bookboon.com

Operations Management

Albert Porter

Albert Porter

Operations Management

Operations Management

ISBN 978-87-7681-464-9

Contents

1 Introduction

1.1 What is Operations Management?

Operations Management is the activity of managing the resources which produce and deliver goods and services (Slack et al., 2010). Operations can be seen as one of many functions (e.g. marketing, finance, personnel) within the organisation. The operations function can be described as that part of the organisation devoted to the production or delivery of goods and services. This means all organisations undertake operations activities because every organisation produces goods and/or services.

1.2 Manufacturing and Service Operations

Organisations can be classified in two broad categories as either manufacturing or service. Manufacturing organisations produce physical, tangible items which can be stored as inventory before delivery to the customer. Service organisations produce intangible items that cannot be produced ahead of time. One of the key developments in operations is the increasing importance of service operations as service industry accounts for an increasing proportion of the output of industrialised economies. Service operations management is the term that is used to cover the activities, decisions and responsibilities of operations managers in service organisations (Johnston and Clark, 2008). Some of the main implications of the differences between manufacturing and services for operations management are now discussed. Because a service cannot be stored its production and consumption will occur at the same time that implies that the producer of the service will come into contact with the customer. In fact the customer will be involved to a greater or lesser extent in the actual delivery of the operation. For instance a supermarket requires the customer to choose and transport the goods around the store and queue at an appropriate checkout till. However it should not be assumed that all employees in a service operation have to deal directly with a customer. For the supermarket example, the checkout till is an example of high customer contact, but stores personnel may not have to deal directly with the customer at all. This distinction in services is denoted by 'back office' tasks which add value to the inputs of the service operation (e.g. stocktaking) and 'front office' tasks which deal with the customer both as an input and output of the operation.

Because services are intangible then it follows that they cannot have a store of finished goods. Manufacturing operations will often compensate for fluctuations in demand by fulfilling demand from finished goods inventory produced during a slack period. This option is not open to service operations and they must focus on trying to alter the demand pattern to meet capacity by such strategies as discounting the price of the service during periods of low demand. Because the output of a service is intangible it is more difficult to assess performance by such measures as productivity or output. For example a manufacturer can simply count the volume of output of its product range, but an administration service for example will have more difficulty in measuring the productivity of their employees.

The quality of a service will be judged by the process of delivering that service as well as the quality of any tangible goods that are involved. This leads to the problem that it is more difficult to measure the quality of service delivery than the quality of manufactured goods. In reality most operations systems produce a mixture of goods and services. Most goods have some supporting service element (e.g. a maintenance facility), called a facilitating service, while many services will have supporting goods (e.g. a management consultancy report), termed a facilitating good.

1.3 The Systems View of Operations Management

A system is a group of interrelated items in which no item studied in isolation will act in the same way as it would in the system. A system is divided into a series of parts or subsystems, and any system is a part of a larger system. The system's boundary defines what is inside the system and what is outside. A system's environment is everything outside the system boundary that may have an impact on the behaviour of the system. A system's inputs are the physical objects of information that enter it from the environment and its outputs are the same which leave it for the environment.

The activities in an operations system can be classified as input, transformation process and output. The input activity involves two categories of resources. Transforming resources are the elements that act on, or carry out, the transformation process on other elements. These include such elements as labour, equipment/plant and energy. The nature and mix of these resources will differ between operations. The transformed resources are the elements which give the operations system its purpose or goal. The operations system is concerned with converting the transformed resources from inputs into outputs in the form of goods and services. There are three main types of transformed resource of materials which can be transformed either physically (e.g. manufacturing), by location (e.g. transportation), by ownership (e.g. retail) or by storage (e.g. warehousing), information which can be transformed by property (e.g. accountants), by possession (e.g. market research), by storage (e.g. libraries), or by location (e.g. telecommunications) and customers they can be transformed either physically (hairdresser), by storage (e.g. hotels), by location (e.g. airlines), by physiological state (e.g. hospitals), or by psychological state (e.g. entertainment). Two types of transforming resources are facilities (e.g. building and equipment) and staff (all the people involved in the operations process).

The sub-systems of a firm related to specific business disciplines are termed the functional areas of a business. The three main functional areas in a business are the operations, marketing and finance functions. The marketing function works to find and create demand for the company's goods and services by understanding customer needs and developing new markets. The need for marketing and operations to work closely together is particularly important as the marketing function will provide the forecast of demand from which operations can plan sufficient capacity in order to deliver goods and services on time. The finance function is responsible for the obtaining and controlling of funds and covering decisions such as investment in equipment and price-volume decisions. Other functions which play a supporting role in the organisation include the personnel function which will play a role on the recruitment and labour relations, the research and development function which generates and investigates the potential of new ideas and the information technology department which supplies and co-ordinates the computer-based information needs of the organisation.

The relationship between functions can be seen as a number of sub-systems within the system called the 'organisation'. Thus each function (e.g. marketing) can be treated using the same input/process/output transformation model as the operations function. In other words each function within the organisation can be treated as performing an operations activity, as they are transforming inputs into outputs. This implies every part of the organisation is involved in the operations activity (to an external or internal customer) and thus the theory of operations covered in this book is relevant to them. When operations is cited as a function in itself however it is referring to the part of the organisation which provides goods and services for external customers.

The operations function itself is involved in all parts of the firm and thus has a major impact on the competitive position of the organisation. The traditional view of the operations sub-system is that it is one function within a linear sequence of processes and is thus 'buffered' from the actions of the marketplace. Thus both physical stocks and allocation of responsibility within functions outside of operations are used to protect the operations system from the external environment. For example the R&D function will carry responsibility for the development of new product ideas which are then 'passed on' to the operations function and the purchasing function will take responsibility for the sourcing of materials and bought-in services. Physical buffers include stocks of materials before and after the operations function to ensure stability of supply and ability to meet fluctuating demand respectively. The idea behind this model is that the operations function can concentrate solely on transforming inputs of raw materials into goods and services without the need to consider the external environment outside of the organisational system. The disadvantage of this model includes the slowness of response to changes in the environment as they are transmitted through various connected functions and the inability of operations to develop in response to the needs of customers. In fact the operations function is critical in meeting customer needs and is deeply involved in the performance of the organisation. For example the parameters under which a product/service can be marketed is directly consequent on inputs from the operations functions such as flexibility affecting the product range available.

Thus instead of being seen as simply a 'black box' which takes raw materials and transforms then into a product/service, the operations function should be seen as critical to the marketing position and competitive advantage of the organisation. The need for operations to improve performance across a number of attributes (e.g. quality, delivery, cost) means that competitive improvements will require long-term commitment and thus a strategic view of operations. The approach requires a commitment to quality improvement and then an improvement in other competitive factors that together will lead to a reduction in cost. This contrasts with the direct approach to cost reduction of cutting the labour force or 'downsizing'. Apart from failing to tackle the underlying problems and increase performance across the competitive factors, this approach is limited by the fact that direct labour costs typically account for a small proportion of overall costs.

1.4 The Process View of Organisations

Recently there has been a move away from considering business as a set of discrete functional areas towards a view of the organisation as consisting of sets of processes which link together in order to meet customer needs. Processes can be related in one functional area (e.g. production), but could relate to cross-functional activities (e.g. fulfilling customer orders or even occur in all functional areas (e.g. planning activities).

In functional terms the processes would be situated in areas such as operations, marketing and finance, but from the customer's view the value they gain is dependant on the performance if the set of linked processes involved in the delivery of the product/service. The term 'value added' is used to denote the amount of value a process creates for its internal or external customer. The set of processes used to create value for a customer is often called the value chain. The value chain includes primary processes that directly create the value the customer perceives and support processes that assist the primary process in adding value. The key issue is that the configuration of the value chain should be aligned with the particular way the organisation provides value to the customer.

2 Operations Strategy

2.1 What is Strategy?

Strategic decisions can be classified as those decisions which make major long term changes to the resource base of the organisation in response to external factors such as markets, customers and competitors. Thus strategic decisions occur as a result of an evaluation of the external and internal environment. The external evaluation may reveal market opportunities or threats from competitors. The evaluation of the internal environment may reveal limitations in capabilities relative to competitors. Strategy is seen as complex in nature due to a high degree of uncertainty in future consequences arriving from decisions, integration is required of all aspects and functional areas of business and major change may have to be implemented as a consequence of strategic choices made. Operations strategy is concerned with both what the operation has to do in order to meet current and future challenges and also is concerned with the long-term development of its operations resources and processes so that they can provide the basis for a sustainable advantage (Slack and Lewis, 2011).

2.2 Levels of Strategy

Strategy can be seen to exist at three main levels within the organisation. At the highest or corporate level the strategy provides very general long-range guidance for the whole organisation, often expressed as a statement of its mission. The mission statement describes in general terms what key decision-makers want the company to accomplish and what kind of company they want it to become. Thus the mission focuses the organisation on specific market areas and the basis on which it must compete.

The second level of strategy is termed a business strategy and may be for the organisation or at the strategic business unit level in larger diversified companies. There the concern is with the products and services that should be offered in the market defined at the corporate level. The third level of strategy is termed the operational or functional strategy were the functions of the business (e.g. operations, marketing, finance) make long-range plans which support the business strategy. Since the operations function is responsible in large part for the delivery of the product/service it has a major responsibility for business strategy formulation and implementation. This model implies a 'top-down' approach to strategy formulation in which corporate goals are communicated down to business and then functional areas. Although there has always been interaction within this hierarchy in both directions in this model the role of functional areas such as operations in setting the framework for how a company can compete is being recognised. The increasing importance of operations strategy development is discussed in the following section.

2.3 The Role of Operations in Strategy Development

The operations function plays an important role in the formulation and delivery of the organisation's strategy. Market conditions have changed from a mass production era with an emphasis on high volume, low cost production to an environment demanding performance on measures such as quality and speed of delivery as well as cost. In addition the rapid pace of change in markets means the basis of how the organisation will compete may change quickly over time.

The traditional approach to strategy development has been for senior managers to establish corporate objectives, develop a strategy for meeting these objectives and then to acquire resources necessary to implement the chosen strategy. This approach is intended to ensure that resources are directed efficiently at the areas identified as 'strategically' important from the strategic analysis. The approach is based on the firm's ability to forecast future market conditions and thus identify gaps between future market needs and organisational capability. However in dynamic markets the ability to forecast far enough into the future in order to build a competitive advantage will be limited. Also this approach has led to an emphasis on relatively short-term objectives and a lack of emphasis on 'behavioural' factors such as performance evaluation systems and selection and development of the work-force. The idea is that in dynamic market conditions the strategic plan should indicate the general direction that the organisation should follow based on the capabilities and values it possesses.

2.4 Operations Competitive Priorities

Operations should focus on specific capabilities that give it a competitive edge which may be termed competitive priorities. Four operations priorities or measures of these capabilities can be termed cost, time, quality and flexibility.

2.4.1 Cost

If an organisation is competing on price then it is essential that it keeps its cost base lower than the competition. Then it will either make more profit than rivals, if price is equal, or gain market share if price is lower. Cost is also important for a strategy of providing a product to a market niche, which competitors cannot provide. Thus cost proximity (i.e. to ensure costs are close to the market average) is important to maximise profits and deter competitors from entering the market. The major categories of cost are staff, facilities (including overheads) and material with the greatest scope for cost reduction lies with reduction of the cost of materials. A relatively small proportion of costs are usually assigned to direct labour.

