calculations:* One of the most popular approaches to planning uses spread- sheets. Data can be presented in a variety of formats that show the effects of plans, and they can be easily manipulated in a series of ‘what-if’ analyses.

6. *Simulation:* Simulation imitates real operations over some typical period. Suppose you want some information about a logistics network; you could simply stand and watch the network for some time to see what was happening. Unfortunately, this takes a long time to get results and things may not work normally while you are watching. An alternative is to simulate the process, based on a computer model of the network. Once this has been designed, the computer can generate typical jobs and follow their progress through the model, so that any number of real situations can be simulated.

7. *Expert systems:* These specialised programs allow computers to duplicate the methods of skilled planners. The basic skills, expertise, decisions and rules used by experts are collected in a knowledge base. A user of the system passes a problem to an inference engine, which analyses the problem, relates this to the knowledge base and decides which rules to use for a solution. Expert systems have been developing for many years, and a growing number of organisations report useful results.

8. Mathematical models: Most of the approaches we have described so far rely, at least to some extent, on the skills of a planner. More formal mathematical approaches give optimal solutions without any human intervention. The most common approach uses mathematical programming. This can be complicated and needs considerable expertise. In practice, aggregate plans include so many subjective and non-quantifiable factors, that optimal solutions in the mathematical sense do not necessarily give the best answers for the organisation.

Planning cycles

As you can see from Figure 6.8, planning is not a job that is done once and is then finished. It is continuous, and as plans for one period are finalised and implemented, planning moves on to the next period. The usual way of organising this is to work on plans for several periods at the same time; plans for the near future are fixed, while those for the more distant future are still tentative. Planning is then done in cycles. In one cycle an organisation might finalise plans for the next period and make provisional plans for the following period, and outline plans for the period after that. This gives the pattern of planning shown in Figure 6.10.

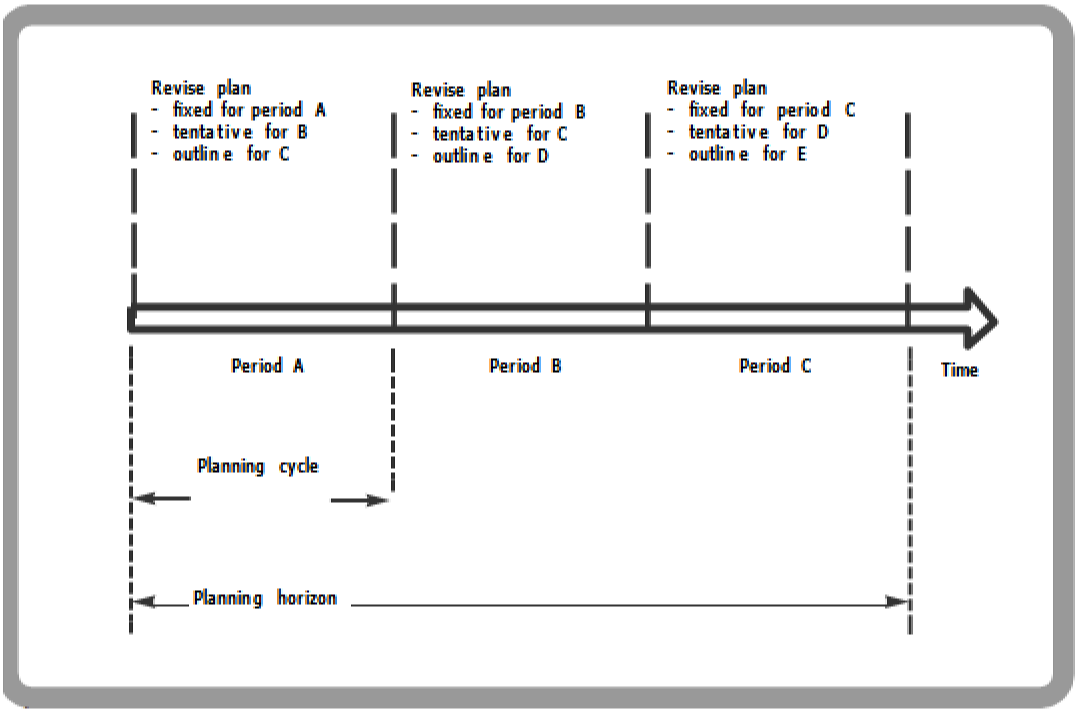


Figure 6.10 Revision of plans during cycles

It is difficult to generalise, but strategic plans might cover the next four years and be updated annually; aggregate plans might cover the next year and be updated every quarter; master schedules may cover the next three months and be updated monthly. This pattern of repeated cycles actually makes planning a lot easier. Most operations are relatively stable, so the plans for one period can be used as the basis for plans in following periods.

SHORT-TERM SCHEDULES

Definitions

The master schedule gives a timetable for different activities, typically for each week. But this is not the end to planning, as we still have to design detailed timetables for jobs, equipment, people, materials, facilities and all other resources that are needed by the master schedule. This is the purpose of short-term scheduling.

SHORT-TERM SCHEDULES give detailed timetables for jobs, people, materials, equipment and all other resources.

Short-term schedules give the sequences of activities, and the times when they should be done. 'Sam the Fridge' runs a repair service and his daily schedule lists the customer to visit (with the order and time of each job) and the resources needed (the repair people, tools, spare parts, vans and so on needed for the jobs). The aim of these schedules is to organise the resources needed for the master schedule, giving low costs, high utilisations, or achieving some other measure of performance.

Designing these operational schedules is one of the most common problems in any organisation. As it is so common, **you might think that short-term scheduling is easy – but in practice it is notoriously difficult**. To start with there are so many possible schedules to consider. Imagine that you have ten jobs that you must finish today. In how many different ways can you arrange the ten jobs? You can choose the first job as any one of the ten; then the second job can be any one of the remaining nine, the third job can be any one of the remaining eight, and so on. This gives the number of possible schedules as:

$10 \times 9 \times 8 \times 7 \times 6 \times 5 \times 4 \times 3 \times 2 \times 1 = 3,628,800$

If you have a real problem with hundreds or thousands of jobs, you have a huge number of possible schedules to consider. Each of these has different features, and performs well by some criteria, but badly by others. You have to balance each type of performance, and take into account the complications of real problems, such as the amount and type of equipment, number and skills of people assigned to jobs, materials needed, patterns of work flow through equipment, different priority of jobs, objectives of the schedulers, and so on.

The result is that apparently simple scheduling jobs are actually very difficult to solve. Eilon et al.1 noted that this type of problem 'has become famous for its ease of statement and great difficulty of solution'.

Approach to scheduling

You can imagine a typical scheduling problem in terms of a set of jobs waiting to use equipment. You want to organise the jobs to achieve some objective. The master schedule shows when jobs have to be finished, so the short-term schedules must take these dates into account. There are two ways of doing this:

- *Backward scheduling*, where schedulers know when a job has to be finished. Then they can work back through all the activities to find the date when the job must be started.
- *Forward scheduling*, where schedulers know when a job can start. Then they can work forward through all activities to find the date when the job will be finished.

Suppose you are giving a talk in three weeks time and want some photographs to illustrate this. It will take one week to prepare the photographs. With backward scheduling you know that the photographs must be ready in three weeks, so you can prepare them in two weeks time. With forward scheduling, you prepare the photographs as early as possible – starting now and finishing next week.

These two approaches suggest general principles, but we need some way of finding the best order for jobs. The available methods are basically variations on the list given above for tactical plans, and range from negotiation through to mathematical programming. The more complicated methods are usually too difficult and time-consuming for short-term schedules, and most organisations use simple methods, often based on **scheduling rules**. You see an example of a scheduling rule in banks which schedule customer service at their tellers in the order 'first come, first served'.

If you have a number of jobs waiting to use a single piece of equipment, the total processing time is fixed regardless of the order in which the jobs are scheduled (providing the set-up time for each job is constant, regardless of the job that was done previously). But the order of taking jobs does change other measures of performance. You can see this in the following four scheduling rules.

1. *First come, first served:* This is the most obvious scheduling rule and simply takes jobs in the order they arrive. It assumes no priority, no urgency, or any other measure of relative importance. Its drawback is that urgent jobs may be delayed while less urgent ones are being processed.

2. *Most urgent job first:* This rule assigns an importance, or urgency, to each job and they are processed in order of decreasing urgency. Emergency departments in hospitals, for example, treat those who are most seriously in need first. The benefit of this rule is that more important jobs have higher priority. Unfortunately, jobs that have low priority may be stuck at the end of a queue for a very long time.

3. *Shortest job first:* A useful objective is to minimise the average time spent in the system, where:

   time in the system = processing time + waiting time

   If a job needs one day of processing but it waits in the queue for four days, its time in the system is five days. Taking the jobs in order of increasing duration minimises the average time spent in the system. It allows those jobs that can be done quickly to move on through the system, while longer jobs are left until later. The disadvantage is that long jobs can spend a long time waiting.

4. *Earliest due date first:* This sorts jobs into order of delivery date, and the ones that are due earliest are processed first. This has the benefit of minimising the maximum lateness of jobs, but again some jobs may wait a long time.

