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The Basics of Operations Management

Course material

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Content

PREFACE

This material aims to make Readers aware of the key concepts and objectives of operations management, as well as the various methods and tools that support management activities, while exemplifying their use. The theories and methods presented in the following are mainly based on the related chapters of the books of Koltai (2009) and Kövesi (2015).

The field of operations management deals with problems related to production and service system processes and its purpose is to make efficient use of resources directly involved in process improving actions. According to Gaither (1990, 4), "*operations management is the planning, organizing, staffing, directing, and controlling of all of the activities of production systems – those portions of organizations that convert inputs into products and services".*

This course material illustrates that engineers and managers do not represent two separate worlds, but look at the company's operations and tasks from a different aspect. Moving up in the corporate hierarchy, along with a purely professional approach, the managerial viewpoint will inevitably appear. It is an important task to strengthen the link between engineering education and management skills, to increase mutual respect between the two sides, as well as to prepare engineers (and, of course, other professionals) for new (increasingly managerial) challenges as a natural advance in their careers.

1. INTRODUCTION TO OPERATIONS MANAGEMENT

Operations management is considered to be an area of management, although most of the issues it deals with lie at the borderline of management and engineering. According to Gaither's (1990) definition, *operations management is responsible for the management of the system which converts input resources into products and services*. Chase and Aquilano (1995) define operations management as *the design, operation and improvement of the system that create and deliver the firm's primary products and services*. This latter definition already includes a reference to the engineering function.

The examples listed in Table 1 all meet the above cited definition by Gaither. As can be seen, an automobile factory, a hospital, a restaurant and a department store are all considered as production systems. This is because the efficient operation of many service systems can be ensured on the same scientific basis that applies to classic manufacturing systems.

Table 1 Examples of production systems according to Gaither's definition

System	Primary Inputs	Resources (among others)	Primary Transformation	Typical Desired Output
Hospital	Patients	MDs, nurses, medical supplies, medicines	Cure, healing, consult	Healthy individuals
Restaurant	Hungry customers	Food supplies, personnel, building	Preparation, cooking, serving	Satisfied customers
Automobile factory	Sheet steel, engine parts	Workers, raw material, equipment, tools	Fabrication and assembly of cars	High-quality cars
College or university	High school graduates	Teachers, books, classrooms, buildings	Transmit knowledge and skills	Educated individuals
Department store	Shoppers	Display, stock of goods, shopping carts	Attract shoppers, promote and sells products	Marketed goods
Accounting firm	Customers, information	Utilities, computers, office furniture	Compile data, compute taxes	Tax services

While ensuring the effective operation of manufacturing and service systems is a management task, the creation of a well-functioning system belongs to the scope of what is called *industrial engineering*. It implies that there is an overlap between operations management and industrial engineering. This is no accident, because a system cannot be managed successfully without having some understanding of its technical-technological aspects; and a good system cannot be designed without having a basic idea about management. Its engineering and management aspects place operations management on the borderline between the domains of management and technical sciences.

Operations management is an operative area of management with a distinct body of knowledge. The current form of theories and methods employed in operations management has been strongly influenced by many historical, economic and technological developments. Gaither (1990) among others listed some significant progresses which had an impact on operations management:

- One of the defining pillars of today's operations management toolkit, as he mentioned, is the *industrial revolution* of the 1700s, after which the use of machine power accelerated and the factory system established.
- Thanks to the researchers of *scientific management*, many studies focused on, for example, standardization and production planning (Frederick Winslow Taylor), efficiency measurement and improvement (Harrington Emerson), reassessment of the role of the human factor in manufacturing (Lillian M. Gilbreth) or application of mathematical analyses (Carl G. Barth).
- The scientific basis of this body of knowledge is *operations research* (OR), a field of mathematics concerned with developing and using models to optimise system operation. OR approaches problem solving and decision making from the total system's perspective. A significant part of the operations management toolkit is consisted of mathematical models, which greatly contribute to the support of managerial decisions and the successful operation of systems (Kalló, 2012).
- With the advent of *computer technology*, more and more methods and tools have been used to make processes more efficient. Thanks to the advancements in technology, computer-integrated manufacturing was introduced in the 1980s. The development of robotics has attracted the appearance of computer-aided design (CAD) and computer-aided manufacturing (CAM) concepts. With the help of these new and new production automation processes, special software and hardware were born. Technology has evolved to include, for example, Flexible Manufacturing Systems (FMS), Automated Storage and Retrieval Systems (ASRS) and Automated Identification Systems (AIS).
- The spread of various services and, consequently, the growth of the service sector have significantly transformed the economy. The majority of the workforce is employed in this sector, it plays an important role in the production of national and international economic indicators, and most of the investments goes into this sector. This *"service revolution"* has a significant impact on operations management.

Nowadays, the most important competitive advantage for leading companies is the information available on operations, their proper analysis and application in different models (Davenport, 2006). To maintain and gain further competitive advantage, companies that compete in cost-, quality-, and time-based competition must also compete in quantitative competition. It means that they have to apply a wide range of quantitative tools and incorporate all available information into their decision support models (Kalló and Koltai, 2013). To remain capable of competing and evolving, companies must incorporate Big Data, as well as Industry 4.0 philosophies and achievements into their strategies.

Operations management deals with the management of resources that are directly involved in manufacturing and service processes. Thus, when reviewing its task, it is important to talk about the indicators on the basis of which the consequences of managerial decisions can be evaluated. Corporate management is usually interested in improving the financial performance of the company (maximizing shareholder value) and therefore expresses its expectations and goals with the help of financial indicators. Thus, for example, corporate management expects profit growth, a faster return on investment and remedies for cash flow problems. However, an operations management problem is often very remote from the evolution of corporate profits. Decisions made in this field have a direct impact on the production process. The indicators used for the evaluation of decisions in the field of operations management fall into the following three groups:

- *Production volume indicators* can be used to measure, summarize or evaluate the quantity produced by the production process. These indices include, for example, the *production rate*, which expresses the volume produced per unit time (hour, month, etc.), and the *cycle time*, which is the average time interval between two consecutive finished products leaving the production line. If the output rate is high, the production volume is high. Conversely, if the cycle time is long, the production volume is probably not very high.
- *Inventory indices* describe the amount of materials (raw materials, parts, finished products) necessary for the production process. If the production process requires a high inventory, then the operations management function is probably in need of improvement. One of the inventory indices is average inventory, which may be reduced, for example, by organising production according to Just-In-Time (JIT) principles[1].
- *The operating (operational) costs of production* include, for example, maintenance costs, quality costs and direct wage costs associated with pieceworkers. These costs can be influenced by operations management decisions. By contrast, marketing costs or financing costs cannot be used for evaluating operations management decisions.

These three factors should not be considered independently. Management should seek to establish and maintain the relationship between production volume, inventory and operating cost indicators. If the production rate is growing while the inventory level and the operating costs are simultaneously falling, then the production process is clearly improving. Of course, such an ideal situation rarely occurs, but the objective remains the simultaneous improvement of the three indices. In the following, three special fields of operations management are presented briefly according to the three operational indices discussed above.

[1]JIT production systems align raw-material orders from suppliers directly with production schedules. The main objectives of JIT are to produce the finished products at the right time, in the right quantities and to improve process efficiency by eliminating waste. According to lean management principles, waste can come from 7 sources: overproduction, over-processing, transport, motion, waiting, inventory, defects.

2. Capacity Planning

One of the main tasks for operations management is to plan the amount of capacity available. This information serves as a basis for deciding about, for example, which orders to accept, when to raise or lower inventory levels or where to increase or reduce capacity.