2.4.2 Time

The time delay or speed of operation can be measured as the time between a customer request for a product/service and then receiving that product/service. Speed is an important factor to the customer in making a choice about which organisation to use. The concept of P:D ratios (Shingo, 1989) compares the demand time D (from customer request to receipt of goods/services) to the total throughput time P of the purchase, make and delivery stages. Thus in a make-to-stock system D is basically the delivery time, but for a customer-to-order system the customer demand time is equal to the purchase, make and delivery stages (P). In this case the speed of the internal processes of purchase and make will directly effect the delivery time experienced by the customer. Thus the advantage of speed is that it can either be used to reduce the amount of speculative activity and keep the delivery time constant or for the same amount of speculative activity it can reduce overall delivery lead time. Thus in competitive terms speed can be used to both reduce costs (making to inaccurate forecasts) and reduce delivery time (better customer service).

2.4.3 Quality

Quality covers both the quality of the product/service itself and the quality of the process that delivers the product/service. Quality can be measured by the 'cost of quality' model were costs are categorised as either the cost of achieving good quality (the cost of quality assurance) or the cost of poor quality products (the costs of not conforming to specifications). The advantages of good quality on competitiveness include increased dependability, reduced costs and improved customer service.

2.4.4 Flexibility

There are a number of areas in which flexibility can be demonstrated. For example it can mean the ability to offer a wide variety of products/services to the customer and to be able to change these products/services quickly. Flexibility is needed so the organisation can adapt to changing customer needs in terms of product range and varying demand and to cope with capacity shortfalls due to equipment breakdown or component shortage. Types of flexibility include product flexibility which is the ability to be able to quickly act in response to changing customer needs with new product/service designs and volume flexibility which is the ability to be able to decrease or increase output in response to changes in demand. Volume flexibility may be needed for seasonal changes in demand as services may have to react to demand changes minute by minute.

3 Product Design and Process Selection

New product designs can provide a competitive edge by bringing new ideas to the market quickly, doing a better job of satisfying customer needs, or being easier to manufacture, use and repair (Russell and Taylor, 2009). The product design process involves the steps of generating ideas, product screening, preliminary design and final design.

3.1 Generating Ideas

Ideas for new products and services should be sought from a variety of sources including market research, customer viewpoints, the organisation's research and development (R&D) department if one exists, competitors or relevant developments in new technology. Competitors can provide a good source of ideas and it is important that the organisation analyses any new products they introduce to the market and make an appropriate response. Reverse Engineering is a systematic approach to dismantling and inspecting a competitor's product to look for aspects of design that could be incorporated into the organisation's own product. This is especially prevalent when the product is a complex assembly such as a car, were design choices are myriad. Benchmarking compares a product against what is considered the best in that market segment and the making recommendations on how the product can be improved to meet that standard. Although a reactive strategy, benchmarking can be useful to organisation's who have lost ground to innovative competitors.

3.2 Product Screening

The screening process consists of market analysis, economic analysis and technical analysis.

3.2.1 Market analysis

Market analysis consists of evaluating the product concept with potential customers through interviews, focus groups and other data collection methods. The physical product may be tested by supplying a sample for customer evaluation. The market analysis should identify whether sufficient demand for the proposed product exists and its fit with the existing marketing strategy. At a strategic level the organisation can use the product life cycle to determine the likely cost and volume characteristics of the product. The product life cycle describes the product sales volume over time. In the early introduction phase production costs are high and design changes may be frequent. However there should be little or no competition for the new product and so a premium price can be charged to customers attracted to innovative products. The growth phase sees a rapid increase in volumes and the possibility of competitors entering the market. At this stage it is important to establish the product in the market as firmly as possible in order to secure future sales. Production costs should be declining as process improvements and standardisation takes place. In the mature phase competitive pressures will increase and it is important that sales are secured through a branded product to differentiate it from competitors and a competitive price. There should be a continued effort at design improvement to both product and process. Some products, such as consumer durables, may stay in the mature phase almost indefinitely, and techniques such as advertising are used to maintain interest and market share.

3.2.2 Economic Analysis

Economic Analysis consists of developing estimates of production and demand costs and comparing them with estimates of demand. In order to perform the analysis requires an accurate estimate of demand as possible derived from statistical forecasts of industry sales and estimates of market share in the sector the product is competing in. These estimates will be based on a predicted price range for the product which is compatible with the position of the new product in the market. In order to assess the feasibility of the projected estimates of product costs in terms of such factors as materials, equipment and personnel must be estimated. Techniques such as cost/benefit analysis, decision theory and accounting measures such as net present value (NPV) and internal rate of return (IRR) may be used to calculate the profitability of a product. Another tool that can be used is the cost-volume-profit model that provides a simplified representation that can be used to estimate the profit level generated by a product at a certain product volume.

Assuming all products made are sold then the volume for a certain profit can be given by the following formula

$$X = \frac{(P + FC)}{(SP - VC)}$$

where

X = volume (units)
P = profit
FC = fixed costs
SP = selling price
VC = variable costs

When profit = 0 (i.e. selling costs = production costs) this is termed the breakeven point and can be given by the following formula:

$$X = \frac{FC}{SP - VC}$$

3.2.3 Technical Analysis

Technical analysis consists of determining whether technical capability to manufacture the product. This covers such issues as ensuring materials are available to make the product to the specification required, and ensuring the appropriate machinery and skills are available to work with these materials. The technical analysis must take into account the target market and so product designers have to consider the costs of manufacturing and distributing the product in order to ensure it can be sold at a competitive price. Strategic analysis involves ensuring that the product provides a competitive edge for the organisation, drawing on its competitive strengths and is compatible with the core business.

3.3 Preliminary Design

Product concepts that pass the feasibility stage enter preliminary design. The specification of the components of the package requires a product /service structure which describes the relationship between the components and a bill of materials or list of component quantities derived from the product structure. The process by which the package is created must also be specified in terms of mapping out the sequence of activities which are undertaken. This can be achieved with the aid of such devices as process flow charts.

3.4 Final Design

The final design stage involves the use of a prototype to test the preliminary design until a final design can be chosen. Computer Aided Design (CAD) and Simulation Modelling can be used to construct a computer-based prototype of the product design.

3.5 Methods for Improving Product Design

A number of methods are available that help to improve the design process.

3.5.1 Design for Manufacture (DFM)

Although the ability of the product or service to fulfil customers needs is a major factor in design there is also a need to ensure that the product designed can be produced easily and at low cost. Design for Manufacture (DFM) is a concept which provides guidelines on how this can be achieved using techniques such as simplification, standardisation and modularization. Simplification involves a reduction in the number of components in the design in order to reduce cost and increase reliability. Standardisation involves using components that can be used in a number of products again reducing costs through economies of scale and minimising inventory. Modularisation means using modules or blocks of components that are standard across products. Again costs are reduced and reliability increased.

3.5.2 Concurrent Engineering

Concurrent engineering is when contributors to the design effort provide work throughout the design process as a team. This differs from the traditional design process when work is undertaken separately within functional areas such as engineering and operations. The problem with the traditional approach is the cost and time involved in bringing the product to market. In a traditional approach time is wasted when each stage in the design process waits for the previous stage to finish completely before it can commence and their may be a lack of communication between functional areas involved in the different stages of design. This can lead to an attitude of "throwing the design over the wall" without any consideration of problems that may be encountered by later stages. An example of this is decisions made at the preliminary design stage that adversely effect choices at the product build stage. This can cause the design to be repeatedly passed between departments to satisfy everyone's needs, increasing time and costs. By facilitating communication through the establishment of a project team problems of this type can be reduced.

3.6 Process Selection

When considering product design the issue of the design of the process that is used to produce that design should be considered also. The design of processes is different in all organisations and should be related to the volume and variety of the demand for the product in the market. In order to assist in selecting the appropriate process, process designs can be categorised under four process types of project, jobbing, batch, mass and continuous (Barnes, 2008). A description of each process type is followed by some examples of where each process type might be used.

3.6.1 Project

Processes that produce products of high variety and low volume are termed projects. Project processes are used to make a one-off product to a customer specification. Normally transforming resources such as staff and equipment that make the product must move or be moved to the location of the product. Other characteristics of projects are that they may require the coordination of many individuals and activities, demand a problem-solving approach to ensure they are completed on time and have a comparatively long duration of manufacture. The timescale of the completion of the project is an important performance measure. Because each project is unique it is likely that transforming resources will comprise general purpose equipment which can be used on a number of projects. Examples of the use of a project process include building construction, interior design and custom-built furniture.

3.6.2 Jobbing

Jobbing processes are used to make a one-off or low volume product to a customer specification. A feature of a jobbing process is that the product moves to the location of transforming resources such as equipment. Thus resources such as staff and equipment can be shared between many products. Other characteristics of jobbing processes are the use of skilled labour in order to cope with the need for customisation (i.e. variety) and the use of general purpose equipment which is shared between the products. There tends to be low utilisation of equipment in jobbing processes due to the need to undertake frequent setting up of the machinery when moving from processing one product to another. Examples of the use of a jobbing process include bespoke tailors and precision engineers.

3.6.3 Batch

Processes that produce products of medium variety and medium volume are termed batch which denotes that the products are grouped as they move through the design process. In a batch process the product moves to the location of transforming resources such as equipment and so resources are shared between the batches. Instead of setting up machinery between each product, as in a jobbing process, setups occur between batches, leading to a higher utilisation of equipment. Because of the relatively high volumes involved in batch it can be cost-effective to use specialised labour and equipment dedicated to certain product batches. A feature of batch processes is that, because it is difficult to predict when a batch of work will arrive at a machine, a lack of coordination can lead to many products waiting for that machine at any one time. These queues of work may dramatically increase the time the product takes to progress through the process. Examples of the use of a batch process include book printing, university classes and clothing manufacture.

3.6.4 Line

Processes that produce products of high volume and low variety are termed line or mass processes. Although there may be variants within the product design the production process will essentially be the same for all the products. Because of the high volumes of product it is cost effective to use specialised labour and equipment. A feature of line processes is that the movement of the product may be automated using a conveyor system and the production process broken down into a number of small, simple tasks. In order to ensure a smooth flow of product the process times per unit must be equalised at each stage of production using a technique called line balancing. Because of the low product variety, setting up of equipment is minimised and utilisation of equipment is high. Examples of the use of a mass process include cars, consumer durables such as televisions and food items.

3.6.5 Continuous

Processes that operate continually to produce a very high volume of a standard product are termed continuous. The products produced by a continuous operation are usually a continuous flow such as oil and gas. Continuous processes use a large amount of equipment specialised and dedicated to producing a single product (such as an oil refinery for example). To make this large investment in dedicated equipment cost effective continuous processes are often in constant operation, 24 hours a day. The role of labour in the operation of the processes is mainly one of monitoring and control of the process equipment with little contact with the product itself. Examples of a continuous process include water treatment plants, electricity production and steel making.