REVIEW OF RESOURCE PLANNING

- The logistics strategy gives the general shape of the supply chain. After this, tactical and operational plans are needed to manage the flow of materials. Planning is essential, as it gives timetables for all the activities and resources in the supply chain.
- Capacity is an important feature of a supply chain, as it sets the maximum amount of products that can be delivered to final customers in a given time. The capacity of the whole chain is set by a bottleneck.
- Capacity planning matches the available capacity to demand. Resource requirement planning gives a standard procedure which iteratively searches for a reasonable solution.
- There are many practical difficulties with organising the capacity, including discrete capacity size and changing capacity over time.
- Capacity plans focus on the longer term, but with shorter term adjustments. They set the scene for more detailed tactical and operational planning.
- Tactical aggregate plans describe timetables for families of activities over the medium term. Master schedules add more details, giving plans for individual activities. Both of these can use the approach of resource requirement planning, with plans actually designed by different methods ranging from negotiation through to mathematical programming.
- Short-term schedules give timetables for the resources that support the tactical plans. The most common approach to short-term scheduling uses simple rules to get reasonable solutions

III	**Planning Resources and Controlling Material Flow:** Types of Planning Capacity Planning Adjusting Capacity Tactical Planning Shortterm Schedules Material Requirements Planning Extending the Role of MRP Principles of Justintime Achieving Justintime Operations Extending JIT Along the Supply Chain	09

Controlling Material Flow

AIMS OF THE CHAPTER

After reading this chapter you should be able to:

- DESCRIBE the distinctive approach of material requirements planning
- USE MRP to timetable orders and deliveries
- DISCUSS the benefits and disadvantages of MRP
- EXTEND the MRP approach along the supply chain
- DESCRIBE the principles of just-in-time operations
- DESIGN *kanban* systems for controlling JIT
- DISCUSS the benefits and disadvantages of JIT
- EXTEND JIT along the supply chain for efficient

MATERIAL REQUIREMENTS PLANNING

Introduction

In the previous chapter we described an approach to planning logistics based on resource requirement planning. This takes the logistics strategy and continually adds more details to get capacity plans, aggregate plans, master schedules and shortterm schedules. The result is a set of timetables showing what all the facilities, equipment, people and resources should do at any time.

This seems a reasonable approach, but it does have drawbacks. It is, for

example, fairly rigid and can be slow to react to changing conditions. If a customer urgently wants a delivery, we cannot tell them to wait until we fit them in to the next planning cycle. Another concern arises from the reliance on forecasts. Essentially planners take forecasts of demand for logistics, and then plan the supply to meet this. The problem, of course, is that forecasts are often wrong.

A way of getting around these problems is to match the supply of logistics to actual demand. In other words, we want some way of finding the known, actual demand rather than using unreliable forecasts. This might seem rather optimistic, but there are several circumstances when we know the actual demand in advance.

We can illustrate the first of these with **material requirements planning** (MRP). This uses the master schedule to give a timetable for the delivery of materials.

Dependent and independent demand

The conventional approach to planning assumes that overall demand for a product is made up of individual demands from many separate customers. These demands are independent of each other, so the demand from one customer is not related to the demand from another customer. If you are selling Nike shoes, the overall demand comes from hundreds of separate customers, all independently asking for a pair of shoes. This gives an **independent demand**, where planning is done using the standard methods we described in Chapter 6.

There are, however, many situations where demands are not independent. One demand for a product is not independent of a second demand for the product; or demand for one product is not independent of demand for a second product. When a manufacturer uses a number of components to make a product, the demands for all components are clearly related, since they all depend on the production plan for the final product. This gives **dependent demand**. The characteristic approach of MRP is that it 'explodes' a master schedule to plan the deliveries of related materials.

- **MATERIAL REQUIREMENTS PLANNING** uses the master schedule, along with other relevant information, to plan the supply of materials.
- It is used for dependent demand.

You can see the differences between the traditional approach and MRP in the way that restaurant chefs plan the ingredients for a week's meals. With the traditional approach, the chefs see what ingredients they used in previous weeks, use these past demands to forecast future demands, and then make sure there is enough ingredients in the pantry to cover these forecast demands. With the alternative MRP approach, chefs look at the meals they are going to cook each day, analyse these to see what ingredients they need, and then order the ingredients to arrive at the right time.

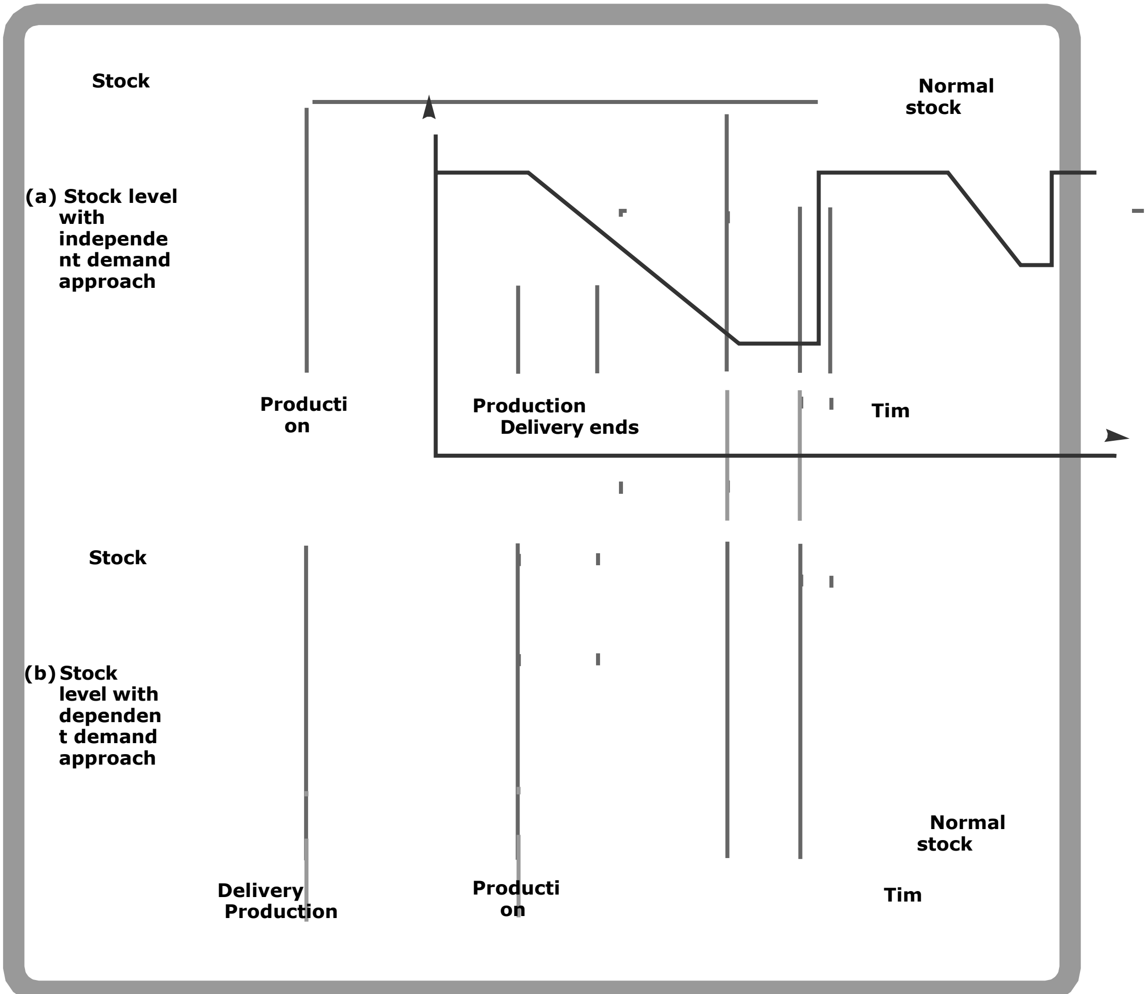


Figure 7.1 Comparison of stock levels

An important difference between the two approaches is the pattern of material stocks. With independent demand systems, stocks are not related to production plans so they must be high enough to cover any likely demand. These stocks decline during operations, but are soon replaced to give the pattern shown in Figure 7.1(a). With MRP, stocks are generally low but rise as orders are delivered just before operations starts. The stock is then used during production and declines to its normal, low level. This pattern is shown in Figure 7.1(b).

The MRP approach

MRP uses a lot of information about schedules, products and materials. This comes from three main sources:

master schedule, giving the number of every product to be made in every period

bill of materials, listing the materials needed for every product

inventory records, showing the materials available.