Resource capacity is defined as *the amount of products or services that can be produced or provided in a given period of time*. It is important to note that this definition contains a reference to time. When the capacity of a given resource is expressed in numerical terms, it must always be related to a specific period of time (for example, units per month, tonnes per year, or customers per day). Saying that a piece of equipment works 200 hours a month does not tell much about the actual capacity of it because that is determined by the resource requirements of the product it makes. However, the capacity of many resources does not depend on solely technical parameters. For example, the capacity of a passenger aircraft is not equal to its seating capacity. Its monthly capacity will also depend on the number of flights it is scheduled for and the routes it flies.

Another important aspect of the above definition is its general applicability to the capacity of any resource. It is equally valid for manufacturing systems (machines, production lines, plants), service systems (bank counters, restaurants) and organizational units (purchasing department). In the following, we will present some simple ways to determine and characterize capacity. First, we will discuss methods for short-term capacity analysis, the aim of which is to adjust capacity to temporary changes in demand over the short term. Then we will look at some problems of long-term capacity analysis in order to show how capacity can be adjusted to meet increasing or decreasing customer demands while taking into account economic considerations.

2.1. Formulae for short-term capacity analysis

This section will present the calculation of four important and widely used capacity indices.

1. ***Design capacity*** is the maximum output of a resource (machine, organizational unit, service point) *under ideal conditions* in a given period. This index shows the amount that a resource can produce if it works as much as possible under ideal conditions. The design capacity is calculated as follows:

$$\text{Design capacity} = \frac{\text{total time available}}{\text{time needed to make one unit of product or service}} = \frac{NDSH}{M},$$

where:

- N - number of parallel resources having equivalent properties
- D - number of working days available
- S - number of shifts per day
- H - number of hours worked during one shift
- M - time needed to produce one item or serve one customer

The calculation principle is simple: the numerator is the time available, the denominator is the time needed to make one unit of the product or service.

2. ***Effective capacity*** is the maximum output that a resource (machine, organizational unit, service point) can be expected to produce in a given period when it works *in an actual operating schedule*.

$$\text{Effective capacity} = \frac{\text{planned working time}}{\text{time needed to make one unit of product or service}} = \frac{NDSH(1-\xi)}{M},$$

where ξ is a factor between 0 and 1 which represents the expected time loss attributable to the particularities of the process and the operating schedule. In practice, its value is often given as a percentage loss. ξ may include several types of time loss, like the time lost due to *maintenance, scheduled rest periods and setup times*.

For example, a plant of a multinational company producing pneumatic parts divides ξ into four components for the purpose of defining effective capacity. These reflect the losses associated with worker productivity (man), equipment characteristics (machine), product features (material), and organizational reasons (method) – according to the 4M method, described in the chapter of Quality Management. The essence of the formula is that there is *a predictable, expected and reasonable downtime* which may reduce the amount of time available for producing products or serve customers.

The design capacity and the effective capacity are *absolute indices* that refer to the maximum output a system is capable of producing under ideal and realistic conditions, respectively. However, management is also interested in the actual output produced by a manufacturing or service system compared to these maximum values. This is given by the following two *relative capacity indices*:

3. ***Capacity utilization*** refers to the proportion of the design capacity that is actually used:

$$\text{Capacity utilization} = \frac{\text{Actual output}}{\text{Design capacity}}$$

4. ***Efficiency*** refers to the proportion of the capacity actually used under normal conditions:

$$\text{Efficiency} = \frac{\text{Actual output}}{\text{Effective capacity}}$$

The following simple example illustrates the application of absolute and relative capacity indices. A machine works for one eight-hour shift on five days a week. When working, it can produce 100 units an hour. 10% of its time is needed for maintenance and setups. The output of the machine was 3000 units in a particular week. The time needed to make one unit (M) can be expressed as the reciprocal of the production rate (P), since both measures give reference to the productivity ability of the machine but in an inverse way. In our example, P is given as 100 units an hour. From this data, M is expressed as 1/100. On the basis of these data, the capacity indices are:

$$\text{Design capacity} = \frac{NDSH}{M} = \frac{1 \times 5 \times 1 \times 8}{\frac{1}{100}} = 5 \times 8 \times 100 = 4{,}000 \text{ units a week}$$

Effective capacity = $\dfrac{NDSH\left(1-\xi\right)}{M} = \dfrac{1\times5\times1\times8\times\left(1-0.1\right)}{\frac{1}{100}} = 5\times8\times100\times0.9$

$= 3{,}600$ units a week

Capacity utilization = $\dfrac{\text{Actual output}}{\text{Design capacity}} = \dfrac{3000}{4000} = 0.75 \quad \rightarrow \quad 75\%$

Efficiency = $\dfrac{\text{Actual output}}{\text{Effective capacity}} = \dfrac{3000}{3600} = 0.833 \quad \rightarrow \quad 83.3\%$

The results of the calculations show that the actual output was lower than what could be possible in the given operating schedule (83.3% efficiency). The reasons for this may include less orders than expected, or raw material problems and the resultant increase in the time to make one unit. The difference between capacity utilization and efficiency indicates that the output may be increased if necessary, for example by scheduling maintenance outside operating hours.

When measuring the utilization of a manufacturing or service system, capacity utilization should be considered in conjunction with efficiency. These two indices indicate problems that should be solved at different levels of management. That is why assessing resource use solely on the basis of capacity utilization often leads to wrong conclusions or incorrect identification of the reasons (Waters, 1996).

These four capacity indices are widely used for evaluating capacity in practice. There are, however, limits to their application. Two of the most important ones are the following:

- These formulas can only be used to describe capacity in cases involving a single product or service because they only include one variable referring to time (*M*). Where several products or services use the same capacity, we may either use an average time (weighted, for example, by the production volume) in the calculations or, in more complex cases, have recourse to mathematical optimization (Johnson, 1974). There is no doubt, however, that these formulae are useful for making short-term calculations, for example in order to decide if a certain amount of a given product can be produced during the next shift on a machine that also produces other products.
- The formulae presented in this section are deterministic because they ignore the fact that the time available and/or the time to make one unit may be a random variable. Queuing theory has shown that lower capacity utilization (for example, 60%) also results in acceptable operation (for reasons such as low inventory or short waiting time) if the service (manufacturing) time and the inter-arrival time are random variables (Kleinrock, 1979). The formulae discussed here give a general and static view of systems. More detailed analyses of dynamic system behaviour must be based on queuing models and simulation (Law, 1991).

Nevertheless, despite all the criticism, the presented absolute and relative capacity indices belong to the most important operational indices of manufacturing and service systems.

2.2. Short-term capacity planning

The formulae introduced in the previous section can be used to address issues related to the short-term availability of capacity. Short-term decisions concern whether an order or a temporary increase in demand can be met in the short term (within a few days, weeks, months). In other words, capacity needs to be adjusted to *temporary*, and not permanent, changes in demand. *The aim of short-term capacity planning is, therefore, to ensure that capacity matches demand over the short-term*. There are two ways to do this: one is to influence demand, and the other is to change the capacity available.

1. ***Demand management.*** Solving short-term capacity problems by influencing demand has become popular in recent years. The aim of demand management is to redirect demand from periods of capacity shortage to periods of spare capacity. This approach is effective if, firstly, it is possible to influence demand and, secondly, influencing demand is less costly than changing capacity. Typical ways of influencing demand for reasons related to capacity may include the following:

    - *Promotions.* Price reductions are often used to stimulate purchases/consumption in periods of spare capacity in cases where changing the capacity of a manufacturing or service system is costly. A typical example of this is the so called "happy hour", which is a discount that is only available for a specific time period. This is a common practice among airlines, hotels and fast food restaurants, among others.

    - *Producing for stock in periods of spare capacity.* Where it is possible to store the product, the production system may produce for stock in periods of spare capacity so that it can satisfy a large part of the demand from stock in periods of capacity shortage. An important condition for this is that the holding cost of the stored product must be lower than the cost of increasing capacity in periods of capacity shortage. This practice is typical of manufacturers of seasonal products (such as ice cream).