4 Total Quality Management

Total Quality Management (TQM) requires that the principles of quality management are applied in all aspects and at every level in an organisation (Hill, 2005). TQM has evolved over a number of years from ideas presented by a number of quality Gurus. Deming (1985) proposed an implementation plan consisting of 14 steps which emphasises continuous improvement of the production process to achieve conformance to specification and reduce variability. This is achieved by eliminating common causes of quality problems such as poor design and insufficient training and special causes such as a specific machine or operator. He also places great emphasis on statistical quality control techniques and promotes extensive employee involvement in the quality improvement program. Juran (2001) put forward a 10 step plan in which he emphasises the elements of quality planning - designing the product quality level and ensuring the process can meet this, quality control - using statistical process control methods to ensure quality levels are kept during the production process and quality improvement - tackling quality problems through improvement projects. Crosby (1996) suggested a 14-step programme for the implementation of TQM. He is known for changing perceptions of the cost of quality when he pointed out that the costs of poor quality far outweigh the cost of preventing poor quality, a view not traditionally accepted at the time.

Attempting to summarise the main principles of TQM covered in these plans are the following three statements. Firstly the customer defines quality and thus their needs must be met. The organisation should consider quality both from the producer and customer point of view. Thus product design must take into consideration the production process in order that the design specification can be met. Thus it means viewing things from a customer perspective and requires that the implications for customers are considered at all stages in corporate decision making. Secondly quality is the responsibility of all employees in all parts of the organisation. In order to ensure the complete involvement of the whole organisation in quality issues TQM uses the concept of the internal customer and internal supplier. This recognises that everyone in the organisation consumes goods and services provided by other organisational members or internal suppliers. In turn every service provided by an organisational member will have a internal customer. The implication is that poor quality provided within an organisation will, if allowed to go unchecked along the chain of customer/supplier relationships, eventually lead to the external customer. Therefore it is essential that each internal customer's needs are satisfied. This requires a definition for each internal customer about what constitutes an acceptable quality of service. It is a principle of TQM that the responsibility for quality should rest with the people undertaking the tasks which can either directly or indirectly affect the quality of customer service. This requires not only a commitment to avoid mistakes but actually a capability to improve the ways in which they undertake their jobs. This requires management to adopt an approach of empowerment with people provided with training and the decision making authority necessary in order that they can take responsibility for the work they are involved in and learn from their experiences. Finally a continuous process of improvement culture must be developed to instil a culture which recognises the importance of quality to performance.

4.1 The Cost of Quality

All areas in the production system will incur costs as part of their TQM program. For example the marketing department will incur the cost of consumer research in trying to establish customer needs. Quality costs are categorised as either the cost of achieving good quality - the *cost of quality assurance* or the cost of poor-quality products - the *cost of not conforming* to specifications.

4.1.1 The Cost of Achieving Good Quality

The costs of maintaining an effective quality management program can be categorised into prevention costs and appraisal costs. Prevention reflects the quality philosophy of "doing it right the first time" and includes those costs incurred in trying to prevent problems occurring in the first place. Examples of prevention costs include:

- The cost of designing products with quality control characteristics
- The cost of designing processes which conform to quality specifications
- The cost of the implementation of staff training programmes

Appraisal costs are the costs associated with controlling quality through the use of measuring and testing products and processes to ensure that quality specifications are conformed to. Examples of appraisal costs include:

- The cost of testing and inspecting products
- The costs of maintaining testing equipment
- The time spent in gathering data for testing
- The time spent adjusting equipment to maintain quality

4.1.2 The Cost of Poor Quality

This can be seen as the difference between what it actually costs to provide a good or service and what it would cost if there was no poor quality or failures. This can account for 70% to 90% of total quality costs and can be categorised into internal failure costs and external failure costs. Internal failure costs occur before the good is delivered to the customer. Examples of internal failure costs include:

- The scrap cost of poor quality parts that must be discarded
- The rework cost of fixing defective products
- The downtime cost of machine time lost due to fixing equipment or replacing defective product

External failure costs occur after the customer has received the product and primarily relate to customer service. Examples of external failure costs include:

- The cost of responding to customer complaints
- The cost of handling and replacing poor-quality products
- The litigation cost resulting from product liability
- The lost sales incurred because of customer goodwill affecting future business

4.2 Quality Systems

ISO 9000 provides a standard quality standard between suppliers and a customer that helps to reduce the complexity of managing a number of different quality standards when a customer has many suppliers. ISO 9000 is a series of standards for quality management and assurance and has five major subsections as follows:

- ISO 9000 provides guidelines for the use of the following four standards in the series.
- ISO 9001 applies when the supplier is responsible for the development, design, production, installation, and servicing of the product.
- ISO 9002 applies when the supplier is responsible for production and installation.
- ISO 9003 applies to final inspection and testing of products.
- ISO 9004 provides guidelines for managers of organisations to help them to develop their quality systems. It gives suggestions to help organisations meet the requirements of the previous four standards.

The standard is general enough to apply to almost any good or service, but it is the specific organisation or facility that is registered or certified to the standard. To achieve certification a facility must document its procedures for every element in the standard. These procedures are then audited by a third party periodically. The system thus ensures that the organisation is following a documented, and thus consistent, procedure which makes errors easier to find and correct. However the system does not improve quality in itself and has been criticised for incurring cost in maintaining documentation while not providing guidance in quality improvement techniques such as statistical process control.

5 Statistical Process Control

Statistical Process Control (SPC) is a widely used sampling technique which checks the quality of an item which is engaged in a process. SPC can also be used to inform management of improved process changes (Krajewski et al., 2010). SPC identifies the nature of variations in a process, which are classified as being caused by 'chance' causes or 'assignable' causes.

5.1 Chance Causes of Variation

Processes will have some inherent variability due to factors such as ambient temperature, wear of moving parts or slight variations in the composition of the material that is being processed. The technique of SPC involves calculating the limits of these chance-cause variations for a stable system, so any problems with the process can be identified quickly. The limits of the chance-cause variations are called control limits and are shown on a control chart, which also shows sample data of the measured characteristic over time. There are control limits above and below the target value for the measurement, termed the upper control limit (UCL) and lower control limit (LCL) respectively. The behaviour of the process is observed by studying the control chart and if the sample data plotted on the chart shows a random pattern within the upper and lower control limits then the process is 'in-control'. However if a sample falls outside the control limits or the plot shows a non-random pattern then the process is 'out-of-control'.

5.2 Assignable Causes of Variation

An assignable cause of variation is a variation in the process which is not due to random variation but can be attributed to some change in the process, which needs to be investigated and rectified. However in some instances the process could actually be working properly and the results could have been caused by sampling error. There are two types of error which can occur when sampling from a population. A type I error is indicated from the sample output when none actually occurs. The probability of a type I error is termed . A type II error is when an error is occurring but has not been indicated by the sample output. The probability of a type II error is termed . Type I errors may lead to rectification work which is unnecessary and even the unnecessary recall of 'faulty' products. Type II errors will lead to defective products as an out-of-control process goes unnoticed. Customer compensation and loss of sales may result if defective products reach the marketplace. The sampling methodology should ensure that the probability of type I and type II errors should be kept as low as reasonably possible.

5.3 Types of Control Charts

Two types of control charts are for variable data and for discrete data.. Control charts for variable data display samples of a measurement that will fall in or out of a range around a specified target value. Examples of variable data could be a customer transaction time in a bank or the width of an assembly component. Two control charts are used in measuring variable data. An X,$^-$ chart shows the distance of sample values from the target value (central tendency). An R chart shows the variability of sample values (dispersion). Attribute control charts measure discrete values such as if a component is defective or not. Thus there are no values, as in a variable control chart, from which a mean and range can be calculated. The data will simply provide a count of how many items conform to a specification and how many do not. Two control charts will be described for attribute data. The p-chart which shows the proportion of defectives in a sample and the c-chart which shows the number of defectives in a sample.

6 Supply Chain Management

Supply Chain Management is the management of the interconnection of organisations that relate to each other through upstream and downstream linkages between the processes that produce value to the ultimate consumer in the form of products and services (Slack et al., 2010). Activities in the supply chain include sourcing materials and components, manufacturing products, storing products in warehousing facilities and distributing products to customers. The management of the supply chain involves the coordination of the products through this process which will include the sharing of information between interested parties such as suppliers, distributors and customers.

6.1 Fluctuations in the Supply Chain

The behaviour of supply chains that are subject to demand fluctuations has been described as the bullwhip effect and occurs when there is a lack of synchronisation is supply chain members, when even a slight change in consumer sales will ripple backwards in the form of magnified oscillations in demand upstream. The bullwhip effect occurs because each tier in the supply chain, increases demand by the current amount, but also assumes that demand is now at this new level, so increases demand to cover the next week also. Thus each member in the supply chain updates their demand forecast with every inventory review.

There are other factors which increase variability in the supply chain. These include a time lag between ordering materials and getting them delivered, leading to over-ordering in advance to ensure sufficient stock are available to meet customer demand. Also the use of order batching (when orders are not placed until they reach a predetermined batch size) can cause a mismatch between demand and the order quantity. Price fluctuations such as price cuts and quantity discounts also lead to more demand variability in the supply chain as companies buy products before they need them.

In order to limit the bullwhip effect certain actions can be taken. The major aspect that can limit supply chain variability is to share information amongst members of the supply chain. In particular it is useful for members to have access to the product demand to the final seller, so that all members in the chain are aware of the true customer demand. Information Technology such as Electronic point-of-sale (EPOS) systems can be used by retailers to collect customer demand information at cash registers which can be transmitted to warehouses and suppliers further down the supply chain. If information is available to all parts of the supply chain it will also help to reduce lead times between ordering and delivery by using a system of coordinated or synchronised material movement.

Using smaller batch sizes will also smooth the demand pattern. Often batch sizes are large because of the relative high cost of each order. Technologies such as e-procurement and Electronic Data Interchange (EDI) can reduce the cost of placing an order and so help eliminate the need for large batch orders. Finally the use of a stable pricing policy can also help limit demand fluctuations.

6.2 Supply Chain Procurement

An important aspect of supply chain activities is the role of procurement in not only acquiring the materials needed by an organisation but also undertaking activities such as selecting suppliers, approving orders and receiving goods from suppliers. The term procurement is often associated with the term purchasing but this is taken to refer to the actual act of buying the raw materials, parts, equipment and all the other goods and services used in operations systems. There has recently been an enhanced focus on the procurement activity due to the increased use of process technology, both in terms of materials and information processing. In terms of materials processing the use of process technology such as flexible manufacturing systems has meant a reduction in labour costs and thus a further increase in the relative cost of materials associated with a manufactured product. This means that the control of material costs becomes a major focus in the control of overall manufacturing costs for a product. Another issue that has increased the importance of procurement is that the efficient use of automated systems requires a high quality and reliable source of materials to be available. This is also the case with the adoption of production planning systems such as JIT which require the delivery of materials of perfect quality, at the right time and the right quantity.

6.2.1 Choosing Suppliers

Before choosing a supplier, the organisation must decide whether it is feasible and desirable to produce the good or service in-house. Buyers in purchasing departments, with assistance from operations, will regularly perform a make-or-buy analysis to determine the source of supply. Often goods can be sourced internally at a lower cost, with higher quality or faster delivery than from a supplier. On the other hand suppliers who focus on delivering a good or service can specialise their expertise and resources and thus provide better performance. Strategic issues may also need to be considered when contemplating the outsourcing of supplies. For instance internal skills required to offer a distinctive competence may be lost if certain activities are outsourced. It may also mean that distinctive competencies can be offered to competitors by the supplier.