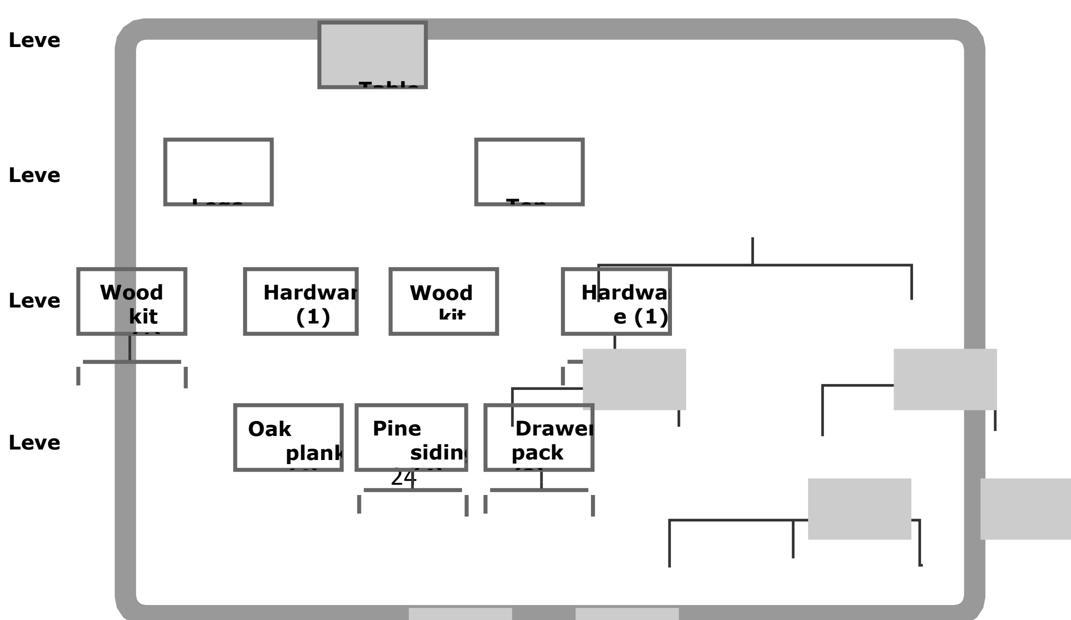
A bill of materials is an ordered list of all the parts needed to make a particular product. It shows the materials, parts and components – and also the order in which they are used. Suppose a company makes tables from a top and four legs. Then each top is made from a wood kit and hardware; the wood kit has four oak planks, side panels, and so on. The bill of mate rials for this is shown in Figure 7.2. You can see that every item has a 'level' number that shows where it fits into the process, and figures in brackets show the numbers needed to make each unit. The finished product is level 0; level 1 items are used directly to make the level 0 item, level 2 items are used to make the level 1 items, and so on.

A full bill of materials keeps going down through different levels until it reaches materials that the organisation always buys in from suppliers. By this time, there might be hundreds or even thousands of different materials. MRP uses this bill of materials, along with the master schedule, to get a timetable for the delivery of each of the materials.

Suppose a master schedule shows that the company plans to make 10 tables in February. It obviously needs 10 tops and 40 legs ready for assembly at the beginning of February. In practice, these are the **gross requirements**. The company may not have to order them all, as it may already have some in stock, or have outstanding orders that are due to arrive shortly. If we subtract these from the gross requirements we get the **net requirements** for materials. The company needs 40 table legs by the beginning of February, but if it already has 8 in stock and an order of 10 that is due to arrive in January, the net requirement is for 40 – 8 – 10 = 22.

Net requirements = gross requirements – current stock – stock on order

Figure 7.2 Part of a bill of materials for a table



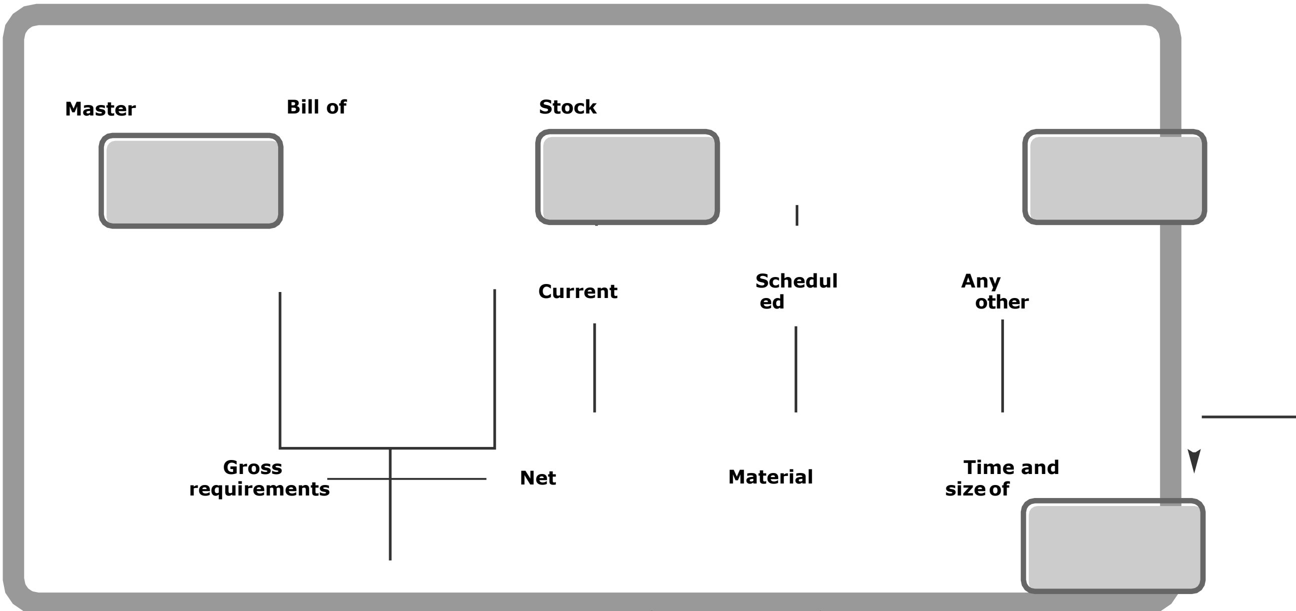


Figure 7.3 Summary of MRP procedure

Now we know the quantities to order, and when these orders should arrive. The next step is to find the time to place the order. For this we need the lead times – and we place orders this lead time before the materials are actually needed. If the company buys tabletops and legs from suppliers who give a lead time of four weeks, it needs to place orders at the beginning of January. These orders will arrive by the end of January just before assembly is due to start.

Finally, we have to consider any other relevant information, such as minimum order sizes, discounts, minimum stock levels, variation in lead time, and so on. When the company takes all of this into account it gets a detailed timetable for orders. This procedure is shown in Figure 7.3.

We can summarise this MRP procedure by the following steps:

- *Step 1:* Use the master schedule to find the gross requirements of level 0 items.
- *Step 2:* Subtract any stock on hand and orders arriving to give the net requirements for level 0 items. Then schedule production, with starting times to meet these net requirements.
- *Step 3:* Take the next level. Use the bill of materials to translate the net requirements from the last level into gross requirements for this level.
- *Step 4:* Take each material in turn and:

    subtract the stock on hand and scheduled deliveries to find the materials needed

    use the lead time and any other relevant information to give the size and timing of these orders.

Then if there are more levels of materials, go back to step 3.

- *Step 5:* Finalise the timetable, adding any specific adjustments.

Traditional, independent demand systems forecast likely demand for materials, and then hold stocks that are high enough to meet these. To allow for the inevitable errors in their forecasts, organisations hold more stocks than they really need. These extra stocks give a measure of safety, but they also increase the inventory costs. MRP avoids these costs by relating the supply of materials directly to demand. **Benefits that come from this direct link include**:

- lower stock levels, with savings in capital, space, warehousing, and so on
- higher stock turnover
- better customer service – with no delays caused by shortages of materials
- more reliable and faster delivery times
- less time spent on expediting and emergency orders
- MRP schedules can be used for planning other logistics activities.

MRP can also give early warning of potential problems and shortages. If the MRP schedules show that some materials will arrive too late, the organisation can speed up deliveries or change the production plans. In this way MRP improves the wider performance of the organisation – measured in terms of equipment utilisation, productivity, customer service, response to market conditions, and so on.

Disadvantages of MRP

There are also some problems with MRP, the most obvious being the amount of information and calculation that it needs. The basic information comes from a detailed master schedule, so MRP cannot be used when there is no master schedule, the master schedule is not designed far enough in advance, it is inaccurate and does not show what actually happens, or when plans are changed frequently.

Other requirements of MRP include a bill of materials, information about current stocks, orders outstanding, lead times, and other information about suppliers. Many organisations simply do not record this information. Others find that their information does not have enough detail, or is in the wrong format, or is not accurate enough. Accuracy is particularly important, as large numbers of small stock transactions can introduce errors. Ordinarily these errors are small enough not to matter, as there is enough stock to give cover until the errors are detected. MRP, however, does not have these reserve stocks, so there is no room for errors. Another problem with MRP is its inflexibility. The only materials available are those needed for the specified master schedule, so this cannot easily be adjusted. Some general disadvantages of MRP include:

- reduced flexibility to deal with changes
- needs a lot of detailed and reliable information
- systems can become very complex
- the order sizes suggested by MRP can be inefficient
- MRP may not recognise capacity and other constraints
- can be expensive and time consuming to implement.

EXTENDING THE ROLE OF MRP

Initial ideas

We have outlined the basic approach of MRP and now can look at ways of improving the results. For example, the basic procedure might suggest a series of small, frequent orders. It may be cheaper and more convenient to combine several of these small orders into one larger one. This is called **batching**. There are four common methods of batching:

1. **Lot for lot** – where you order exactly the net requirement suggested by MRP for each period. This has the advantage of minimising the amount of stock, but can give high ordering, delivery and administration costs.