    - *Changing/increasing the lead time for order fulfilment.* In periods of lack of capacity, companies may take orders with increased lead times (with an extended deadline). This is possible if the cost of increasing capacity is higher than the loss associated with losing customers because of the longer lead time. A good example of this is the increased delivery time of mail order companies during the Christmas season.

    - *Introducing advance ordering, making appointments.* In this case, customers will only be able to make purchases during certain periods if they have previously booked the order. This is only feasible if the cost of losing customers due to introducing the advance ordering (or reservation) system is not higher than the cost of increasing capacity. This is a common practice in the service sector, such as in restaurants, beauty salons or confectioneries.

It should be emphasized again that, in the above cases, the aim of influencing customers is not to increase demand, but to redirect some of the demand from a period of capacity shortage to a period of spare capacity.

2. ***Capacity management.*** Influencing capacity in the short term means changing the data used in the formula for calculating the effective capacity. This may include varying the number of resources available (N), the number of working days (D), the number of shifts (S), the number of hours in a shift (H), the scheduled downtime (ξ), and the time to make one unit (or to serve one customer) (M). Some of the typical ways of increasing capacity in the short term are the following:

   - *Working overtime.* Capacity may be temporarily increased by working beyond the normal working hours, at increased wage cost. This is an acceptable way of expanding capacity if the additional wage costs are lower than the direct or indirect losses caused by capacity shortage.
   - *Increasing the number of shifts.* Many manufacturing plants and service systems work different numbers of shifts on different days. Not infrequently, the bottleneck of a production system works more shifts than its other parts. The additional costs incurred by increasing the number of shifts must be lower than the direct or indirect losses caused by capacity shortage.
   - *Rescheduling maintenance.* Capacity may be expanded by performing maintenance work outside operating hours. This will not change the design capacity of the manufacturing or service system, but its effective capacity will increase as a result of the reduction of planned intermissions.
   - *Using subcontractors.* One way of increasing capacity is to accept orders beyond capacity and have the work done by subcontractors. The cost of subcontracting manufacturing is usually higher than the cost of using one's own resources, but the additional costs may still be lower than the direct or indirect losses arising from the rejection of orders.
   - *Leasing equipment.* The number of resources used may be increased in the short term by leasing machines and equipment. Since the rent represents an additional cost, it is necessary to consider the cost-effectiveness of this solution.
   - *Making the customer perform certain operations.* Not infrequently, capacity is increased by omitting certain operations to reduce the time needed to make a product. The customer may be stimulated to finish the product by offering a cheaper price. For example, a furniture company may achieve a considerable reduction in the required transport and storage capacity by introducing flat packs and making the customer perform the final assembly operations.

These methods of changing capacity on a temporary basis may be used separately or in combination. It is up to management to decide how many hours of overtime are cost-effective, or when it is worth using subcontractors as well. The analysis of economic outcomes must take into account the cost of short-term capacity expansion, as well as the additional cost incurred by using the increased capacity. The economic outcomes must be analysed because it is not enough to increase capacity; capacity should be increased in the most economical way possible.

So far, we have discussed how to increase capacity, but it is also possible that capacity has to be reduced. In that case, the same tools may be applied in the opposite direction. More specifically, working time may be shortened, shift numbers may be decreased, equipment may be leased out, and so on. Finally, it should be stressed again that these changes in capacity are temporary, so it should be easy to reset the system to its original designed and effective capacity when the period of capacity shortage is over.

2.3. Problems of long term capacity planning

The aim of long-term capacity analysis is to find appropriate responses to permanent changes in demand. When demand changes temporarily, for example in the holiday season, short-term adjustments to capacity can be made by using the methods discussed in the previous section. However, when there is a long-term increase in demand, the high costs of overtime or an extra shift may create a competitive disadvantage over competitors operating with higher capacity and lower wage costs due to using normal work. What is needed in such case is not to avoid a temporary mismatch, but to find an economical way to balance capacity against demand over the long term. This should be done bearing in mind two important considerations:

- The *uncertainty of future data* is a determining factor in making long-term decisions. The difficulty of predicting well the demand, economic or technological data used in capacity analysis increases with the time span for which the prediction is made. One solution is to express the uncertainty of the result in numerical terms, using the tools of probability theory. Where this cannot be done, the possible outcomes of alternative decisions should be assessed through scenario analysis.
- The demand for a product or service tends to change over time, as the product or service goes through different stages of its life cycle. While *the change in demand is a continuous process*, *capacity can only be matched to demand in discrete steps*. Changing capacity over the long term may include purchasing a new machine, opening a new plant, and so on. Such actions increase capacity by a large discrete amount. That is why temporary mismatches between demand and capacity are normal in the long term. It is up to management to decide *whether and to what extent capacity should stay ahead or lag behind demand*.

The following figures illustrate three typical cases of increasing capacity to match growing demand. Figure 1 shows an option which ensures that capacity is always more or less sufficient, but sometimes there is an excess capacity and sometimes there is a shortage. The discrete changes in capacity are represented by a dashed step line, which is *sometimes above* and *sometimes below* the straight line demand curve. Capacity is increased whenever a shortage occurs. Customers are made to wait until excess capacity allows all demand to be satisfied (unless the company produces for stock).

Figure 2 illustrates the case of increasing capacity with a view to ensuring full capacity utilization. In this case, management waits until the demand significantly exceeds the available capacity and only adds capacity when the additional capacity will be fully used. As can be seen, the straight line demand curve is *always above* the dashed step line representing the discrete changes in capacity. This strategy can be applied successfully if customers are willing to wait until there is enough capacity.

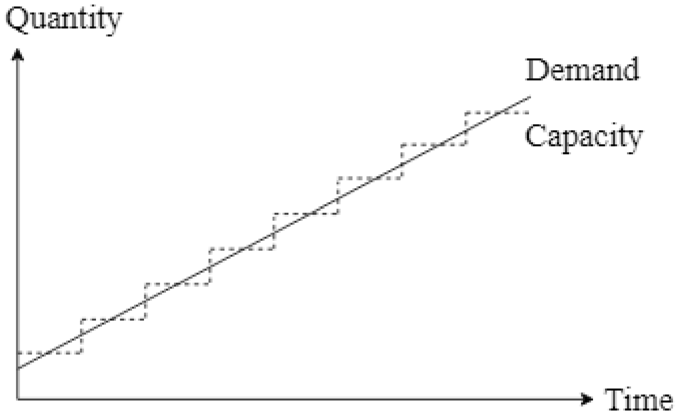

Figure 1 Capacity expansion aimed to more or less meet demand

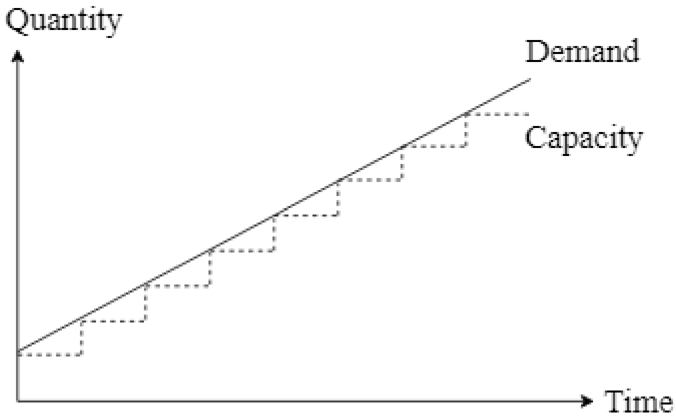

Figure 2 Capacity expansion aimed to ensure full capacity utilization

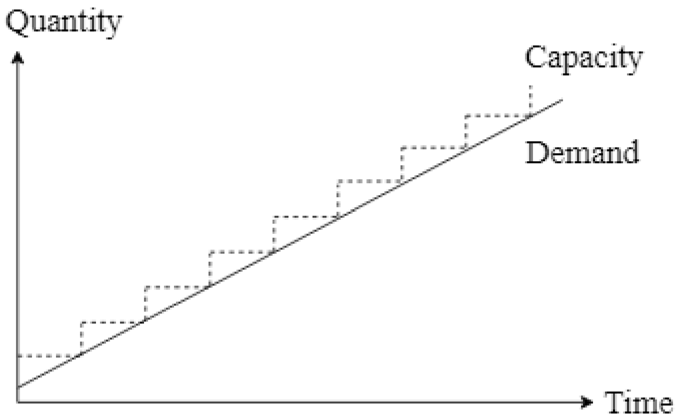

Figure 3 Capacity expansion aimed to meet all demand

Finally, Figure 3 shows a capacity expansion strategy aimed to meet all demand. This usually results in excess capacity, as capacity is added as soon as demand matches the available capacity. The dashed step line representing the discrete changes in capacity is *always above* the straight demand line. This strategy can be effective where maintaining unused capacity is not very expensive or where the direct or indirect losses associated with unsatisfied customers are very high.