If a decision is made to use an external supplier, the next decision relates to the choice of that supplier. Criteria for choosing suppliers for quotation and approval include the following:

Price – As stated in the introduction, the cost of goods and services from suppliers is forming an increasingly large percentage of the cost of goods and services which are delivered to customers. Thus minimising the price of purchased goods and services can provide a significant cost advantage to the organisation.

Quality – To be considered as a supplier, it is expected that a company will provide an assured level of quality of product or service. This is because poor quality goods and services can have a significant disruptive effect on the performance of the operations function. For example resources may have to be deployed checking for quality before products can be used, poor quality products that get into the production system may be processed at expense before faults are found and poor quality goods and services that reach the customer will lead to returns and loss of goodwill.

Delivery – In terms of delivery, suppliers who can deliver on-time, every time, in other words show reliability, are required. The ability to deliver with a short lead time and respond quickly once an order has been placed, can also be an important aspect of performance.

The process of locating a supplier will depend on the nature of the good or service and its importance to the organisation. If there are few suppliers capable of providing the service then they will most likely be well known to the organisation. If there are a number of potential suppliers and the goods are important to the organisation then a relatively lengthy process of searching for suppliers and the evaluation of quotations may take place. Most organisations have a list of approved suppliers they have used in the past, or are otherwise known to be reliable. However it is important to monitor suppliers in order to ensure that they continue to provide a satisfactory service. A system of supplier rating, or vendor rating is used to undertake this. One form of vendor rating is a checklist which provides feedback to the supplier on their performance and suggestions for improvement. Another approach is to identify the important performance criteria required of the supplier, for example delivery reliability, product quality and price. The supplier can then be rated on each of these performance measures against historical performance and competitor performance. When choosing suppliers a decision is made whether to source each good or service from an individual supplier, termed single sourcing or whether to use a number of suppliers, termed multi-sourcing.

6.3 Supply Chain Distribution

Supply chain distribution refers to the movement of materials through the supply chain to the customer. Two main areas of physical distribution management are materials handling and warehousing.

6.3.1 Materials Handling

There are three types of materials handling systems available can be categorised as manual, mechanised and automated. A manual handling system uses people to move material. This provides a flexible system, but is only feasible when materials are movable using people with little assistance. An example is a supermarket where trolleys are used to assist with movement, but the presence of customers and the nature of the items make the use of mechanisation or automation not feasible. Mechanised warehouses use equipment such as forklift trucks, cranes and conveyor systems to provide a more efficient handling system, which can also handle items too heavy for people. Automated warehouses use technology such as Automated Guided Vehicles (AGVs) and loading/unloading machines to process high volumes of material efficiently.

6.3.2 Warehousing

Warehouses serve an obvious function as a long-term storage area for goods but also provide a useful staging post for activities within the supply chain such as sorting, consolidating and packing goods for distribution. Consolidation occurs by merging products from multiple suppliers over time, for transportation in a single load to the operations site. Finished goods sourced from a number of suppliers may also be grouped together for delivery to a customer in order to reduce the number of communication and transportation links between suppliers and customers. The opposite of consolidation is break-bulk where a supplier sends all the demand for a particular geographical area to a local warehouse. The warehouse then processes the goods and delivers the separate orders to the customers.

One of the major issues in warehouse management is the level of decentralisation and thus the number and size of the warehouses required in inventory distribution. Decentralised facilities offer a service closer to the customer and thus should provide a better service level in terms of knowledge of customer needs and speed of service. Centralisation however offers the potential for less handling of goods between service points, less control costs and less overall inventory levels due to lower overall buffer levels required. The overall demand pattern for a centralised facility will be an aggregation of a number of variable demand patterns from customer outlets and so will be a smoother overall demand pattern thus requiring lower buffer stocks. Thus there is a trade-off between the customer service levels or effectiveness offered by a decentralised system and the lower costs or efficiency offered by a centralised system. One way of combining the advantages of a centralised facility with a high level of customer service is to reduce the delivery lead time between the centralised distribution centre and the customer outlet. This can be accomplished by using the facility of Electronic Data Interchange (EDI) or e-procurement systems discussed in the procurement section.

The warehouse or distribution system can be itself outsourced and this will often be the only feasible option for small firms. The choice is between a single-user or private warehouse which is owned or leased by the organisation for its own use and a multi-user or public warehouse which is run as an independent business. The choice of single-user or multi-user warehouse may be seen as a break-even analysis with a comparison of the lower fixed costs, but higher operating costs of a multi-user warehouse, against the high fixed costs and lower operating cost of a single-user warehouse. However the cost analysis should be put into a strategic context. For example the warehouse and distribution system may enable a superior service to be offered to customers. It may also be seen as a barrier to entry to competitors due to the time and cost of setting up such a system.

7 JIT and Lean Systems

Just-In-time (JIT) is a philosophy originating from the Japanese auto maker Toyota where Taiichi Ohno developed the Toyota Production system (Ohno, 1988). The basic idea behind JIT is to produce only what you need, when you need it. This may seem a simple idea but to deliver it requires a number of elements in place such as the elimination of wasteful activities and continuous improvements.

7.1 Eliminate Waste

Waste is considered in the widest sense as any activity which does not add value to the operation. Seven types of waste identified by Toyota are as follows:

- Over-Production. This is classified as the greatest source of waste and is an outcome of producing more than is needed by the next process.

- Waiting Time. This is the time spent by labour or equipment waiting to add value to a product. This may be disguised by undertaking unnecessary operations (e.g. generating work in progress (WIP) on a machine) which are not immediately needed (i.e. the waste is converted from time to WIP).

- Transport. Unnecessary transportation of WIP is another source of waste. Layout changes can substantially reduce transportation time.

- Process. Some operations do not add value to the product but are simply there because of poor design or machine maintenance. Improved design or preventative maintenance should eliminate these processes.

- Inventory. Inventory of all types (e.g. pipeline, cycle) is considered as waste and should be eliminated.

- Motion. Simplification of work movement will reduce waste caused by unnecessary motion of labour and equipment.

- Defective Goods. The total costs of poor quality can be very high and will include scrap material, wasted labour time and time expediting orders and loss of goodwill through missed delivery dates.

7.2 Continuous Improvement

Continuous Improvement or Kaizen, the Japanese term, is a philosophy which believes that it is possible to get to the ideals of JIT by a continuous stream of improvements over time.

7.3 JIT Pull Systems

The idea of a pull system comes from the need to reduce inventory within the production system. In a push system a schedule pushes work on to machines which is then passed through to the next work centre. A production system for an automobile will require the co-ordination of thousands of components, many of which will need to be grouped together to form an assembly. In order to ensure that there are no stoppages it is necessary to have inventory in the system because it is difficult to co-ordinate parts to arrive at a particular station simultaneously. The pull system comes from the idea of a supermarket in which items are purchased by a customer only when needed and are replenished as they are removed. Thus inventory co-ordination is controlled by a customer pulling items from the system which are then replaced as needed.

To implement a pull system a kanban (Japanese for 'card' or 'sign') is used to pass information through the production system. Each kanban provides information on the part identification, quantity per container that the part is transported in and the preceding and next work station. Kanbans in themselves do not provide the schedule for production but without them production cannot take place as they authorise the production and movement of material through the pull system. Kanbans need not be a card, but something that can be used as a signal for production such as a marked area of floorspace. There are two types of kanban system, the single-card and two-card. The single-card system uses only one type of kanban card called the conveyance kanban which authorises the movement of parts. The number of containers at a work centre is limited by the number of kanbans. A signal to replace inventory at the work centre can only be sent when the container is emptied. Toyota use a dual card system which in addition to the conveyance kanban, utilises a production kanban to authorise the production of parts. This system permits greater control over production as well as inventory. If the processes are tightly linked (i.e. one always follows the other) then a single kanban can be used. In order for a kanban system to be implemented it is important that the seven operational rules that govern the system are followed. These rules can be summarised as follows:

- Move a kanban only when the lot it represents is consumed
- No withdrawal of parts without a kanban is allowed
- The number of parts issued to the subsequent process must be the exact number specified by the kanban.
- A kanban should always be attached to the physical product
- The preceding process should always produce its parts in the quantities withdrawn by the subsequent process.
- Defective parts should never be conveyed to the subsequent process
- A high level of quality must be maintained because of the lack of buffer inventory. A feedback mechanism which reports quality problems quickly to the preceding process must be implemented.
- Process the kanbans in every work centre strictly in order in which they arrive at the work centre

If several kanbans are waiting for production they must be served in the order that they have arrived. If the rule is not followed there will be a gap in the production rate of one or more of the subsequent processes. The system is implemented with a given number of cards in order to obtain a smooth flow. The number of cards is then decreased, decreasing inventory and any problems which surface are tackled. Cards are decreased, one at a time, to continue the continuous improvement process.

8 Capacity Planning

Capacity comprises the resources to serve customers, process information or make products and is a mix of the people, systems, equipment and facilities needed to meet the services or products involved (Hill, 2005). A definition of capacity should take into account both the volume and the time over which capacity is available. Thus capacity can be taken as a measure of an organisation's ability to provide customers with services or goods in the amount requested at the time requested. Capacity decisions should be taken by firstly identifying capacity requirements and then evaluating the alternative capacity plans generated.

8.1 Identifying Capacity Requirements

This stage consists of both estimating future customer demand but also determining current capacity levels to meet that demand.

8.1.1 Measuring Demand

In a capacity planning context the business planning process is driven by two elements; the company strategy and forecasts of demand for the product/service the organisation is offering to the market. Demand forecasts will usually be developed by the marketing department and their accuracy will form an important element in the success of any capacity management plans implemented by operations. The demand forecast should express demand requirements in terms of the capacity constraints applicable to the organisation. This could be machine hours or worker hours as appropriate. The demand forecast should permit the operations manager to ensure that enough capacity is available to meet demand at a particular point in time, whilst minimising the cost of employing too much capacity for demand needs. The amount of capacity supplied should take into account the negative effects of losing an order due to too little capacity and the increase in costs on the competitiveness of the product in its market.

Organisations must develop forecasts of the level of demand they should be prepared to meet. The forecast provides a basis for co-ordination of plans for activities in various parts of the organisation. For example personnel employ the right amount of people, purchasing order the right amount of material and finance can estimate the capital required for the business. Forecasts can either be developed through a qualitative approach or a quantitative approach.

8.1.2 Measuring Capacity

When measuring capacity it must be considered that capacity is not fixed but is a variable that is dependent on a number of factors such as the product mix processed by the operation and machine setup requirements. When the product mix can change then it can be more useful to measure capacity in terms of input measures, which provides some indication of the potential output. Also for planning purposes when demand is stated in output terms it is necessary to convert input measures to an estimated output measure. For example in hospitals which undertake a range of activities, capacity is often measured in terms of beds available (an input) measure. An output measure such as number of patients treated per week will be highly dependent on the mix of activities the hospital performs. The theoretical design capacity of an operation is rarely met due to such factors as maintenance and machine setup time between different products so the effective capacity is a more realistic measure. However this will also be above the level of capacity which is available due to unplanned occurrences such as a machine breakdown.