2. **Fixed order quantity** – where you find an order size that is convenient, such as a truck load, a container load, or an economic order quantity (which we describe in Chapter 9). When you want a delivery, you always order this amount, and put any spare in stock.

3. **Periodic orders** – where you combine the requirements over some fixed period, and place regular orders for different quantities. You might, for example, place a weekly order for the amount of materials needed in the following week. Working to a regular timetable is simple and makes ordering routine.

4. **Batching rules** – which uses a specific procedure to calculate the best pattern of orders. Typically they look for the combination of orders that gives the lowest overall cost. In practice, this can be quite a difficult scheduling problem.

Another improvement comes when the same material is used for different products. Then we combine the demands from all products to give the overall gross requirement. Similarly, when several materials are ordered from the same supplier, it obviously makes sense to add them all to a single order. Now the batching rules have to extend to cover different products, and different materials from the same source.

A more significant extension to MRP adds feedback for planning. MRP uses the master schedule to generate orders for materials, and this schedule usually has some variation. But this variation can get magnified in the supply chain to give widely varying demands for upstream suppliers. Their operations may not be able to deal with this varying demand, particularly during the peaks. It is obviously better to anticipate such problems during the planning stage, so that schedules or capacity can be adjusted before the plans are finalised. In other words, we introduce feedback from MRP to capacity planning. This linking of capacity planning to MRP is called **capacity requirements planning**. Overall systems with feedback of this kind are called **closedloop MRP**, with one system summarised in Figure 7.4.

Moving to MRP II

You can see how capacity requirements planning extends the MRP approach further into the organisation. We started by using MRP to schedule the delivery of materials, and can now use it in capacity planning. But we need not stop here. Materials are only one resource, and organisa tions have to schedule others, including people, equipment, facilities, finances, transport, and so on. Surely we can use the same MRP approach to consider these other resources. This thinking has led to a major extension of MRP into Manufacturing Resources Planning, or MRP II.

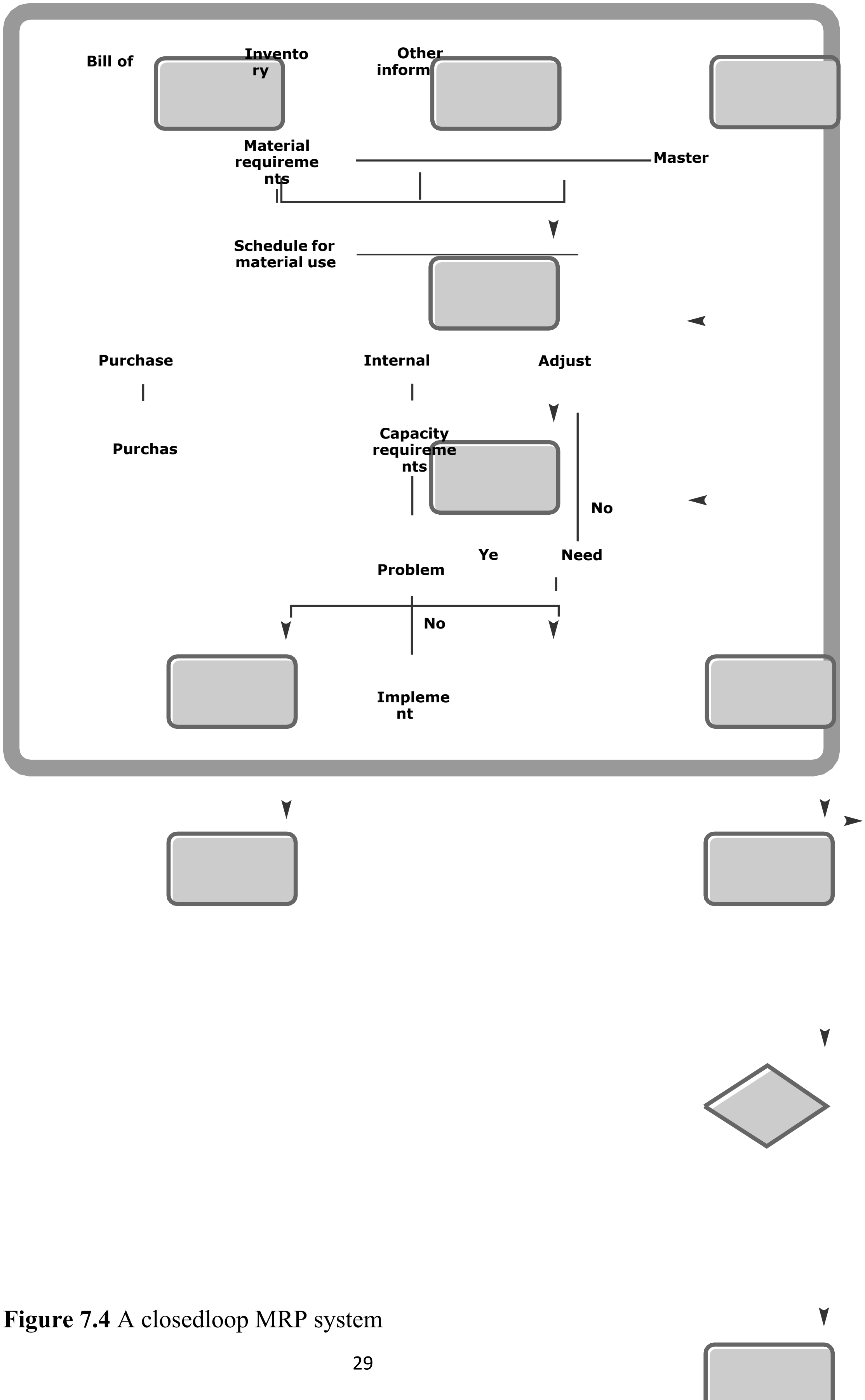


Figure 7.4 A closedloop MRP system

Imagine an organisation that uses MRP to get a timetable for purchasing materials and preparing materials internally. If it knows when the internal materials have to be ready, it knows when to start preparing them. In other words, MRP can give schedules for the production of components. But we can use the schedules for components to get timetables for production equipment, people working on it, raw materials, and other resources. And if we know when the raw materials are needed, we can schedule inward transport, drivers, quality checks, and so on. Continuing in this way, we could build an integrated system that would 'explode' the master schedule to give timetables for all the jobs, equipment, operators, machines, and facilities needed to achieve it.

With this approach, MRP would schedule all the operations. However, there is no reason why we should stop there, and we could look at the associated finance, marketing, sales, human resource management, and so on. Eventually we would get a completely integrated system that would use the master schedule as the basis for planning all the resources in an organisation. This is the aim of MRP II.

- **MRP II** gives an integrated system for synchronising all functions within an organisation.
- It connects schedules for all functions and resources back to the master schedule.

Linking all activities to the master schedule can give very efficient logistics. There are no late deliveries or shortages, no stocks of work in progress accumulate, and products move smoothly through the whole process. These benefits have encouraged many organisations to move towards MRP II. Unfortunately, there can be serious practical difficulties. To start with, it is difficult to get schedules that everyone accepts as being good and workable. A more serious problem, though, is the difficulty of integrating all functions and systems. Many organisations have asked if the rewards from such close integration are worth the effort. MRP tends to be inflexible, so a whole organisation run in this way might become cumbersome, unwieldy, slow to respond to changing conditions.

Because of these difficulties, many organisations have moved towards MRP II, but have not implemented complete systems. Often different names are used for these partial systems, and you might hear about **distribution resource planning** or **logistics resource planning**, where the MRP approach is used to plan logistics. Unfortunately, such terms are used rather inconsistently. Some people, for example, use distribution resource planning to describe more limited systems where the demand does not come from a production plan, but from received customer orders.

Working with other organisations

MRP II can generate plans for all activities and material movements within an organisation. But this is still not the end of the story. Following the trend for integrating the supply chain, we can extend the planning to other organisations. This gives the basis of **Enterprise Resource Planning** (ERP).

Suppose a manufacturer's MRP system finds that it needs a delivery of 100 units of some material at the beginning of June. It uses this information to schedule its purchases.