The choice of strategy, or combination of strategies, depends on numerous factors. The most important of these are the following:

- *Market position*. Companies holding a monopoly tend to follow a strategy aimed at full capacity utilization, while those facing fierce competition are more inclined to choose the option of meeting all demand.
- *Profitability of the product or service*. If a product or service generates a high profit, the best strategy is the one aimed to meet all demand in order to avoid losing profit due to capacity shortage. Where profitability is low, the cost of unused capacity may be higher than the profit generated by the product, so full capacity utilization is a better strategy.
- *Loss from unmet demand*. Unmet demand may lead to lost profits as well as other negative economic consequences. If a company loses market share due to capacity shortage, the price of its shares may fall and its competitors may become stronger. In such cases, a strategy aimed to meet all demand may be beneficial.
- *Stability of product range*. Capacity utilization also depends on the product range. Different products can be manufactured at different capacity utilization rates. If the product range changes frequently, it is useful to maintain spare capacity so that additional capacity requirements can be met when there is a change in the product range.
- *Reliability*. If a process is liable to fail frequently, full capacity utilization is not an appropriate strategy because the failures may easily cause a capacity shortage.
- *Cost of unused capacity*. Where the fixed costs of a system are high, unused capacity represents significant additional costs and a large amount of capital tied up in unproductive resources. In that case, the negative economic impact of unused capacity usually exceeds the lost profits associated with orders unmet due to capacity shortage. Therefore, a strategy aimed to ensure full capacity utilization may be a good choice.

Obviously, these three strategies can also be applied when capacity needs to be matched to falling demand. The possible aims of capacity reduction are the same as those of capacity expansion, namely to meet demand more or less, to meet all demand, or to ensure full capacity utilization.

The *sizing and timing* of capacity increments are important issues in each of the capacity expansion strategies illustrated in Figures 1-3. Two alternatives for matching capacity to steadily increasing demand appear in Figure 4. One is to implement frequent smaller increases (bold dashed line), and the other is to carry out a few larger expansions (dotted line). It can be seen that the latter creates more unused capacity, while the former allows a more flexible response to increases in demand.

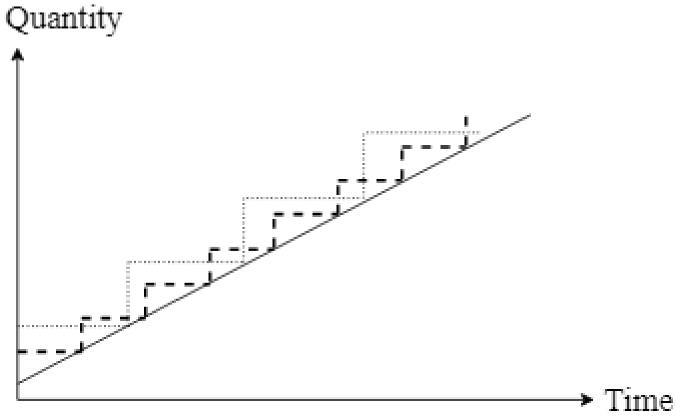

Figure 4 Increasing capacity in different-sized increments

The main factors affecting the sizing and timing of capacity increments are economies of scale and the way of financing the expansion:

- *The effect of economies of scale*. Large-scale expansions have lower unit costs than small-scale ones. Regardless of its scale, capacity expansion involves a range of activities. If the capacity increment is large, the costs of these activities are spread over more capacity and, therefore, the unit cost of expansion is lower. Hence, a strategy that favours a few large increases can be justified by the unit cost of capacity expansion.
- *The effect of financing the expansion*. Infrequent large increases in capacity require a few large investments, while frequent small-scale expansions require many small investments. It is easy to see that, from a cash flow perspective, spending an amount in a single step now is not equivalent to spending the same amount in more future steps, because the unspent amount may yield a return (interest) elsewhere before being used for financing capacity expansion. Frequent small expansions are therefore more favourable as regards the financing of expansion is concerned.

These two aspects should be considered in conjunction to find the optimal policy for expansion. The same applies to capacity reduction strategies as well, of course with the processes interpreted in reverse order.

3. INVENTORY MANAGEMENT

Inventory (or stock) management is an important area of operations management. Decisions on the desirable inventory levels are significantly influenced by the size of the capacity available, the characteristics of the demand for the product or service concerned, the uncertainties of the system supplying or producing it, and the costs of procurement and production processes. The efficiency of inventory management can fundamentally influence the success of a business.

Inventory management plays an important role in the life of companies in many ways. First of all, inventories act as a buffer between supply and demand, thus, they stabilize production processes. On the other hand, stocks help companies protect against the uncertainty and the fluctuation of customer demand. Furthermore, stockpiling allows companies to take advantage of quantity discounts. However, keeping stocks has disadvantages also. On the one hand, that inventories entail significant costs. In addition, the accumulation of inventories can cover production disruptions, that is, hide weak points in the production process where improvements would be needed to make the production process cheaper and of higher quality. Therefore, it is important for managers to be aware of the principles of inventory management, so they can make good short- and long-term decisions.

There are two main types of decisions in inventory management. *Strategic* decisions are related to set the level of satisfying customer needs. A strategic issue is whether a discount store at a highway intersection can afford to have stock-outs or not. That may occur if the inventory level is kept low, which means that the store spends less on holding stocks and can offer lower prices to customers. Alternatively, the store management may decide to maintain a higher service level and higher prices. This is a strategic decision. Production management is concerned with implementing the adopted strategy as effectively as possible. This is done through *operational* decisions on how to ensure the specified service level in the most economical way or, in other words, on *what, when, how much and how to order*.

This section intends to show how to find the best answers to these questions, while the scope of investigations will remain an independent demand inventory system. *Independent demand inventory systems* hold items the demand for which does not depend on the demand for any other product. In contrast, *dependent demand inventory systems* hold items the demand for which depends on the demand for other products. For example, if the amount of tyres to be made by a manufacturer is determined by the number of cars produced by one of its major customers, then the demand for the tyres ultimately depends on the demand for cars. Such issues are dealt with in the field of material requirement planning (MRP). (Vollmann et al., 1997; Koltai, 2003)

3.1. Classic inventory control mechanisms

The answer for the question of *how to order* is determined by inventory control mechanisms. It must define two things: (i) the event or events that must occur for an order to be placed and (ii) the principles for calculating the amount to be ordered. The inventory control mechanisms applied in practice can essentially be divided into two groups according to the type of inventory review, which may be either continuous or periodic.

Continuous review means that the inventory level is monitored continuously and an order is placed when the inventory level reaches a specified value. The inventory must be known at all times in order to recognize that it is time to place an order. Figure 5 illustrates how this system works.