8.2 Evaluating Capacity Plans

The organisation's ability to reconcile capacity with demand will be dependent on the amount of flexibility it possesses. Flexible facilities allow organisations to adapt to changing customer needs in terms of product range and varying demand and to cope with capacity shortfalls due to equipment breakdown or component failure. The amount of flexibility should be determined in the context of the organisation's competitive strategy. Methods for reconciling capacity and demand can be classified into three 'pure' strategies of level capacity, chase demand and demand management although in practice a mix of these three strategies will be implemented.

8.2.1 Level Capacity

This approach fixes capacity at a constant level throughout the planning period regardless of fluctuations in forecast demand. This means production is set at a fixed rate, usually to meet average demand and inventory is used to absorb variations in demand. During periods of low demand any overproduction can be transferred to finished goods inventory in anticipation of sales at a later time period. The disadvantage of this strategy is the cost of holding inventory and the cost of perishable items that may have to be discarded. To avoid producing obsolete items firms will try to create inventory for products which are relatively certain to be sold. This strategy has limited value for perishable goods. For a service organisation output cannot be stored as inventory so a level capacity plan involves running at a uniformly high level of capacity. The drawback of this approach is the cost of maintaining this high level of capacity although it could be relevant when the cost of lost sales is particularly high, for example in a high value retail outlet such as a luxury car outlet where every sale is very profitable.

8.2.2 Chase Demand

This strategy seeks to change production capacity to match the demand pattern over time. Capacity can be altered by various policies such as changing the amount of part-time staff, changing the amount of staff availability through overtime working, changing equipment levels and subcontracting. The chase demand strategy is costly in terms of the costs of changing staffing levels and overtime payments. The costs may be particularly high in industries in which skills are scarce. Disadvantages of subcontracting include reduced profit margin lost to the subcontractor, loss of control, potentially longer lead times and the risk that the subcontractor may decide to enter the same market. For these reasons a pure chase demand strategy is more usually adopted by service operations which cannot store their output and so make a level capacity plan less feasible.

8.2.3 Demand Management

While the level capacity and chase demand strategies aim to adjust capacity to match demand, the demand management strategy attempts to adjust demand to meet available capacity. There are many ways this can be done, but most will involve altering the marketing mix and will require co-ordination with the marketing function. Demand Management strategies include:

- Varying the Price - During periods of low demand price discounts can be used to stimulate the demand level. Conversely when demand is higher than the capacity limit, price could be increased.
- Provide increased marketing effort to product lines with excess capacity.
- Use advertising to increase sales during low demand periods.
- Use the existing process to develop alternative product during low demand periods.
- Offer instant delivery of product during low demand periods.
- Use an appointment system to level out demand

9 Facility Location and Layout

9.1 Facility Location

The organisation's strategy will need to address the issue of facility location. This must be considered in terms of the need to serve customer markets effectively and to meet long-range demand forecasts. The issues can be considered in terms of the competition and cost of the location decision and the size of the facility. A company's competitiveness will be affected by its locations as it will impact on costs such as for transportation and labour. In service operations when the facility may not only produce the good but also deliver it to the customer from the facility, the convenience of the location for the customer is vital. A location decision is costly and time consuming to change. The costs include the purchase of land and construction of buildings. An organisation may be located inappropriately due to a previous poor location decision and an unwillingness to face the costs of a subsequent relocation. A change in input costs, such as materials or labour, may also lead to a need to change location. Finally in order to meet the long-term demand forecast it is necessary to consider the size of the facility. Within a medium term planning cycle the size of the facility will impose an upper limit on the organisation's capacity. Purchasing additional components from suppliers or sub-contracting work can however increase this level. However these strategies may lead to higher costs and thus a loss of competitiveness. The ability to supplement capacity is most restricted in service operations when contact with the customer is required.

9.2 Location Factors

Many factors affect the location decision including the following.

9.2.1 Proximity to Customers

For many service organisations in particular the location of the facility must be convenient for the potential customer. This can range from restaurants were customers may be prepared to travel a short distance to hospitals were the speed of response is vital to the service. High transportation costs for heavy or bulky materials may also lead to locating close to the customer.

9.2.2 Proximity to suppliers

The volume and bulk of the raw material involved in operations such as steel production means that a location decision will tend to favour areas near to suppliers. A manufacturer and seller of custom-built furniture however will need to be near potential customers. For service companies such as supermarkets and restaurants the need to be in a market-oriented locations means that the cost of transportation of goods will not be a major factor in the location decision. Distribution across country borders means that a whole series of additional costs and delays must be taken into account, including import duties and delays in moving freight between different transportation methods. A site near to an airport or a rail link to an airport may be an important factor if delivery speed is important.

9.2.3 Proximity to labour

Labour costs have generally become less important as the proportion of direct labour cost in high volume manufacturing have fallen. What is becoming more important is the skills and flexibility of the labour force to adapt to new working methods and to engage in continuous improvement efforts. The wage rate of labour can be a factor in location decisions, especially when the service can be provided easily in alternative locations. Information Technology companies involved in data entry can locate in alternative countries without the customer being aware.

9.3 Layout Design

Layout design concerns the physical placement of resources such as equipment and storage facilities. Layout design is important because it can have a significant effect on the cost and efficiency of an operation and can entail substantial investment in time and money. In many operations the installation of a new layout, or redesign of an existing layout, can be difficult to alter once implemented due to the significant investment required on items such as equipment. There are four basic layout types of process, product, hybrid and fixed-position layout. The characteristics of each of the layout types will now be considered.

9.3.1 Process layout

A process layout is one in which resources (such as equipment and people) which have similar processes or functions are grouped together. Process layouts are used when there is a large variety in the products or services being delivered and it may not be feasible to dedicate facilities to each individual product or service. A process layout allows the products or customers to move to each group of resources in turn, based on their individual requirements. Because of their flexibility process layouts are widely used. One advantage is that in service systems they allow a wide variety of routes that may be chosen by customers depending on their needs. Another advantage is that the product or service range may be extended and as long as no new resources are required may be accommodated within the current layout.

An important issue with process layouts is the management of the flow of products or services between the resource groups. One problem is that transportation between process groups can be a significant factor in terms of transportation time and handling costs. Another problem is that the number of products or services involved and the fact that each product/service can follow an individual route between the process groups, makes it difficult to predict when a particular product will be delivered or a service completed. This is because at certain times the number of customers or products arriving at a particular process group exceeds its capacity and so a queue forms until resources are available. This queuing time may take up a significant part of the time that the product or customer is in the process. This behaviour can lead to long throughput times (i.e. the time taken for a product or customer to progress through the layout). In a manufacturing organisation a significant amount of time may be spent 'progress chasing' to give certain products priority to ensure they are delivered to customers on time. In a service system the customers may feel they are queuing in the system longer than they perceive is necessary for the service they require. However in services there may be flexibility to add or remove staff to match the current arrival rate of customers to the service delivery point. Examples of process layouts include supermarkets, hospitals, department stores and component manufacturers.

9.3.2 Product Layout

Product layouts, also termed line layouts, arrange the resources required for a product or service around the needs of that product or service. In manufacturing applications such as assembly lines with a high volume of a standard product the products will move in a flow from one processing station to the next. In contrast to the process layout in which products move to the resources, here the resources are arranged and dedicated to a particular product or service. The term product layout refers to the arrangement of the resources around the product or service. In services the requirements of a specific group of customers are identified and resources setup sequentially so the customers flow through the system, moving from one stage to another until the service is complete.

A key issue in product layouts is that the stages in the assembly line or flow line must be 'balanced'. This means that the time spent by components or customers should be approximately the same for each stage, otherwise queues will occur at the slowest stage. The topic of line balancing is considered later in this chapter.

The product or line layout is an efficient delivery system in that the use of dedicated equipment in a balanced line will allow a much faster throughput time than in a process layout. The major disadvantage of the approach is that it lacks the flexibility of a process layout and only produces a standard product or service. Another issue is that if any stage of the line fails, then in effect the output from the whole line is lost and so it lacks the robustness to loss of resources (for example equipment failure or staff illness) that the process layout can provide. Examples of product layouts include car assembly, self-service cafes and car valeting.

9.3.3 Hybrid Layout

A hybrid layout attempts to combine the efficiency of a product layout with the flexibility of a process layout. Hybrid layouts are created from placing together resources which service a subset of the total range of products or services. When grouping products or services together in this way the grouping is termed a family. The process of grouping the products or services to create a family is termed group technology.

Group technology has three aspects:

1. Grouping parts into families

Grouping parts or customers into families has the objective of reducing the changeover time between batches, allowing smaller batch sizes, and thus improving flexibility. Parts family formation is based on the idea of grouping parts or customers together according to factors such as processing similarity.

2. Group physical facilities into cells to reduce transportation time between processes

Physical facilities are grouped into cells with the intention of reducing material or customer movements. Whereas a process layout involves extensive movement of materials or customers between departments with common processes, a cell comprises all the facilities required to manufacture a family of components or delivery a service. Material and customer movement is therefore restricted to within the cell and throughput times are therefore reduced. Cells can be U-shaped to allow workers to work at more than one process whilst minimising movement.

3. Creating groups of multi-skilled workers

Creating groups of multi-skilled workers enables increased autonomy and flexibility on the part of operators. This enables easier changeovers from one part to another and increases the job enrichment of members of the group. This in turn can improve motivation and have a beneficial effect on quality.

Creating cells with dedicated resources can significantly reduce the time it takes for products and services to pass through the process by reducing queuing time. It also offers the opportunity for automation due to the close proximity of the process stages. Thus process technology can be used to replace a number of general purpose resources with a single dedicated multi-functional system such as a Flexible Manufacturing System. A disadvantage of hybrid layouts can be the extra expenditure due to the extra resources required in creating cells.

Examples of hybrid layouts include custom manufacture, maternity unit in a hospital, cafeteria with multiple serving areas. In services a cell layout could involve an insurance organisation organised by type of claim (e.g. car, home, travel).

9.3.4 Fixed-Position layout

This layout design is used when the product or service cannot be moved and so the transforming process must take place at the location of product creation or service delivery. In a fixed position layout all resources for producing the product, such as equipment and labour must move to the site of the product or service. The emphasis when using a fixed-position layout is on the scheduling and coordination of resources to ensure that they are available in the required amounts at the required time. For example on a construction site most activities are dependent on the completion of other activities and cannot be undertaken simultaneously. The space available on the site may also constrain the amount of work activity that can take place at any one time. This means detailed scheduling of resources is required to minimise delays. In a restaurant it is important that the order is taken and food delivered to the table at the appropriate time. Examples of fixed-position layouts include construction sites such as for buildings or for large ships, aircraft manufacture and full service restaurants.

9.4 Designing Product Layouts - Line Balancing

A product layout consists of a number of processes arranged one after another in a 'line' to produce a standard product or service in a relatively high volume. These systems which have a characteristic flow (product) layout use specialised equipment or staff dedicated to achieving an optimal flow of work through the system. This is important because all items follow virtually the same sequence of operations. A major aim of flow systems is to ensure that each stage of production is able to maintain production at an equal rate. The technique of line balancing is used to ensure that the output of each production stage is equal and maximum efficiency is attained.