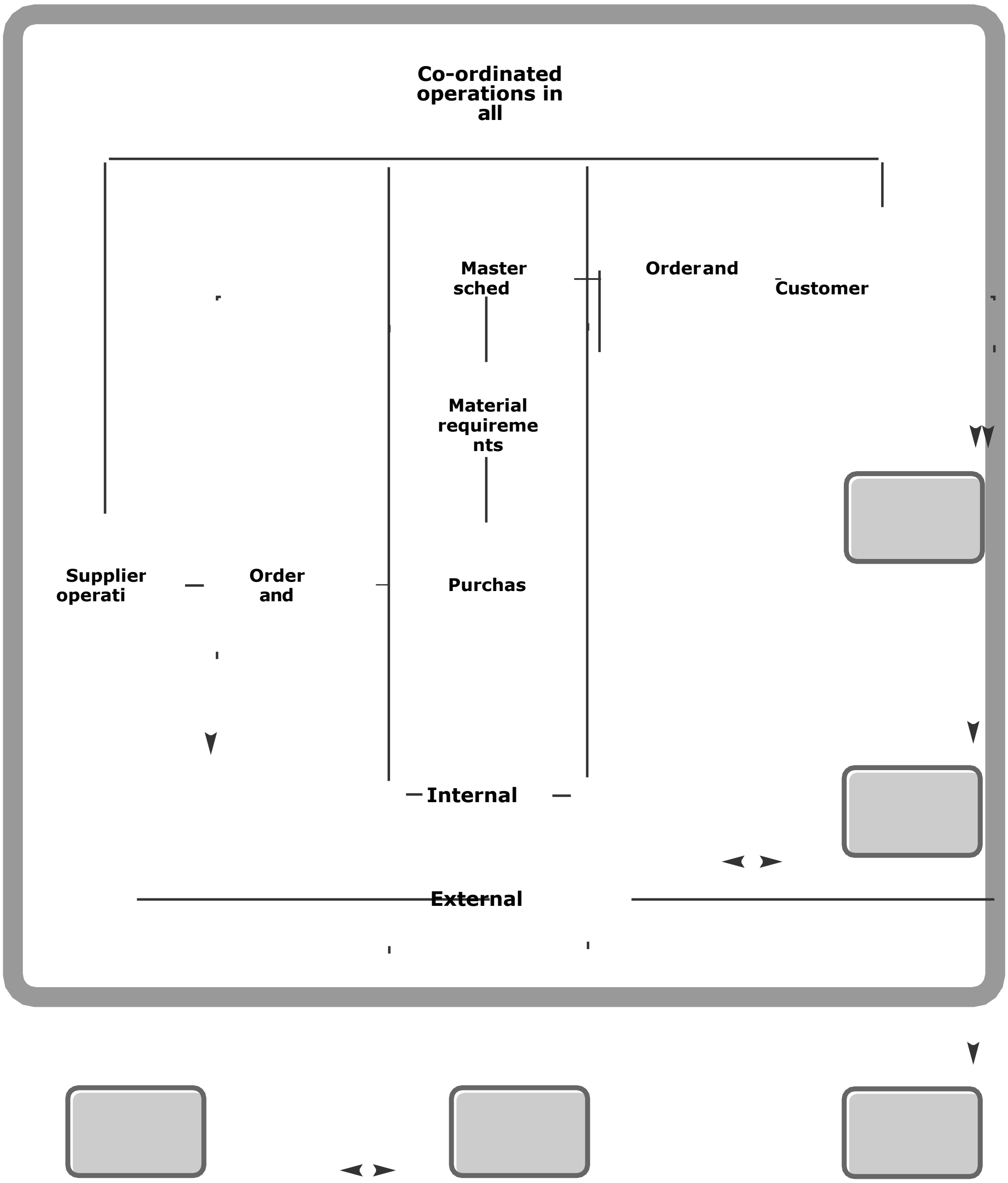


Figure 7.5 Enterprise resource planning

However, EDI (electronic data interchange) can link the MRP system to the supplier's system, so the supplier knows in advance when it has to deliver this material, and it can start sched uling operations to make sure that it is ready in time. If second tier suppliers are linked to the MRP system of the first tier supplier, they can also start their preparations. In this way, the message moves backwards through the supply chain, giving integrated planning (illus trated in Figure 7.5).

In principle, the free flow of information needed by ERP is relatively easy to organise with EDI, EFT, the Internet and other tools of ebusiness. However, it might be difficult to get such complete trust between organisations, even when they are prepared to form alliances. You can also imagine the complexity of systems needed, and the practical problems that arise. Nonetheless, this approach has considerable potential, and is leading to the next stage of 'virtual enterprise resource allocation'.3

PRINCIPLES OF JUSTINTIME

Principles and definitions

Justintime (JIT) offers another way of planning. It organises all activities so they occur at exactly the time they are needed. They are not done too early (which would leave materials hanging around until they were actually needed) and they are not done too late (which would give poor customer service). You can see this effect when you order a taxi to collect you at 08:00. If the taxi arrives at 07:30 you are not ready and it wastes time sitting and waiting; if it arrives at 08:30 you are not happy and will not use the service again. When the taxi arrives at 08:00 – justintime for your trip – it does not waste time waiting, and you are pleased that the service arrives exactly when you wanted it.

JIT seems an obvious idea, but it can have a dramatic effect on the way that materials are organised. You can see this with stocks of raw materials. The traditional approach buys mate rials early and keeps them in stock until they are needed. MRP reduces stock by coordinating the arrival of materials with the demand. But JIT aims at delivering materials directly to oper ations and virtually eliminating stock.

Companies such as Toyota6,7 spent years developing JIT through the 1970s. Their methods were so successful that all major organisations now use some elements of JIT. We can start describing the principles by looking at the effect on stock, and then generalise the approach to other areas.

The main purpose of stock is to give a buffer between operations. Stocks are builtup during good times, to be used when there are problems. Then if some equipment breaks down, or a delivery is delayed, or demand is unexpectedly high, everything continues to work normally by using the stocks. The traditional view of managers is that stocks are essential to guarantee smooth operations. They allow for any mismatches between the supply and demand for materials.

Inventory control systems (which we describe in Chapter 9) define stock levels that are high enough to cover likely problems. Unfortunately, with widely varying demand or poten tial problems, these stock levels can be very high – and expensive. MRP reduces the amount of stock by using the master schedule to match the supply of materials more closely to demand. In practice, the batching rules of MRP add some stock, and they keep some more to allow for uncertainty and problems. However, the principle is clear – the more closely we can match the supply of materials to demand, the less stock we need to carry. If we can completely eliminate any mismatch, we need no stocks at all. This is the basis of justintime systems (illustrated in Figure 7.6).

■ **JUSTINTIME** systems organise materials to arrive just as they are needed.
■ By coordinating supply and demand, they eliminate stocks of raw materials and work in progress.

You can see an example of justintime operations with the fuel in a lawnmower. If a lawn mower has a petrol engine, there is a mismatch between the fuel supply that you buy from a garage, and demand when you actually mow the lawn. You allow for this mismatch by keeping stocks of fuel in the petrol tank and spare can. This is the traditional approach to inventory control, where stocks are high enough to cover any likely demand. If a lawnmower has an electric motor the supply of electricity exactly matches demand and there are no stocks of fuel. This is a justintime system.

So what happens when there really is a mismatch between supply and demand? What does a supermarket do when it sells loaves of bread one at a time, but gets them delivered by the truckload? The traditional answer is to hold enough stock to cover the mismatch – the super market puts the truckload of bread on its shelves until it is sold or goes stale. JIT says that this is a mistake. There is an alternative, which is to remove the mismatch. The supermarket might approach this by using smaller delivery vehicles, or opening a small bakery on the premises.

Now we can summarise JIT's view of stock:

- Stocks are held to cover shortterm mismatches between supply and demand.
- These stocks serve no useful purpose – they only exist because poor coordination does not match the supply of materials to the demand.
- As long as stocks are held, there are no obvious problems and no incentive for managers to improve the flow of materials.
- Then operations continue to be poorly managed, with problems hidden by stocks.
- The real answer is to improve operations, find the reasons for differences between supply and demand, and then take whatever action is needed to overcome the differences.

As you can see, JIT is based on very simple principles. Instead of holding stocks to allow for problems, you identify the problems and solve them. Unfortunately, this often puts new pres sures on logistics. With deliveries of bread to a supermarket, for example, logistics managers have to design new systems that can deliver small, frequent quantities of fresh bread.

Wider effects of JIT

We have introduced JIT as a way of reducing stock levels, but it is much more than this. JIT involves a change in the way an organisation looks at all its operations. Its supporters describe it as '**a way of eliminating waste**', or, '**a way of enforced problem solving**'. In this wider sense, JIT sees an organisation as having a series of problems that hinder efficient operations. These problems include long lead times, unreliable deliveries, unbalanced operations, constrained capacity, equipment breakdowns, defective materials, interruptions, unreliable suppliers, poor quality, too much paperwork and too many changes. Managers try to get around these problems by holding large stocks, buying extra capacity, keeping backup equipment, employing 'troubleshooters', and so on. But these methods only hide the symptoms of problems.

A much more constructive approach is to identify the real problems – and solve them. This approach leads to a number of changes in viewpoint.

- *Stocks:* As we have seen, organisations hold stocks to cover shortterm differences between supply and demand. **JIT assumes that these stocks actually hide problems.** Organisations should find the reasons for differences between supply and demand, and then take what ever action is needed to remove them.

- *Quality:* Organisations have defined some arbitrary level of acceptable quality, such as, 'we will accept one defect in a hundred units'. JIT recognises that all defects have costs, and it is better to find the cause and make sure that no defects are produced (supporting the view of total quality management).

- *Suppliers:* JIT relies totally on its suppliers – so it supports the view of **customers and suppliers working closely together** in longterm partnerships pursuing common objectives.

- *Batch size:* Operations often use large batch sizes, as they reduce setup costs and disrup tions. But if demand is low, the products made in large batches sit in stock for a long time. **JIT looks for ways of reducing the batch size so that it more closely matches demand.**

- *Lead times:* Long lead times encourage high stocks, as they have to cover uncertainty until the next delivery. **JIT aims for small, frequent deliveries with short lead times.**

- *Reliability:* **JIT is based on continuous, uninterrupted production, so all operations must be reliable**. If, say, equipment breaks down, managers must find the reasons and make sure it does not happen again.