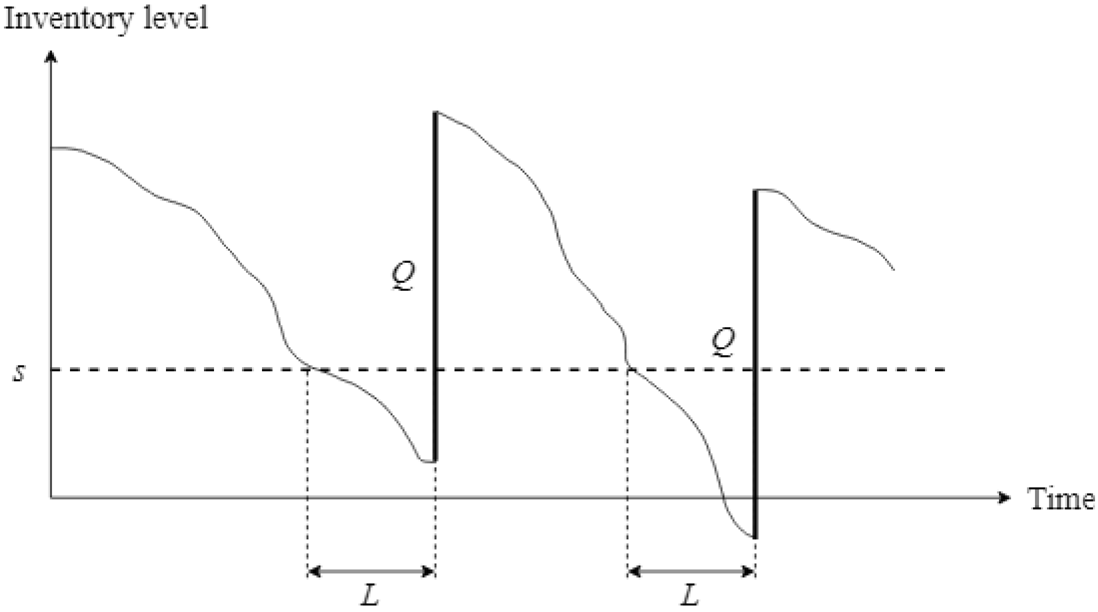

Figure 5 Inventory level in a continuous review system

The inventory starts to decline from a certain level. When it reaches the reorder level, *s*, an order for quantity *Q* is placed. When the order (delivery) lead time, *L*, ends, the ordered amount arrives, raising the inventory level that has dropped below *s* in the meantime. This process is repeated over and over again, with orders placed for the same quantity, *Q*, at all times. Because of the orders of fixed size, this system is also known as a *fixed order quantity system*. Continuous review systems are also called *(Q, s) systems*, referring to the two parameters on the basis of which management answers the questions of how much and when to order. The ordering policy can be summarized as placing an order for *Q* whenever the inventory level reaches *s*. With the development of modern information technology, continuous inventory review is now easy to implement.

Periodic inventory review essentially means that stocks are reviewed (and accordingly orders are placed) at regular intervals (*R*) – e.g. weekly, monthly, etc. – to raise the inventory level to a specified value. This mechanism is illustrated in Figure 6. The process starts with a certain level of inventory. When it is time to review the inventory level, an order is placed for the amount that brings the inventory on hand up to the target inventory level, *S*. The ordered amount, Q_i, arrives at the end of the order lead time, *L*. Since the inventory level continues to fall during this time, the ordered amount will bring the inventory level up to a value that is less than *S*. The increased inventory level starts to decline again after the arrival of the ordered amount. At the end of the interval *R*, the inventory on hand is reviewed again and an order is placed for the amount that brings it up to the target inventory level. The order size may vary, as it depends on the demand between two orders. Inventory reviews and orders repeat at regular intervals of length *R*. Periodic review systems are also called *(S, R) systems*, referring to the two parameters on the basis of which management answers the question of how much and when to order. The ordering policy can be summarized as placing orders at regular intervals R for amounts that bring up the inventory level to S.

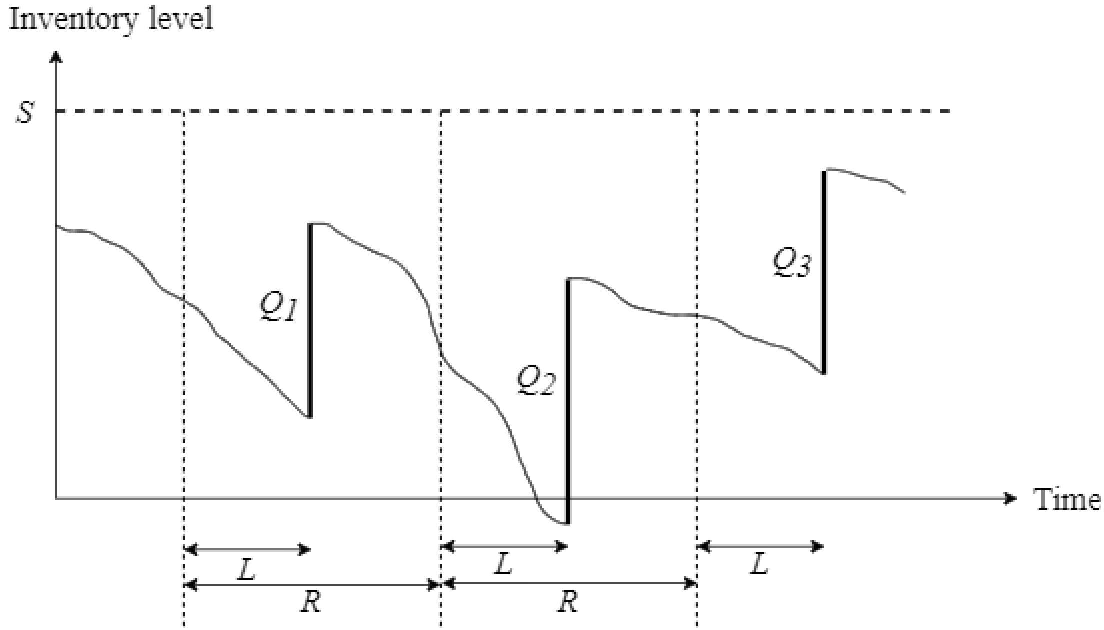

Figure 6 Inventory level in a periodic review system

There are two important differences between the two inventory review systems presented above that management should consider:

- Continuous review systems are able to respond more flexibly to changes in demand, so there is a *lower risk of stocking out*. The inventory level is kept under continuous review, so an order can be placed sooner if there is an unexpected increase in demand, because the inventory level reaches s sooner. The ordered amount is supposed to arrive within time L. If the demand increases significantly (and exceeds s) during this time, then a shortage will occur. Therefore, the risk of shortage is high *during the lead time* in continuous review systems. In periodic review systems, the inventory level is not inspected during the time interval between two reviews (R). If there is an unexpected increase in demand during this time, a shortage may occur. Moreover, the higher quantity ordered to meet the increased demand will not arrive before the lead time (L) ends, so the risk of shortage continues to exist during this time. Therefore, periodic review systems are exposed to shortages during *the review interval as well as during the lead time*. Since the risk of shortage persists for a longer time, the probability of stocking out is greater in a periodic review system than in a continuous review system, but only with the same average inventory level. In other words, continuous review systems require a lower inventory level to prevent shortages and, thus, they are less costly than periodic review systems.
- Periodic inventory reviews are easier to organize because the inventory on hand is only checked at time intervals R. By contrast, continuous review requires checking if the inventory level has already dropped to s each time an item is removed from inventory. While modern information technology makes it fairly easy to continuously monitor

inventory, maintaining a continuous review system still involves greater organizational efforts and higher costs than a periodic review system.