Line balancing involves ensuring that the stages of production are co-ordinated and bottlenecks are avoided. Because of the line flow configuration the tasks in the line must be undertaken in order (precedence) and the output of the whole line will be determined by the slowest or bottleneck process. The actual design of the line is thus guided by the order of the tasks which are involved in producing the product or delivering the service and the required output rate required to meet demand. This provides information which determines the number of stages and the output rate of each stage.

The steps in line balancing are as follows:

1. Draw a precedence diagram

The first step in line balancing is to identify the tasks involved in the process and the order that these tasks must be undertaken in. Once the tasks have been identified it is necessary to define their relationship to one another. There are some tasks that can only begin when other tasks have been completed and this is termed a serial relationship. The execution of other tasks may be totally independent and thus they have a parallel relationship. Precedence diagrams are used to show the tasks undertaken in a line process and the dependencies between these tasks.

2. Determine the cycle time for the line

For a particular line process we will wish to reach a desired rate of output for the line to meet projected demand. This is usually expressed in work items per time period, for example 30 parts per hour. Another way of expressing this output rate is that 30 parts per hour means that a part must leave the system every 2 minutes (60 minutes/30 parts). This measure, termed the cycle time, represents the longest time any part is allowed to spend at each task.

Cycle Time = Available Time/Desired Output

Taking into consideration the discussion of bottleneck processes above, the cycle time for the line process is thus determined by the task with the highest cycle time or lowest output level.

3. Assign tasks to workstations

Once the cycle time for the line has been calculated we have the cycle time for each stage or workstation in the line process. We can now allocate tasks to each workstation based on their task times. As a rule of thumb it is more efficient to allocate eligible tasks to a workstation in the order of longest task times first. When the total task time would exceed the cycle time for a workstation then it is necessary to start a new workstation and repeat the allocation of tasks as before. If a task time is longer than the workstation cycle time then it is necessary either to allocate multiple tasks in parallel in order to meet the target time or to break the task down into smaller elements.

4. Calculate the efficiency of the line

When tasks are assigned to workstations it is very unlikely that their total tasks times at each workstation will match the cycle time exactly. A measure of how close these two values do meet for the whole line, is called the line efficiency. To calculate the line efficiency:

Line Efficiency % = (Sum of the task times/(number of workstations * desired cycle time))*100

10 Work Systems Design

The following are examples of approaches to work systems design that have been used in an attempt to bring these desirable job characteristics to people's work leading to an improved mental state and thus increased performance.

10.1 Job Enlargement

This involves the horizontal integration of tasks to expand the range of tasks involved in a particular job. If successfully implemented this can increase task identity, task significance and skill variety through involving the worker in the whole work task either individually or within the context of a group. Job Rotation is a common form of job enlargement and involves a worker changing job roles with another worker on a periodic basis. If successfully implemented this can help increase task identity, skill variety and autonomy through involvement in a wider range of work task with discretion about when these mix of tasks can be undertaken. However this method does not actually improve the design of the jobs and it can mean that people gravitate to the jobs that suit them and are not interested in initiating rotation with colleagues. At worst it can mean rotation between a number of boring jobs with no acquisition of new skills.

10.2 Job Enrichment

Job enrichment involves the vertical integration of tasks and the integration of responsibility and decision making. If successfully implemented this can increase all five of the desirable job characteristics by involving the worker in a wider range of tasks and providing responsibility for the successful execution of these tasks. This technique does require feedback to so that the success of the work can be judged. The managerial and staff responsibilities potentially given to an employee through enrichment can be seen as a form of empowerment. This should in turn lead to improved productivity and product quality.

10.3 Implementation of Work Design Approaches

There are a number of factors which account for the fact that job enlargement and job enrichment are not more widely implemented. Firstly the scope for using different forms of work organisation will be dependent to a large extent on the type of operation in which the work is organised.

Job shop manufacturing will require skilled workers who will be involved in a variety of tasks and will have some discretion in how they undertake these tasks. Sales personnel may also have a high level of discretion in how they undertake their job duties also.

The amount of variety in a batch manufacturing environment will to a large extent depend on the length of the production runs used. Firms producing large batches of a single item will obviously have less scope for job enrichment than firms producing in small batches on a make-to-order basis. One method for providing job enlargement is to use a cellular manufacturing system, which can permit a worker to undertake a range of tasks on a part. When combined with responsibility for cell performance this can lead to job enrichment.

Jobs in mass production industries may be more difficult to enlarge. Car plants must work at a certain rate in order to meet production targets and on a moving line it is only viable for each worker to spend a few minutes on a task before the next worker on the line must take over. A way of overcoming this problem is to use teams. Here tasks are exchanged between team members and performance measurements are supplied for the team as a whole. This provides workers with greater variety and feedback, but also some autonomy and participation in the decisions of the team.

Secondly financial factors may be a constraint on further use. These may include the performance of individuals who actually prefer simple jobs, higher wage rates paid for the higher skills of employees increasing average wage costs and the capital costs of introducing the approaches. The problem is that many of the benefits associated with the technique, such as an increase in creativity, may be difficult to measure financially.

Finally the political aspects of job design changes have little effect on organisational structures and the role of management. Although job enrichment may affect supervisory levels of management, by replacement with a team leader for example, the power structures in which technology is used to justify decisions for personal objectives is intact.

10.4 Methods Analysis

Dividing and analysing a job is called method study. The approach takes a systematic approach to reducing waste, time and effort. The approach can be analysed in a six-step procedure:

1. Select

Tasks most suitable will probably be repetitive, require extensive labour input and be critical to overall performance.

2. Record

This involves observation and documentation of the correct method of performing the selected tasks. Flow process charts are often used to represent a sequence of events graphically. They are intended to highlight unnecessary material movements and unnecessary delay periods.

3. Examine

This involves examination of the current method, looking for ways in which tasks can be eliminated, combined, rearranged and simplified. This can be achieved by looking at the flow process chart for example and re-designing the sequence of tasks necessary to perform the activity.

4. Develop

Developing the best method and obtaining approval for this method. This means choosing the best alternative considered taking into account the constraints of the system such as the performance of the firm's equipment. The new method will require adequate documentation in order that procedures can be followed. Specifications may include tooling, operator skill level and working conditions.

5. Install

Implement the new method. Changes such as installation of new equipment and operator training will need to be undertaken.

6. Maintain

Routinely verify that the new method is being followed correctly

New methods may not be followed due to inadequate training or support. On the other hand people may find ways to gradually improve the method over time. Learning curves can be used to analyse these effects.

10.5 Motion Study

Motion study is the study of the individual human motions that are used in a job task. The purpose of motion study is to try to ensure that the job does not include any unnecessary motion or movement by the worker and to select the sequence of motions that ensure that the job is being carried out in the most efficient manner possible. For even more detail videotapes can be used to study individual work motions in slow motion and analyse them to find improvement - a technique termed micromotion analysis. The principles are generally categorised according to the efficient use of the human body, efficient arrangement of the workplace and the efficient use of equipment and machinery. These principles can be summarised into general guidelines as follows:

- Efficient Use of the Human Body
  Work should be rhythmic, symmetrical and simplified. The full capabilities of the human body should be employed. Energy should be conserved by letting machines perform tasks when possible.

- Efficient Arrangement of the Workplace
  Tools, materials and controls should have a defined place and be located to minimise the motions needed to get to them. The workplace should be comfortable and healthy.

- Efficient use of Equipment
  Equipment and mechanised tools enhance worker abilities. Controls and foot-operated devices that can relieve the hand/arms of work should be maximised. Equipment should be constructed and arranged to fit worker use.

Motion study is seen as one of the fundamental aspects of scientific management and indeed it was effective in the design of repetitive, simplified jobs with the task specialisation which was a feature of the mass production system. The use of motion study as declined as there as been a movement towards greater job responsibility and a wider range of tasks within a job. However the technique is still a useful analysis tool and particularly in the service industries, can help improve process performance.

10.6 Work Measurement

The second element of work-study is work measurement which determines the length of time it will take to undertake a particular task. This is important not only to determine pay rates but also to ensure that each stage in a production line system is of an equal duration (i.e. 'balanced') thus ensuring maximum output. Usually the method study and work measurement activities are undertaken together to develop time as well as method standards. Setting time standards in a structured manner permits the use of benchmarks against which to measure a range of variables such as cost of the product and share of work between team members. However the work measurement technique has been criticised for being misused by management in determining worker compensation. The time needed to perform each work element can be determined by the use of historical data, work sampling or most usually time study.

10.6.1 Time Study

The purpose of Time Study is through the use of statistical techniques to arrive at a standard time for performing one cycle of a repetitive job. This is arrived at by observing a task a number of times. The standard time refers to the time allowed for the job under specific circumstances, taking into account allowances for rest and relaxation. The basic steps in a time study are indicated below:

1. Establish the standard job method

It is essential that the best method of undertaking the job is determined using method study before a time study is undertaken. If a better method for the job is found then the time study analysis will need to be repeated.

2. Break down the job into elements

The job should be broken down into a number of easily measurable tasks. This will permit a more accurate calculation of standard time as varying proficiencies at different parts of the whole job can be taken into account.

3. Study the job

This has traditionally been undertaken with a stopwatch, or electronic timer, by observation of the task. Each time element is recorded on an observation sheet. A Video camera can be used for observation, which permits study away from the workplace, and in slow motion which permits a higher degree of accuracy of measurement.

4. Rate the worker's performance

As the time study is being conducted a rating of the worker's performance is also taken in order to achieve a true time rating for the task. Rating factors are usually between 80% and 120% of normal. This is an important but subjective element in the procedure and is best done if the observer is familiar with the job itself.

5. Compute the average time

Once a sufficient sample of job cycles have been undertaken an average is taken of the observed times called the cycle time. The sample size can be determined statistically, but is often around five to fifteen due to cost restrictions.

6. Compute the normal time

Adjust the cycle time for the efficiency and speed of the worker who was observed. The normal time is calculated by multiplying the cycle time by the performance rating factors.

Normal Time (NT) = cycle time (CT) x rating factor (RF)

7. Compute the standard time

The standard time is computed by adjusting the normal time by an allowance factor to take account of unavoidable delays such as machine breakdown and rest periods. The standard time is calculated as Standard Time (ST) = Normal Time (NT) x allowance

10.6.2 Predetermined Motion Times

One problem with time studies is that workers will not always co-operate with their use, especially if they know the results will be used to set wage rates. Combined with the costs of undertaking a time study, a company may use historical data in the form of time files to construct a new standard job time from previous job element. This has the disadvantage however of the reliability and applicability of old data.

Another method for calculating standard times without a time study is to use predetermined motion time system (PMTS) which provides generic times for standard micromotions such as reach, move and release which are common to many jobs. The standard item for the job is then constructed by breaking down the job into micromotions that can then be assigned a time from the motion time database. The standard time for the job is the sum of these micromotion times. Factors such as load weight for move operations are included in the time motion database.