- ***Employees**:* Some organisations still have a friction between 'managers' and ‘workers’. JIT argues that this is a meaningless distinction, as the welfare of everyone depends on the success of the organisation. **All employees should be treated fairly and equitably.**

By now, you can see that JIT is not just a way of minimising stocks. By coordinating all activities, it increases efficiency and eliminates waste.

Key Elements in JIT

One problem with JIT is that it only works well in certain types of organisation. The most successful users of JIT are largescale assembly plants, which make virtually identical products in a continuous process. You can see why this is, from the following arguments:

- Every time there are changes to a process, or it switches from making one product to making another, there are delays, disruptions and costs. JIT says that these changes waste resources and should be eliminated. In other words, JIT needs a stable environment where a process makes large numbers of a standard product, at a fixed rate, for a long time.

- This stable environment can reduce costs by using specialised automation. Then JIT works best with high volume, mass production.

- The level of production must allow a smooth and continuous flow of products through the process. Each part of the process should be fully utilised, so the process is likely to be a wellbalanced assembly line.

- Deliveries of materials are made directly to the assembly line at just the time they are needed. Suppliers must be able to adapt to this kind of operation. It would be impractical to bring each individual unit from suppliers, so the next best thing is to use very small batches.

- If small batches are used, reorder costs must be reduced as much as possible or the frequent deliveries will be too expensive.

- Lead times must be short or the delay in answering a request for materials becomes too long. This means working closely with suppliers, and encouraging them to build facilities that are physically close.

- As there are no stocks to give safety cover, any defects in materials would disrupt produc tion. Suppliers must, therefore, be totally reliable and provide materials that are free from defects.

- If something goes wrong, people working on the process must be able to find the cause, take the action needed to correct the fault, and make sure that it does not happen again. This needs a skilled and flexible workforce that is committed to the success of the organisation.

ACHIEVING JUSTINTIME OPERATIONS

Push and pull systems

The success of JIT is not solely based on its idea of organising activities at just the time they are needed, but on its description of how to achieve this. It works by 'pulling' materials through the process.

In a traditional process, each operation has a timetable of work that must be finished in a given time. Finished items are then 'pushed' through to form a stock of work in progress in front of the next operation. Unfortunately, this ignores what the next operation is actually doing – it might be working on something completely different, or be waiting for a different item to arrive. At best, the second operation must finish its current job before it can start working on the new material just passed to it. The result is delays and increased stock of work in progress.

JIT uses another approach to 'pull' work through the process. When one operation finishes work on a unit, it passes a message back to the preceding operation to say that it needs another unit to work on. The preceding operation only passes materials forward when it gets this request. As you can see, this kind of process does not have earlier operations **pushing** work through, but has a later operation **pulling** it through. You can see the difference in a take away sandwich bar. With the traditional push system, someone makes a batch of sandwiches and delivers them to the counter where they sit until a customer buys them. With a JIT pull system, a customer asks for a particular type of sandwich, and this is specially made and deliv ered – thus eliminating the stocks of work in progress. You can also see that there is inevitably some lead time between an operation requesting material and having it arrive. In real JIT systems, messages are passed backwards this lead time before they are actually needed. Mate rials are also delivered in small batches rather than continuous amounts, so JIT still has some stocks of work in progress. These stocks are as small as possible, so it would be fairer to say that JIT minimises stocks rather than eliminates them.

Kanbans

JIT needs some way of organising the flow of materials that are pulled through the process. The simplest system moves materials between two stages in containers. When a second stage needs some materials, it simply passes the empty container back to the previous stage as a signal to fill it (see Figure 7.7).

This method is not reliable enough for most operations, so the usual alternative

uses
kanbans. '*Kanban*' is the Japanese for a card, or some form of visible record.

- ***KANBANS*** are cards that control the flow of materials through JIT operations.
- They arrange the 'pull' of materials through a process.

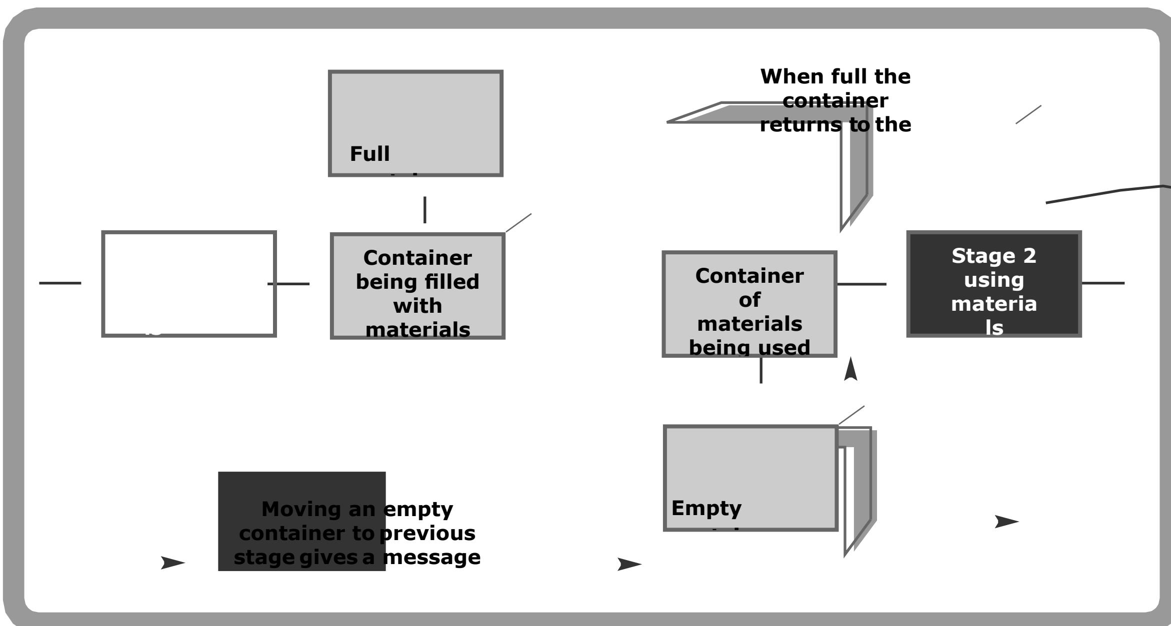


Figure 7.7 The simplest form of message for JIT

There are several ways of using *kanbans*. The most common system (shown in Figure 7.8) uses two distinct types of card, a *production kanban* and a *movement kanban*.

- All material is stored and moved in standard containers – with different containers for each material.

- A container can only be moved when it has a movement *kanban* attached to it.

- When one stage needs more materials – that is when its stock of materials falls to a reorder level – a movement *kanban* is attached to an empty container. This gives permis sion to take the container to a small stock of work in progress.

- A full container is found in this stock, which has a production *kanban* attached.

- The production *kanban* is removed and put on a post. This gives a signal for the preceding workstation to make enough to replace the container of materials.