The comparison of these two approaches to inventory review leads to the conclusion that it is worthwhile to continuously track those items where shortages have more serious consequences, while other items should be subject to periodic review. However, in practice, the two systems are often combined as appropriate according to the characteristics of demand. An example of this is shown in Figure 7, which includes a reorder level, *s*, as well as a target inventory level, *S*.

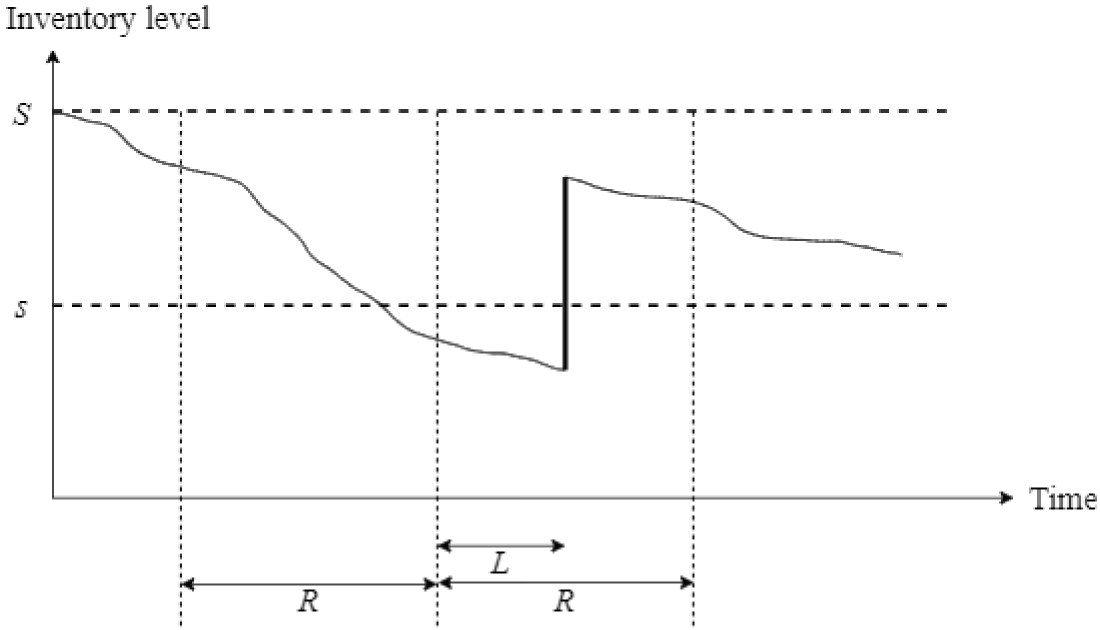

Figure 7 Periodic review with reorder level

In essence, this system works in the same way as a periodic review system. The inventory level is reviewed at regular intervals *R*, but no order is placed if the inventory level is higher than *s* at the time of the review. This inventory control mechanism prevents the placement of orders for uneconomically small quantities, and it is useful primarily where the demand frequently falls below its average level.

3.2. Inventory costs

As has already been mentioned, the main concern of inventory management is to decide what, when and how to order. These decisions must be made by taking into account the costs associated with the inventory system. These costs fall within one of the following four categories:

- *Purchasing cost*. This category includes the costs incurred in purchasing or producing an item. This cost is relevant if it depends on the amount purchased or produced (quantity discount). It is irrelevant in any other case, because the price of each item must be paid sooner or later, irrespective of when it is added to inventory.
- *Ordering cost*. This category includes the costs incurred in placing and receiving orders. In inventory-only systems, these could be the cost of administration, the costs of

transport and quality inspection, and others. In production and inventory systems, the ordering cost includes the setup cost if the production system has to be reset to produce the ordered items. This may entail significant direct costs and, not infrequently, losses and/or lost profits associated with the unproductive setup time.

- *Holding cost*. The costs in this category move up and down together with the level of inventory. One cost belonging to this category could be the cost of financing inventory; others relate to technical and physical deterioration, insurance, wages, and so on.
- *Shortage cost*. This category includes the additional costs incurred when a shortage occurs, such as the costs of late deliveries, as well as lost profits. The cost of shortage is often difficult to quantify because of its spill-over and future impact on purchases.

3.3. The EOQ model

The Economic Order Quantity (EOQ) model is a simplified model of practical inventory management problems. The model is described by the following six assumptions, so its relationships are valid if these are met:

1. The demand is known and constant over a given period (e.g. 100 units per day, 500 litres a month, etc.).
2. The time interval between placing and receiving an order (lead time) is zero, meaning that the ordered amount arrives instantly.
3. The entire order quantity is delivered at the same time (e.g. if an order is placed for 100 units, then the on-hand inventory level increases by 100 units when the ordered amount arrives).
4. Shortages are not allowed to occur. Since the demand is known, orders can be placed in such a manner that shortages are avoided.
5. The ordering cost is independent of the order size. The costs of administration, transport or setup related to an order are assumed to be the same irrespective of the quantity ordered.
6. The holding cost is proportional to the purchasing cost. This condition is based on the fact that a significant part of the holding cost is the cost of capital tied up in inventories, which depends on the size of the capital employed and hence the purchasing cost of inventory items.

Figure 8 shows the inventory movements in the case based on the six assumptions listed. The inventory is declining at a steady rate because the demand is constant. Since shortages are not permitted and the ordered amount arrives instantly, orders are placed when the inventory level drops to zero. It is worth noting that this inventory diagram may imply a continuous review system as well as a periodic review system because orders are always placed for the same quantity and, given that the demand is constant, the order intervals are always the same length. The inventory diagram in Figure 8 is also referred to as a *saw-tooth diagram* in inventory management.

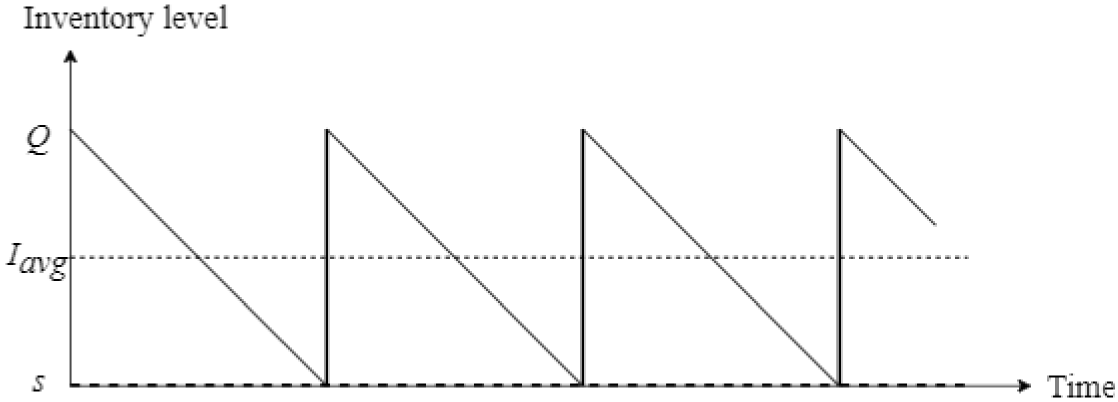

Figure 8 Inventory level in the simple EOQ model

Let us determine the total cost of the simple case defined above as a function of the order quantity. In our case, three of the four cost categories listed in Subsection 3.2 are to be considered, as the exclusion of a shortage occurrence does not result in shortage costs. Thus, the total cost (TC) is the sum of the purchasing (PC), the ordering (OC) and the holding costs (HC), and is formulated as,

$$TC\{Q\} = \mathrm{PC} + \mathrm{OC} + \mathrm{HC} = Dv + A\frac{D}{Q} + I_{Avg}vr,$$

where

D	-	known value of demand per unit time (year, month, week, etc.),
v	-	unit purchasing cost,
A	-	cost of placing an order, which is assumed to be independent of the order quantity,
Q	-	order quantity,
I_{avg}	-	average inventory level,
r	-	holding cost rate, which expresses the holding cost as a proportion of the purchasing cost per unit time. It shows the percentage of the unit purchasing cost that should be taken into account as holding cost.