The advantages of this approach are that standard times can be developed for jobs before they are introduced to the workplace without causing disruption and needing worker compliance. Also performance ratings are factored in to the motion times and so the subjective part of the study is eliminated. The timings should also be much more consistent than historical data for instance. Disadvantages include the fact that these times ignore the context of the job in which they are undertaken i.e. the timings are provided for the micromotion in isolation and not part of a range of movement. The sample is from a broad range of workers in different industries with different skill levels, which may lead to an unrepresentative time. Also the timings are only available for simple repetitious work which is becoming less common in industry.

10.6.3 Work Sampling

Work Sampling is useful for analysing the increasing proportion of non-repetitive tasks that are performed in most jobs. It is a method for determining the proportion of time a worker or machine spends on various activities and as such can be very useful in job redesign and estimating levels of worker output. The basic steps in work sampling are indicated below:

1. Define the job activities

All possible activities must be categorised for a particular job. e.g. "worker idle" and "worker busy" states could be used to define all possible activities.

2. Determine the number of observations in the work sample

The accuracy of the proportion of time the worker is in a particular state is determined by the observation sample size. Assuming the sample is approximately normally distributed the sample size can be estimated using the following formula.

$$n = (z/e)^2 * p(1 - p)$$

where

n = sample size
z = number of standard deviation from the mean for the desired level of confidence
e = the degree of allowable error in the sample estimate
p = the estimated proportion of time spent on a work activity

The accuracy of the estimated proportion p is usually expressed in terms of an allowable degree of error e (e.g. for a 2% degree of error, e = 0.02). The degree of confidence would normally be 95% (giving a z value of 1.96) or 99% (giving a z value of 2.58).

3. Determine the length of the sampling period

There must be sufficient time in order for a random sample of the number of observations given by the equation in 2 to be collected. A random number generate can be used to generate the time between observations in order to achieve a random sample.

4. Conduct the work sampling study and record the observations

Calculate the sample and calculate the proportion (p) by dividing the number of observations for a particular activity by the total number of observations.

5.Periodically re-compute the sample size required

It may be that the actual proportion for an activity is different from the proportion used to calculate the sample size in step 2. Therefore as sampling progresses it is useful to re-compute the sample size based on the proportions actually observed.

10.7 Learning Curves

Organisations have often used learning curves to predict the improvement in productivity that can occur as experience is gained of a process. Thus learning curves can give an organisation a method of measuring continuous improvement activities. If a firm can estimate the rate at which an operation time will decrease then it can predict the impact on cost and increase in effective capacity over time. The learning curve is based on the concept of when productivity doubles, the decrease in time per unit is the rate of the learning curve. Thus if the learning curve is at a rate of 85%, the second unit takes 85% of the time of the first unit, the fourth unit takes 85% of the second unit and the eighth unit takes 85% of the fourth and so on. Mathematically the learning curve is represented by the function

$y = ax^{-b}$

where

x = number of units produced
a = hours required to produce the first unit
y = time to produce the xth unit
b= constant equal to -(ln p)/(ln 2)

where

$\ln = \log_{10}$
p = learning rate (e.g. 80% = 0.8)

Thus for a 80% learning curve

$b = -(\ln 0.8)/\ln(2) = -(-0.233)/0.693 = 0.322$

Learning curves are usually applied to individual operators, but the concept can also be applied in a more aggregate sense, termed an experience or improvement curve, and applied to such areas as manufacturing system performance or cost estimating. Industrial sectors can also be shown to have different rates of learning. It should be noted that improvements along a learning curve do not just happen and the theory is most applicable to new product or process development where scope for improvement is greatest. In addition step changes can occur which can alter the rate of learning, such as organisational change, changes in technology or quality improvement programs. To ensure learning occurs the organisation must invest in factors such as research and development, advanced technology, people and continuous improvement efforts.

11 Project Management

A project is an interrelated set of activities with a definite starting and ending point, which results in a unique outcome for a specific allocation of resources (Krajewski et al., 2010). The complexity of the project will increase with the size and number of activities within the project. Extensive planning and co-ordination activities are required for larger projects to ensure that the project aims are met. Examples of projects include installing an IT system, building a bridge or introducing a new service or product to the market.

11.1 Project Management Activities

The project management process includes the following main elements:

11.1.1 Feasibility Analysis

This step involves evaluating the expected cost of resources needed to execute the project and compare these to expected benefits. At the start of the project a plan of the resources required to undertake the project activities is constructed. If there is a limit on the amount of resources available then the project completion date may have to be set to ensure there resources are not overloaded. This is a resource-constrained approach. Alternatively the need to complete the project by a specific date may take precedence. In this case an alternative source of resources may have to be found, using sub-contractors for example, to ensure timely project completion. This is called a time-constrained approach.

Once a plan has been constructed it is necessary to calculate estimates for the time and resources required to undertake each activity in the project. Statistical methods should be used when the project is large (and therefore complex) or novel. This allows the project team to replace a single estimate of duration with a range within which they are confident the real duration will lie. This is particularly useful for the early stage of the project when uncertainty is greatest. The accuracy of the estimates can also be improved as their use changes from project evaluation purposes to approval and day-to-day project control. The PERT approach allows optimistic, pessimistic and most likely times to be specified for each task from which a probabilistic estimate of project completion time can be computed.

11.1.2 Plan

This stage estimated the amount and timing of resources needed to achieve the project objectives.

The project management method uses a systems approach to dealing with a complex task in that the components of the project are broken down repeatedly into smaller tasks until a manageable chunk is defined. Each task is given its own cost, time and quality objectives. It is then essential that responsibility is assigned to achieving these objectives for each particular task. This procedure should produce a work breakdown structure (WBS) which shows the hierarchical relationship between the project tasks.

11.1.3 Control

This stage involves the monitoring the progress of the project as it executes over time. This is important so that any deviations from the plan can be addressed before it is too near the project completion date to take corrective action. The point at which the project progress is assessed is termed a Milestone.

The type of project structure required will be dependent on the size of the team undertaking the project. Projects with up to six team members can simply report directly to a project leader at appropriate intervals during project execution. For larger projects requiring up to 20 team members it is usual to implement an additional tier of management in the form of team leaders. The team leader could be responsible for either a phase of the development or a type of work. For any structure it is important that the project leader ensures consistency across development phases or development areas as appropriate. For projects with more than 20 members it is likely that additional management layers will be needed in order to ensure that no one person is involved with too much supervision.

The two main methods of reporting the progress of a project are by written reports and verbally at meetings of the project team. It is important that a formal statement of progress is made in written form, preferably in a standard report format, to ensure that everyone is aware of the current project situation. This is particularly important when changes to specifications are made during the project. In order to facilitate two-way communication between team members and team management, regular meetings should be arranged by the project manager. These meetings can increase the commitment of team members by allowing discussion of points of interest and dissemination of information on how each team's effort is contributing to the overall progression of the project.

11.2 Network Analysis

This section describes the major stages in the construction of the critical path method (CPM) and program evaluation and review (PERT) project networks. The stages in network analysis are now outlined.

11.2.1 Identifying Project Activities

In order to undertake network analysis it is necessary to break down the project into a number of identifiable activities or tasks. This enables individuals to be assigned responsibility to particular tasks which have a well-defined start and finish time. Financial and resource planning can also be conducted at the task level and co-ordinated by the project manager who must ensure that each task manager is working to the overall project objectives and not maximising the performance of particular task at the expense of the whole project.

Activities consume time and/or resources. The first stage in planning a project is to break down the project into a number of identifiable activities with a start and end. Performance objectives of time, cost and quality can be associated with each activity. The project is broken down into these tasks using a work breakdown structure. This is a hierarchical tree structure which shows the relationship between the tasks as they are further sub-divided at each level.

11.2.2 Estimating Activity Durations

The next stage is to retrieve information concerning the duration of the tasks involved in the project. The can be collated from a number of sources, such as documentation, observation, interviewing etc. Obviously the accuracy of the project plan will depend on the accuracy of these estimates. There is a trade-off between the cost of collecting information on task duration's and the cost of an inaccurate project plan.

11.2.3 Identifying Activity Relationships

It is necessary to identify any relationships between tasks in the project,. For instance a particular task may not be able to begin until another task has finished. Thus the task waiting to begin is dependent on the former task. Other tasks may not have a dependent relationship and can thus occur simultaneously.

Critical path diagrams are used extensively to show the activities undertaken during a project and the dependencies between these activities. Thus it is easy to see that activity C for example can only take place when activity A and activity B has completed. Once a network diagram has been constructed it is possible to follow a sequence of activities, called a path, through the network from start to end. The length of time it takes to follow the path is the sum of all the durations of activities on that path. The path with the longest duration gives the project completion time. This is called the critical path because any change in duration in any activities on this path will cause the whole project duration to either become shorter or longer. Activities not on the critical path will have a certain amount of slack time in which the activity can be delayed or the duration lengthened and not affect the overall project duration. The amount of slack is a function of the difference between the path duration the activity is on and the critical path duration. By definition all activities on the critical path have zero slack. It is important to note that there must be at least one critical path for each network and there may be several.

There are two methods of constructing critical path diagrams, Activity on Arrow (AOA) were the arrows represent the activities and Activity on Node (AON) were the nodes represent the activities. The issues involved in which one to utilise will be discussed later. The following description on critical path analysis will use the AON method.

11.2.4 Drawing the Network Diagram

For the activity-on-node notation each activity task is represented by a node with the following format. Thus a completed network will consist of a number of nodes connected by lines, one for each task, between a start and end node.

Calculating the Earliest Start/Finish times (forward pass)

From the duration of each task and the dependency relationship between the tasks it is possible to estimate the earliest start and finish time for each task as follows. You move left to right along the network, forward through time.

1. Assume the start (i.e. first) task begins at time = 0.

2. Calculate the earliest finish time where:-

Earliest Finish = Earliest Start + Duration

Calculate the earliest start time of the next task where:-

Earliest Start = Earliest Finish of task immediately before.

If there is more than one task immediately before take the task with the latest finish time to calculate the earliest start time for the current task.

Repeat steps 2 and 3 for all tasks

Calculating the Latest Start/Finish times (backward pass)

It is now possible to estimate the latest start and finish time for each task as follows. You move right to left along the network, backward through time.

1. Assume the end (i.e. last) task end time is the earliest finish time (unless the project end time is given).

2. Calculate the latest start time where:-

Latest Start = Latest Finish - Duration

Calculate the latest finish time of the previous task where:-

Latest Finish = Latest Start of task immediately after.

If there is more than one task immediately after take the task with the earliest start time to calculate the latest finish time for the current task.

Repeat steps 2 and 3 for all tasks

Calculating the slack/float times

The slack or float value is the difference between the earliest start and latest start (or earliest finish and latest finish) times for each task. To calculate the slack time

1. Slack = Latest Start - Earliest Start OR Slack = Latest Finish - Earliest Finish

2. Repeat step 1 for all tasks.

Identifying the Critical Path

Any tasks with a slack time of 0 must obviously be undertaken on schedule at the earliest start time. The critical path is the pathway connecting all the nodes with a zero slack time. There must be at least one critical path through the network, but there can be more than one. The significance of the critical path is that if any node on the path finishes later than the earliest finish time, the overall network time will increase by the same amount, putting the project behind schedule. Thus any planning and control activities should focus on ensuring tasks on the critical path remain within schedule.