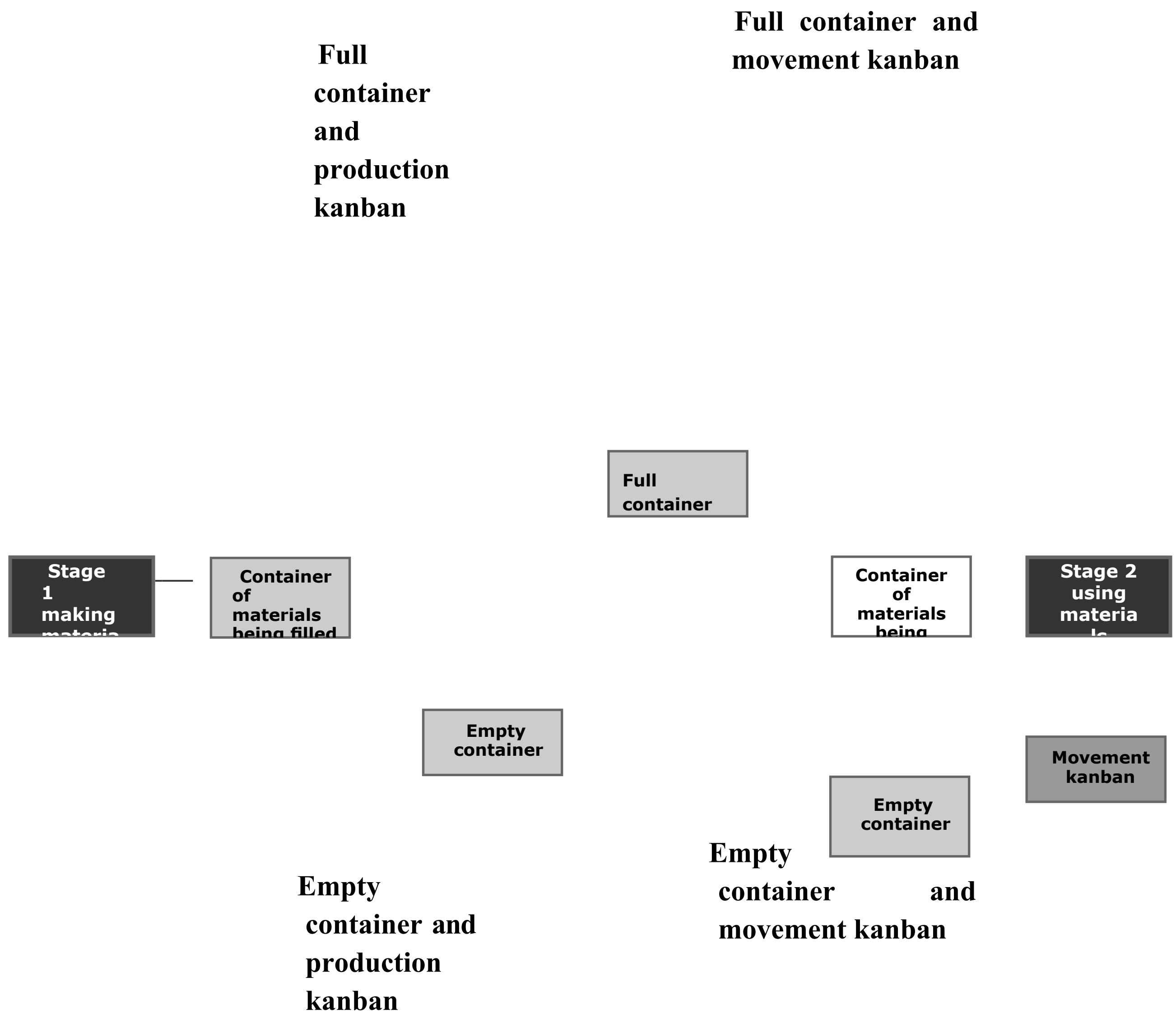
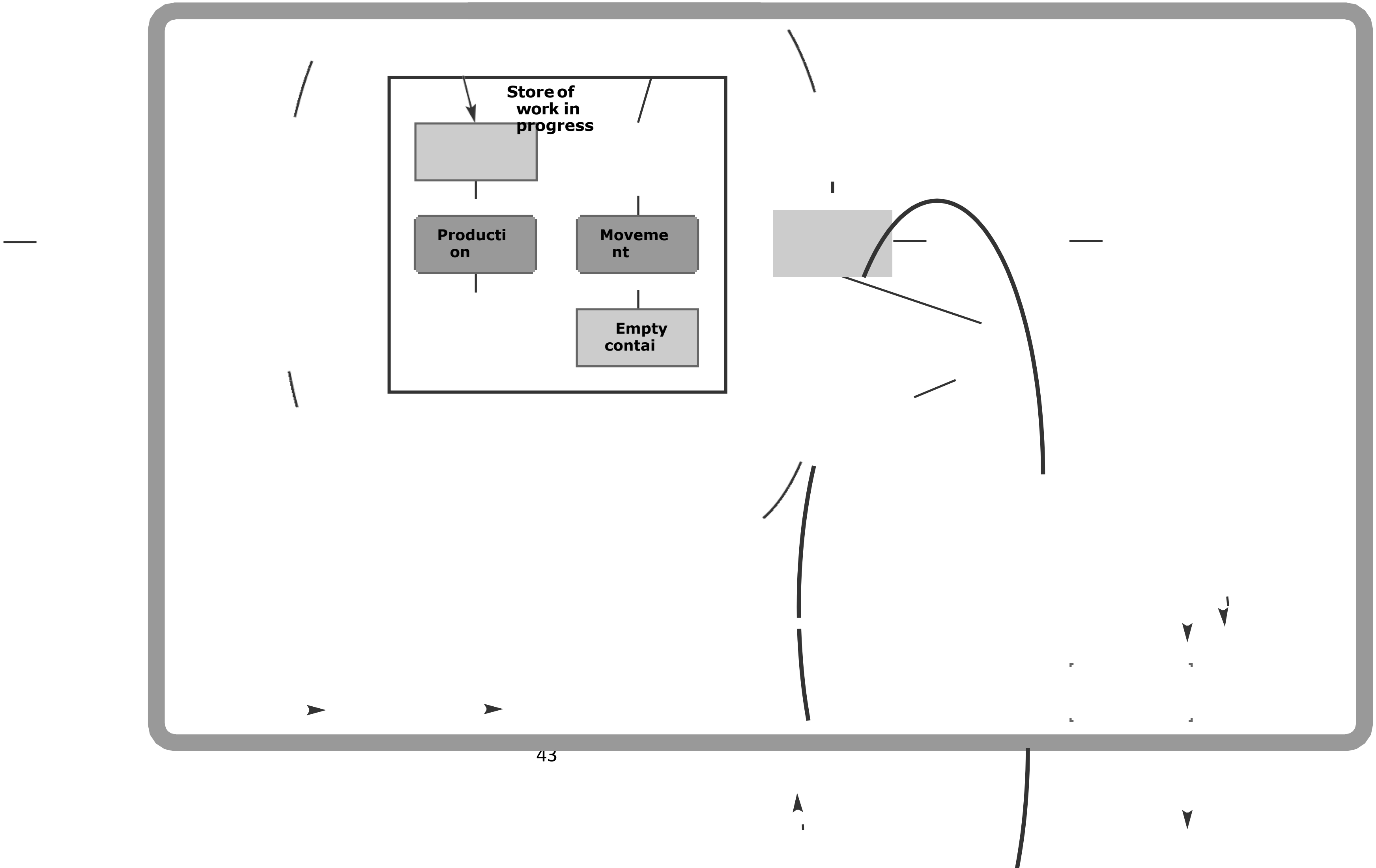

Full container and production kanban
Full container and movement kanban
Full container
Stage 1 making materia
Container of materials being filled
Container of materials being
Stage 2 using materia ls
Empty container
Movement kanban
Empty container
Empty container and movement kanban
Empty container and production kanban

Figure 7.8 A two card kanban system



- The movement *kanban* is attached to the full container, giving permission to move it back to the operation.

Although this system has a stock of work in progress, this stock is small. When a full container is removed, it is usually the only container in stock – and materials are not replaced until the previous workstation makes them. JIT almost always uses a product layout – such as an assembly line – so this stock of work in progress is really a small amount that is kept in the line, and there is no actual movement.

Each full container in the store has a production *kanban* attached to it, so the number of these *kanbans* effectively fixes the amount of work in progress. If there is only one production *kanban*, it means that the stock of work in progress is limited to at most one container of items. If there are two production *kanbans*, this doubles the stock of work in progress, and more *kanbans* would give even higher stocks. The aim of JIT is to work with minimum stocks and, therefore, a minimum feasible number of *kanbans*.

The main features of such *kanban* systems are:

- A message is passed backwards to the preceding workstation to start production, and it only makes enough to fill a container.
- Standard containers are used which hold a specific amount. This amount is usually quite small, and is typically 10% of a day's needs.
- The size of each container is the smallest reasonable batch that can be made, and there are usually only one or two full containers at any point.
- A specific number of containers and *kanbans* is used.
- The stock of work in progress is controlled by the size of containers and the number of *kanbans*.
- Materials can only be moved in containers, and containers can only be moved when they have a *kanban* attached. This gives a rigid means of controlling the amount of materials produced and time they are moved.
- While it is simple to administer, this system makes sure that stocks of work in progress cannot accumulate.

JIT has developed into many different forms. A common one replaces the manual *kanbans* with electronic signals. Then a control system monitors movements of materials using bar codes or other item coding, and it sends a message backwards to signal when it is time to prepare more materials.

Benefits and disadvantages of JIT

We introduced JIT as a way of lowering stocks, and some organisations have reduced these by 90%.8 This gives a number of related benefits, such as reduction in the space needed (up to 40% less), lower procurement costs (up to 15%), less investment in stocks, and so on. In general, JIT gives the following benefits:

- lower stocks of raw materials and work in progress
- shorter lead times

- shorter time needed to make a product
- higher productivity
- higher equipment capacity and utilisation
- simplified planning and scheduling
- less paperwork
- improved quality of materials and products
- less scrap and wastage
- better morale and participation of the workforce
- better relations with suppliers
- emphasis on solving problems in the process.

Unfortunately, some of these benefits can only be bought at a high price. Making high quality products with few interruptions by breakdowns, for example, can mean buying better quality, more expensive equipment. Reduced setup times usually need more sophisticated equipment. Small batches can increase production costs. Higher skills in the workforce increase training costs and the subsequent wage bill. Equipment must respond quickly to changing demands, so there must be more capacity.

One of the main problems with JIT is its inability to deal with unforeseen circumstances. Accidents or breakdowns, for example, can interrupt supplies and cause problems in the supply chain. Early in 2001 fuel supplies in the UK were disrupted by industrial action. Companies working with JIT felt the effects immediately when their materials were not deliv ered, while those with higher stocks kept working normally.

Some specific problems listed by JIT users include:

- high risks of introducing completely new systems and operations
- initial investment and cost of implementation
- long time needed to get significant improvements
- reliance on perfect quality of materials from suppliers
- inability of suppliers to adapt to JIT methods
- need for stable production when demand is highly variable or seasonal
- reduced flexibility to meet specific, or changing, customer demands
- difficulty of reducing setup times and associated costs
- lack of commitment within the organisation
- lack of cooperation and trust between employees
- problems linking JIT to other information systems, such as accounts
- need to change layout of facilities
- increased stress in workforce
- inability of some people to accept devolved responsibilities.