It can be seen from Figure 8 that the average inventory level is exactly $Q/2$ because the saw-tooth diagram can be transformed into an equivalent diagram representing a constant inventory level of $Q/2$. Substituting this into the total cost formula gives:

$$TC\{Q\} = Dv + A\frac{D}{Q} + \frac{Q}{2}vr$$

We need to find the value of Q that minimizes the resulting function. It can be obtained by differentiating the total cost function with respect to Q and setting the result equal to zero:

$$\frac{dTC\{Q\}}{dQ} = 0 - A\frac{D}{Q^2} + \frac{vr}{2} = 0$$

Solving for Q yields the optimal order size, known as the economic order quantity (EOQ):

$$Q_{OPT} = EOQ = \sqrt{\frac{2AD}{vr}}$$

Rearranging the derivative of the total cost function with respect to Q shows that the lowest total cost occurs where the holding cost and the ordering cost have the same value. In symbols:

$$A\frac{D}{Q} = \frac{Q}{2}vr$$

This formula expresses the *principle of equilibrium* in inventory management, namely that the ordering cost equals the holding cost when orders are placed for the economic order quantity. This principle can also be used for solving problems that are more complex than the above simple case. It can be applied to calculate the economic order quantity or can be used to find a suboptimal order size that results in low total cost.

If orders are placed for the economic order quantity, the total cost is given by the following formula:

$$TC\{EOQ\} = Dv + A\frac{D}{EOQ} + \frac{EOQ}{2}vr = Dv + \frac{AD}{\sqrt{\frac{2AD}{vr}}} + \sqrt{\frac{2AD}{vr}}\frac{vr}{2} = Dv + \sqrt{2ADvr}$$

The length of time over which the economic order quantity covers demand is called the *cycle time* and is calculated as follows:

$$T_{EOQ} = \frac{EOQ}{D} = \frac{1}{D}\sqrt{\frac{2AD}{vr}} = \sqrt{\frac{2A}{Dvr}}$$

Figure 9 illustrates how the holding cost (HC) and the ordering cost (OC) change as Q changes. The total cost (TC) also includes the purchasing cost (Dv), but it does not depend on the order quantity. Being constant, the purchasing cost only shifts the sum of the ordering costs and the holding costs upward, but it does not influence the shape of the total cost curve. Thus, the graph in Figure 9 (TC'), which represents the sum of the ordering cost and the holding cost, has the same shape as that of the total cost function (although the two functions may take different values).

As can be seen, the holding cost increases as the order quantity increases, because adding more items causes a higher increase compared to the average level of inventory. On the other hand, a higher order quantity implies less frequent orders and, thus, reduced ordering cost. As the sum of these two opposing effects, we obtain the convex U-shape total cost function, which, according to the principle of equilibrium, has its minimum point at the intersection of the ordering and holding cost functions.

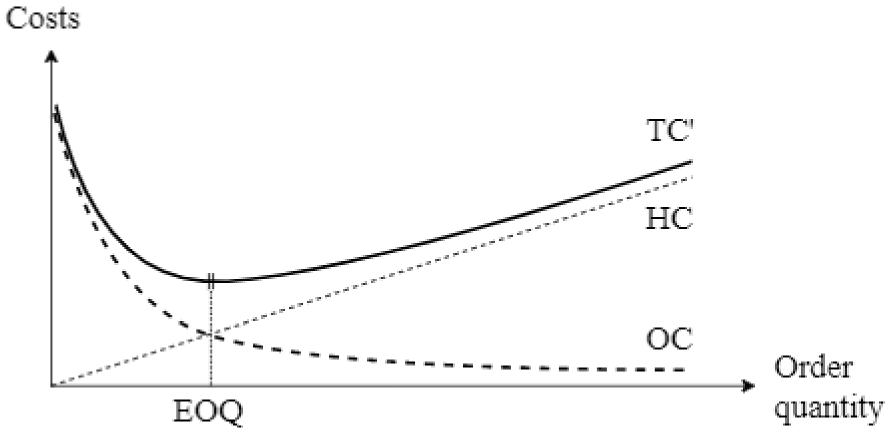

Figure 9 The shape of holding cost (HC), ordering cost (OC) and total cost (TC') curves

The following simple example illustrates the calculation of the economic order quantity. The demand for a product is an average of 3,600 units a year. The ordering cost is HUF 12,000. The purchasing cost is HUF 2,500 a unit, and the annual holding cost rate is 60%. Assume that there are 360 working days a year. Substituting these values into the EOQ formula gives:

$$EOQ = \sqrt{\frac{2AD}{vr}} = \sqrt{\frac{2 \times 12\,000 \times 3600}{2500 \times 0.6}} = 240 \text{ units}$$

The total cost is made up of the following components:

$$TC\{240\} = 3600 \times 2500 + 12\,000 \times \frac{3600}{240} + \frac{240}{2} \times 2500 \times 0.6 =$$
$$= \text{THUF } 9000 + \text{THUF } 180 + \text{THUF } 180 = \text{THUF } 9360$$

It can be seen that the purchasing cost accounts for the highest proportion of the total cost (moreover, it is independent of the order quantity). Thus, operations management decisions can only affect the holding cost and the ordering cost in this case.

If the annual demand of 3,600 units is to be met by placing orders for 240 units, then the number of orders is 3,600 / 240 = 15 a year. The cycle length is:

$$T_{EOQ} = \frac{EOQ}{D} = \frac{240}{3600} = 0.0667 \text{ years} \approx 24 \text{ days}$$

Hence, the ordered 240 units are sufficient to cover demand over 24 days.

Suppose that management thinks it is not worthwhile to place such small orders and suggests placing orders every six months. This means that the ordered amount should be enough to last for six months, so the order quantity would be 3,600 / 2 = 1,800 units. The total cost incurred by using this non-optimal value can be calculated as follows:

$$TC\{1800\} = 3600 \times 2500 + 12\,000 \frac{3600}{1800} + \frac{1800}{2} 2500 \times 0.6 = \text{ THUF } 10\,374$$

The non-optimal ordering policy suggested by the management would result in the following percentage increase in the total cost:

$$\Delta TC = \frac{TC\{1800\} - TC\{240\}}{TC\{240\}} = 0.10833 \quad \rightarrow \quad 10.83\%$$

This generous ordering policy would raise the total cost by 10.83%. This example demonstrates that a procurement policy which seems simple and reasonable may in fact cause significant additional costs and, thus, reduce competitiveness. What is more, such additional costs could be eliminated by introducing a wiser ordering policy, which is a purely organizational and virtually costless measure.

3.4. Calculation of the reorder level

The previous section was concerned with the question of how much to order. This section attempts to answer the question of when to place an order. It is still assumed that the demand is known and constant. This assumption simplifies the problem because, if the demand is known exactly, then it is possible to calculate the demand during the lead time. The time to place an order is when the inventory on hand is just sufficient to cover the lead time demand. An extreme case where the order lead time is assumed to be zero ($L = 0$) has already been mentioned. In that case, the ordered amount arrives instantly and orders are placed when the inventory level drops to zero.