11.2.5 Identifying Schedule Constraints - Gantt Charts

Although network diagrams are ideal for showing the relationship between project tasks, they do not provide a clear view of which tasks are being undertaken over time and particularly how many tasks may be undertaken in parallel at any one time. The Gantt chart provides an overview for the Project Manager to allow them to monitor project progress against planned progress and so provides a valuable information source for project control.

To draw a Gantt Chart manually undertake the following steps:

- Draw a grid with the tasks along the vertical axis and the time-scale (up to the project duration) along the horizontal axis.

- Draw a horizontal bar across from the task identifier along the left of the chart starting at the earliest start time and ending at the earliest finish time.

- Indicate the slack amount by drawing a line from the earliest finish time to the latest finish time.

11.2.6 Project Crashing

The use of additional resources to reduce project completion time is termed *crashing* the network. This involves reducing overall indirect project costs by increasing direct costs on a particular task. One of most obvious ways of decreasing task duration is to allocate additional labour to a task. This can be either an additional team member or through overtime working. To enable a decision to be made on the potential benefits of crashing a task the following information is required.

- The normal task duration
- The crash task duration
- The cost of crashing the task to the crash task duration per unit time

The process by which a task is chosen for crashing is by observing which task can be reduced for the required time for the lowest cost. As stated before the overall project completion time is the sum of the task durations on the critical path. Thus it is always necessary to crash a task which is on the critical path. As the duration of tasks on the critical path are reduced however other paths in the network will also become critical. If this happens it will require the crashing process to be undertaken on all the paths which are critical at any one time.

12 Inventory Management

Inventory is the stock of items kept by an organisation to meet internal or external customer demand (Russell and Taylor, 2009). The type of inventory management system employed is determined by the nature of the demand for the goods and services on the organisation. Demand can be classified into two categories; dependent and independent.

12.1 Dependent Demand

A dependent demand item has a demand which is relatively predictable because it is dependent on other factors. Thus a dependent demand item can be classified has having a demand that can be calculated as the quantity of the item needed to produce a scheduled quantity of an assembly that uses that item.

12.2 Independent Demand

Independent demand is when demand is not directly related to the demand for any other inventory item. Usually this demand comes from customers outside the company and so is not as predictable as dependent demand. Because of the unknown future requirements of customers, forecasting is used to predict the level of demand. A safety stock if then calculated to cover expected forecast error. Independent demand items can be finished goods or spare parts used for after sales service.

12.3 Types of Inventory

Generally inventory is classified as either raw materials, work-in-progress (WIP) or finished goods. The proportion between these inventory types will vary but it is estimated that generally 30% are raw materials, 40% are work in progress and 30% finished goods. The location of inventory can be used to define the inventory type and its characteristics. There are various definitions of inventory types including the following:

- Buffer/Safety
  This is used to compensate for the uncertainties inherent in the timing or rate of supply and demand between two operational stages.

- Cycle
  If it is required to produce multiple products from one operation in batches, there is a need to produce enough to keep a supply while the other batches are being produced.

- Anticipation
  This includes producing to stock to anticipate a increase in demand due to seasonal factors. Also speculative policies such as buying in bulk to take advantage of price discounts may also increase inventory levels.

- Pipeline/Movement
  This is the inventory needed to compensate for the lack of stock while material is being transported between stages. e.g. the time taken in distribution from the warehouse to a retail outlet.

12.4 Inventory Decisions

The main concern of inventory management is the trade-off between the cost of not having an item in stock against the cost of holding and ordering the inventory. A stock-out can either be to an internal customer in which case a loss of production output may occur, or to an external customer when a drop in customer service level will result. In order to achieve a balance between inventory availability and cost the following inventory management aspects must be addressed of volume - how much to order and timing - when to order.

12.5 The Economic Order Quantity (EOQ) Model

The Economic Order Quantity (EOQ) calculates the inventory order volume which minimises the sum of the annual costs of holding inventory and the annual costs of ordering inventory. The model makes a number of assumptions including:

- Stable or Constant Demand
- Fixed and identifiable ordering cost
- The cost of holding inventory varies in a linear fashion to the number of items held
- The item cost does not vary with the order size
- Delivery lead time does not vary
- No quantity discounts are available
- Annual demand exists

These assumptions have led to criticisms of the use of EOQ in practice. The assumption of one delivery per order, and then the use of that stock over time increases inventory levels and goes against a JIT approach. Also annual demand will not exist for products with a life-cycle of less than a year. However the EOQ approach still has a role in inventory management in the right circumstances and if its limitations are recognised.

Using the EOQ each order is assumed to be of Q units and is withdrawn at a constant rate over time until the quantity in stock is just sufficient to satisfy the demand during the order lead time (the time between placing an order and receiving the delivery). At this time an order for Q units is placed with the supplier. Assuming that the usage rate and lead time are constant the order will arrive when the stock level is at zero, thus eliminating excess stock or stock-outs.

The order quantity must be set at a level which is not too small, leading to many orders and thus high order costs and not too large leading to high average levels of inventory and thus high holding costs.

The annual holding cost is the average number of items in stock multiplied by the cost to hold an item for a year. If the amount in stock decreases at a constant rate from Q to 0 then the average in stock is Q/2.

Thus if C_H is the average annual holding cost per unit, the total annual holding cost is:

$$\text{Annual Holding Cost} = \frac{Q}{2} * C_H$$

The annual ordering cost is a function of the number of orders per year and the ordering cost per order. If D is the annual demand, then the number of orders per year is given by D/Q. Thus if C_O is the ordering cost per order then the total annual ordering cost is:

$$\text{Annual Ordering Cost} = \frac{D}{Q} * C_O$$

Thus the total annual inventory cost is the sum of the total annual holding cost and the total annual ordering cost:

$$\text{Total Annual Cost} = \frac{Q}{2} * C_H + \frac{D}{Q} * C_O$$

where

Q = order quantity
C_H = holding cost per unit
D = annual demand
C_O = ordering cost per order

The minimum total cost point is when the holding cost is equal to the ordering cost and solving for Q gives:

$$\text{EOQ} = 2 * \sqrt{}(D * C_O) / C_H$$

12.6 The Re-Order Point (ROP) Model

The EOQ model tells us how much to order, but not when to order. The Reorder point model identifies the time to order when the stock level drops to a predetermined amount. This amount will usually include a quantity of stock to cover for the delay between order and delivery (the delivery lead time) and an element of stock to reduce the risk of running out of stock when levels are low (the safety stock).

The previous economic order quantity model provides a batch size that is then depleted and replenished in a continuous cycle within the organisation. Thus the EOQ in effect provides a batch size which the organisation can work to. However this assumes that demand rates and delivery times are fixed so that the stock can be replenished at the exact time stocks are exhausted. Realistically though both the demand rate for the product and the delivery lead-time will vary and thus the risk of a stock-out is high. The cost of not having a item in stock when the customer requests it can obviously be costly both in terms of the potential loss of sales and the loss of customer goodwill leading to further loss of business.

12.6.1 Safety Stock and Service Level

Safety stock is used in order to prevent a stock-out occurring. It provides an extra level of inventory above that needed to meet predicted demand, to cope with variations in demand over a time period. The level of safety stock used, if any, will vary for each inventory cycle, but an average stock level above that needed to meet demand will be calculated.

To calculate the safety stock level a number of factors should be taken into account including:

- cost due to stock-out
- cost of holding safety stock
- variability in rate of demand
- variability in delivery lead time

It is important to note that there is no stock-out risk between the maximum inventory level and the reorder level. The risk occurs due to variability in the rate of demand and due to variability in the delivery lead time between the reorder point and zero stock level.

The reorder level can of course be estimated by a rule of thumb, such as when stocks are at twice the expected level of demand during the delivery lead time. However to consider the probability of stock-out, cost of inventory and cost of stock-out the idea of a service level is used.

The service level is a measure of the level of service, or how sure, the organisation is that it can supply inventory from stock. This can be expressed as the probability that the inventory on hand during the lead time is sufficient to meet expected demand (e.g. a service level of 90% means that there is a 0.90 probability that demand will be met during the lead time period, and the probability that a stock-out will occur is 10%. The service level set is dependent on a number of factors such as stockholding costs for the extra safety stock and the loss of sales if demand cannot be met.

12.7 The ABC Inventory Classification System

Normally a mix of fixed-order-interval and fixed order quantity inventory systems are used within an organisation. When there are many inventory items involved this raises the issue of deciding which particular inventory system should be used for a particular item. The ABC classification system sorts inventory items into groups depending on the amount of annual expenditure they incur. This will depend on both the estimated number of items used annually multiplied by the unit cost. To instigate a ABC system a table is produced listing the items in expenditure order (with largest expenditure at the top), and showing the percentage of total expenditure and cumulative percentage of the total expenditure for each item.

By reading the cumulative percentage figure it is usually found, following Pareto's Law, that 10-20% of the items account for 60-80% of annual expenditure. These items are called A items and need to be controlled closely to reduce overall expenditure. This often implies a fixed quantity system with perpetual inventory checks or a fixed-interval system employing a small time interval between review periods. It may also require a more strategic approach to management of these items which may translate into closer buyer-supplier relationships. The B items account for the next 20-30% of items and usually account for a similar percentage of total expenditure. These items require fewer inventory level reviews than A items. A fixed order interval system with a minimum order level may be appropriate here. Finally C items represent the remaining 50-70% of items but only account for less than 25% of total expenditure. Here much less rigorous inventory control methods can be used, as the cost of inventory tracking will outweigh the cost of holding additional stock.

It is important to recognise that overall expenditure may not be the only appropriate basis on which to classify items. Other factors include the importance of a component part on the overall product, the variability in delivery time, the loss of value through deterioration and the disruption caused to the production process if a stock-out occurs.

Bibliography

Barnes, D 2008, *Operations Management: An International Perspective*, Thomson Learning, London.

Crosby, P.B. 1996, *Quality is Free: Making Quality Certain in Uncertain Times*, McGraw-Hill.

Deming, W.E. 1985, Transformation of Western-Style Management, *Interfaces*, 15(3), 6-11.

Hill, T 2005, *Operations Management*, 2nd edn, Palgrave Macmillan, Basingstoke.

Johnston, R & Clark, G 2008, *Service Operations Management: Improving Service Delivery*, 3rd edn, Pearson Education, Harlow.

Juran, J.M. 2001, *Juran's Quality Handbook*, 5th Edition, McGraw-Hill.

Krajewski, L.J; Ritzman, L.P; Malhotra, M.K 2010, *Operations Management: Processes and Supply Chains*, 9th edn, Pearson Education, New Jersey.

Ohno, T. 1988 *Toyota Production System: Beyond Large-Scale Production*, Productivity Press.

Russell, R.S & Taylor, B.W 2009, *Operations Management: Along the Supply Chain*, 6th edn, John Wiley & Sons Ltd, New York.

Shingo, S 1989, *A Study of Toyota Production System*, Productivity Press.

Slack, N; Chambers, S; Johnston, R 2010, *Operations Management*, 6th edn, Pearson Education Limited, Harlow.

Slack, N; Lewis, M 2011, *Operations Strategy*, 3rd edn, Pearson Education Limited, Harlow.