EXTENDING JIT ALONG THE SUPPLY CHAIN

Efficient consumer response

JIT forces suppliers to change the way they work, with fast deliveries, perfect quality, small batches, and complete reliability. The easiest way for them to meet these requirements – which also reinforces the idea of an integrated supply chain – is to adopt JIT methods themselves. **Then second tier suppliers adopt JIT to support first tier suppliers, and so on.** This ensures that the whole supply chain is working together with the same aims and principles. This extension of JIT along the supply chain is known by a variety of names, including **quick response** (QR), **continuous replenishment planning** (CRP) and more commonly **efficient consumer response** (ECR).

EFFICIENT CONSUMER RESPONSE pulls materials through tiers of organ isations in the supply chain.

Early work in ECR was done in the fashion industry. This had severe problems with its stockholdings, largely caused by the traditional planning of production around four seasons. At the start of, say, the summer season, shops had to be full of new products in the latest styles. Then shops needed high stocks to give customers a wide choice, and wholesalers needed high stocks to resupply the shops at short notice. To make sure that these stocks were in place, peak manufacturing occurred some time before the start of the season. If demand for a product was particularly high, there would be shortages as manufacturers had already moved on to making their autumn and winter collections. If demand was low, shops could not reduce their purchases as the clothes were already sitting on their shelves and in wholesalers. At the end of each season there were major sales as wholesalers and retailers tried to get rid of their less popular items, and major restocking in preparation for the next season.

The industry realised that it could get huge savings if it smoothed its operations. The way to do this was not to have huge stocks sitting in the supply chain, but to move items quickly, and respond to customer demands by more flexible manufacturing. Now they use justintime operations and link information systems so that they can 'pull' materials through the supply chain. When a retailer sells an item, their cash register automatically sends a message to the wholesaler requesting a replacement. In turn, the wholesaler's system sends a message to the manufacturer asking for a delivery. The manufacturer is not bogged down in making excessive amounts of items that are later sold at discounts, but responds quickly to the demand and replaces garments that have actually been sold.

With ECR, a message passes backwards through the supply chain, and each organisation cooperates in moving materials forwards. In 1985 the US retailer J.C. Penney formed one of the world's first ECR partnerships with Burlington (a fabric manufacturer) and Lanier Clothing (a garment maker). As a result, they increased sales by 22% and reduced stocks by 50%.9 Interest in ECR has grown since the mid 1990s. The grocery trade was quick to see the poten tial benefits, and when you buy a packet of biscuits in a supermarket the till automatically sends a message back to the supplier to send a replacement, and the supplier's system sends a message to its own supplier, and so on back through the chain.

ECR extends the benefits of JIT to the whole supply chain. So it brings lower stocks, better customer service, lower costs, more responsive operations, improved space utilisation, less paperwork, and so on. Organisations introducing ECR in the 1990s reported a string of bene fits. Quaker Oats, for example, reported a threefold increase in stock turnover, 65% lower stocks and 77% reduction in paperwork.10 Integrated Systems Solutions reported 3–4% increase of service level, 40–50% reduction in stock and 2–3 times increase of stock turnover.11

Features of ECR

It is not necessarily physical transport that slows the flow of materials through a supply chain, but the associated flow of information. It might take a month for an organisation to prepare the details for a purchase, collect information, send orders, arrange payments, and so on, while delivery only takes a day. So ECR only became feasible when a practical method of control was designed. With JIT this came with *kanbans*; with ECR it came with EDI.

ECR relies on a string of 'enablers', many of which we have already met. For a start, ECR only really works when organisations and their suppliers are working together in partnerships. This allows full EDI including purchase orders, invoices, planning information, pointofsales data, fund transfer, and so on. Each organisation's control system sends a message to suppliers and signals the need for more materials using an '**electronic *kanban***'. Some systems go further and hand over more responsibility to the supplier in **vendor managed inventory**. Then the supplier becomes responsible for maintaining stocks at their customers' operations, checking the availability, organising deliveries and all other aspects of inventory control that make sure stocks are available when needed.

There is no point in having a sophisticated signalling system if the physical delivery of materials is slow. So ECR relies on very fast movement of materials. To some extent, this needs efficient transport, but we have already noted Beesley's comment12,13 that: 'In typical UK manufacturing supply chains at least 95% of the process time is accounted as nonvalue adding.' Then material movement can be made more efficient by removing nonvalue adding steps and, in particular, reducing the time spent in storage. Karabus and Croza9 say that: 'product should never be warehoused or stored, but should continually be in movement, with the least possible number of handling steps'. Crossdocking – which coordinates materials movement so that they are transferred from the arrival bay directly to the departure bay without ever going into storage – can give much faster delivery and reduce costs to less than half. Luton summarises this by saying that: 'Efficient consumer response requires cross docking'14 and he suggests that an efficient terminal should aim for turning over stock at least daily, or 250 turns a year. These ideas are consolidated in **flow through logistics**, which aims at a smooth, continuous and uninterrupted flow of materials.

In different circumstances there can be many other enablers for ECR. These include integration of the whole supply chain, transparency (so that all organisations can see what is happening and how this affects them), understanding the operations of other organisations (particularly the conditions and constraints they work with), flexible operations that can deliver materials with short lead times, balanced resources to give a smooth flow of materials, and so on.

Introducing ECR

ECR is a deceptively simple idea. Like JIT, though, it needs substantial changes to operations and can only be used in certain circumstances. If the supply chain starts with potatoes, they are grown in a particular season and farmers cannot suddenly grow a crop at short notice. Another problem comes with the length of the supply chain, as a single organisation that does not want to be involved – or cannot adapt – will disrupt the flow. If the supply chain crosses a slow international border, or includes an area where productivity is low, or hits other prob lems, the delays become unacceptable and ECR cannot work.

Introducing JIT can be a huge undertaking, fundamentally changing the way an organisa tion works. When JIT is extended to ECR, implementation becomes an even bigger issue. This is probably why organisations have seemed slow to introduce it. By 1997 almost no organisa tions had a fully established ERC system.15 Nonetheless, interest was clearly growing, and Szymankiewicz said that: 'If the massive increase in ECR activity predicted … becomes a reality, it will become the main catalyst for developments in supplychain thinking. … ECR could well become the basis for supplychain management.'16

The following list includes some key stages for an organisation implementing ECR:

- design a logistics strategy based on responsive replenishment
- understand the principles of ECR and how this will affect operations
- define the aims of ECR for the organisation and measures of performance from partner ships with organisations that can match the organisation's aims
- introduce comprehensive EDI with suppliers and customers
- build 'flow through' logistics, where materials are moved as efficiently as possible
- benchmark other operations and continue to improve.

This is, of course, only a partial list, and it seems deceptively simple. Forming partnerships, for example, is not easy, so integrating an entire supply chain is extremely difficult. If it were easy to get an efficient flow of materials with 'flow through' logistics, more organisations would already be working like this. Despite these cautions ECR can, when working properly, give dramatic improvements. Estimates suggest a typical return on investment of 250% over the first three years of use.9

REVIEW:

- The traditional approach to planning is based on forecasts of demand. When actual demand is known, we can use approaches based on ‘dependent demand’.
- Material requirements planning is a dependent demand system which ‘explodes’ a master schedule to give timetables for the delivery of materials. By relating deliveries to actual requirements, MRP can both reduce costs and improve customer service.
- There are several extensions to MRP, such as closedloop MRP which gives feedback for capacity planning. MRP II extends the idea of MRP to other functions, so that all plans within an organisation are related back to the master schedule.
- Enterprise resource planning extends the MRP approach to suppliers. It co ordinates the movement of materials along the supply chain.
- Justintime aims at eliminating waste from an organisation. It does this by organising operations to occur just as they are needed. This needs a new way of thinking, which solves problems rather than hides them.
- JIT matches the supply of materials to the demand by ‘pulling’ materials through the process. *Kanbans* give a simple, practical method of controlling this flow.
- Efficient consumer response extends the ideas of JIT, by pulling materials through an integrated supply chain. There are several enablers for ECR, including EDI and ‘flow through’ logistics.

DISCUSSION QUESTIONS

1. MRP was developed to plan the supply of parts at manufacturers, so it cannot really be used in other types of organisation. Do you think this is true?
2. MRP II seems a good idea in theory, but it would be difficult to plan logistics, let alone finance and marketing, from a master schedule. The systems would also be so unwieldy that they could never work properly. Even if they did work, operations would be too inflexible to cope with agile competitors. What do you think of these views?
3. What are the main difficulties of using ERP?
4. If you were in hospital and needing a blood transfusion, would you rather the transfusion service used a traditional system of holding stocks of blood, or a justintime system? What does your answer tell you about JIT in other organisations?
5. What are the most significant changes that JIT brings to the planning of logistics in an organisation? What happens if an organisation wants to introduce JIT, but finds that its suppliers cannot cope with the small batches and frequent deliveries?
6. What are the problems of using ECR? How can these problems be overcome?

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