Order placement should be timed in such a way to ensure that the order is delivered when the inventory level hits zero. The time to place an order is a time L earlier than the point in time at which the inventory reaches zero level. However, rather than finding this point in time, it is more convenient to determine the inventory level at the instant an order should be placed. Two cases need to be distinguished. One is where an order placed in a cycle arrives *in the same cycle* (at the end of the cycle). As can be seen on the first (top) graph in Figure 10, the reorder level equals the lead time demand in this case:

$$s = LD \quad \text{if} \quad L \leq T_{EOQ}$$

If the lead time is longer than the length of a cycle, then the ordered amount arrives *in a subsequent cycle*. Also in this case, illustrated by the second (bottom) graph in Figure 10, orders should be placed in such a way to ensure that the ordered amount is delivered when the inventory level drops to zero. What we need to examine here is the number of cycles in the lead time. Since the full cycles do not affect the calculation of the reorder level, we only need to consider the remaining fraction of a cycle. It is denoted by L' and calculated as follows:

$$L' = L - \left\lfloor \frac{L}{T_{EOQ}} \right\rfloor \times T_{EOQ}$$

where

$$\left\lfloor \frac{L}{T_{EOQ}} \right\rfloor = \text{floor}\left(\frac{L}{T_{EOQ}} \right)$$

The floor functions denote the integer part of the value of the enclosed ratio, which is the number of full cycles in the lead time. Then the reorder level can be calculated using a formula that is similar to the one in the previous case:

$$s = L'D \quad \text{if} \quad L > T_{EOQ}$$

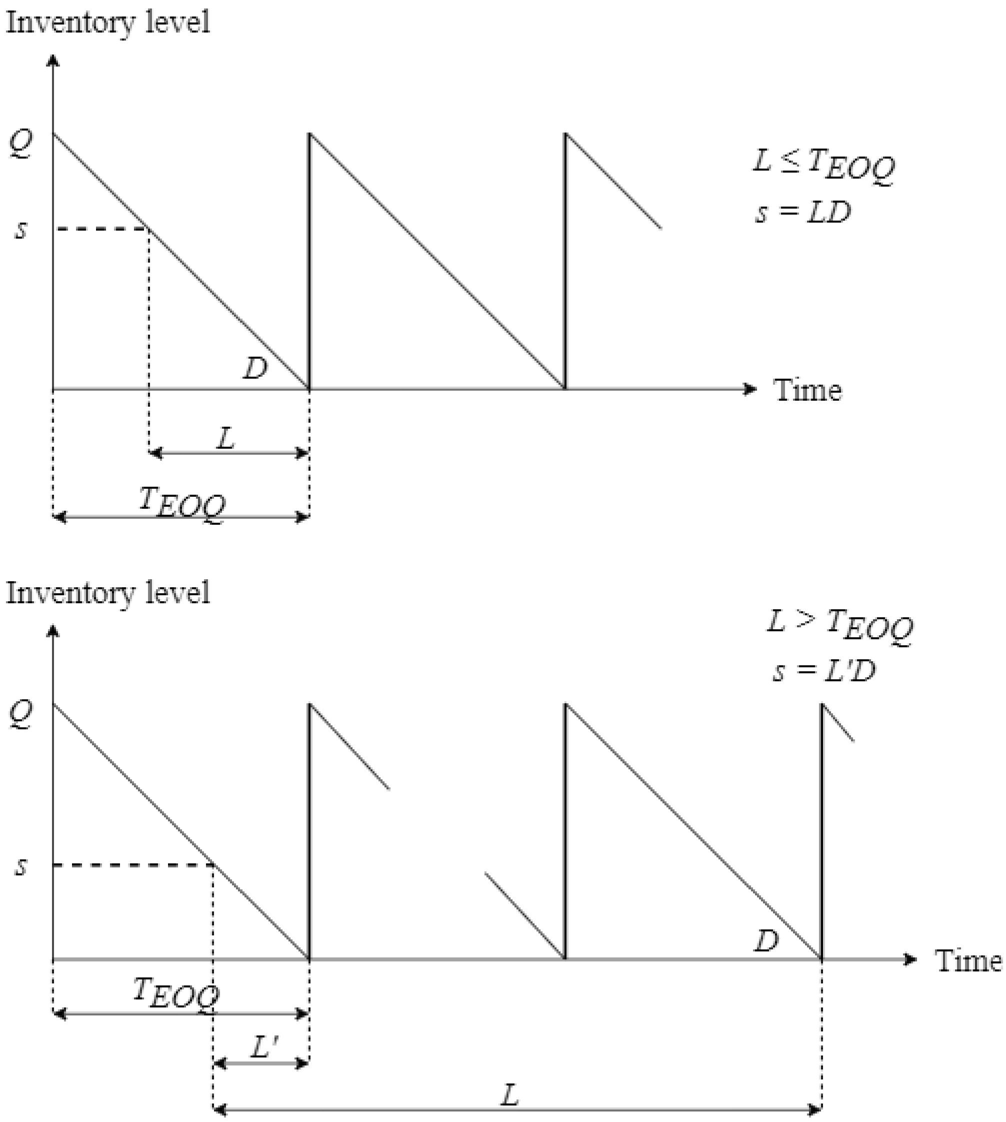

Figure 10 Reorder level calculation

Let us first determine the reorder level. To illustrate the calculation of the reorder level, we will consider again the problem used in Subsection 3.3. The demand for a product is an average of 3,600 units a year. The ordering cost is HUF 12,000. The purchasing cost is HUF 2,500 a unit, and the annual holding cost rate is 60%. We assume that there are 360 working days a year. As calculated above, the economic order quantity (*EOQ*) is 240 units, and the cycle time (T_{EOQ}) is 24 days.

Determine the inventory level at the instant an order should be placed for 240 units if the ordered amount arrives after 15 days, that is, $L = 15$. Since $L \le T_{EOQ}$, the reorder level is calculated as follows:

$$s = LD = 15 \times \frac{3600}{360} = 150 \text{ units}$$

The calculation takes into account that the lead time is expressed in days, while the demand is given on a yearly basis. The optimal policy is to place an order for 240 units whenever the inventory level declines to 150 units.

Let us now calculate the reorder level if the lead time is increased to 50 days, that is, $L = 50$. In this case, $L > T_{EOQ}$, so we need to determine the value of L' that will be taken into account for the calculation:

$$L' = L - \left\lfloor \frac{L}{T_{EOQ}} \right\rfloor T_{EOQ} = 50 - \left\lfloor \frac{50}{24} \right\rfloor \times 24 = 50 - 2 \times 24 = 2 \text{ days}$$

There are two full cycles and two days in the lead time. The reorder level is calculated using only the remaining two days:

$$s = L'D = 2 \times \frac{3600}{360} = 20 \text{ units}$$

In this case, an order for 240 units should be placed whenever the inventory level drops to 20 units.

The result may be surprising. Why should we wait until the inventory falls to a lower level when the lead time is longer? We may think that the inventory level should be higher at the instant an order is placed if it takes longer for the order to arrive. In fact, a longer lead time warrants a higher reorder level only if it also increases uncertainty. However, the demand is well known in our case, there is no uncertainty.

3.5. Extensions for the simple EOQ model

The EOQ model represents a significant simplification of the real inventory management problems, but the findings of this simple case help to understand the complexities of more complex systems that work in reality and, secondly, the result obtained as a heuristic provides a good solution to many problems that differ from the theoretical case examined. There are a number of models in the literature based on the principles presented, which can better take into account the requirements of practical life (see, for example, Koltai, 2001):

- **Continuous replenishment rate**. If the ordered quantity does not arrive in a single lot but gradually arrives at the warehouse. This is the case in most production and inventory systems when a production plant fills its warehouse at the rate of production. It is suitable for describing an inventory-only system if the supplier fills the warehouse at the pace of delivery. Of course, there is a demand for the product at the same time as the warehouse is filled, so the inventory level is shaped by the results of two processes.
- **Quantity-dependent discounts**. Suppliers often attempt to persuade customers to order large batches. Discounts are offered to encourage them to buy more than a specified quantity. Without such an incentive, customers would not be willing to order more than the economic order quantity, as that would increase the total cost. The purpose of the discount is to compensate for the higher total cost. The form of the discount can be many, the two most common cases are the proportional discount and the incremental discount. A *proportional (all-units) discount* is given when the buyer receives all the

pieces at a lower price when buying more than a specified quantity. The i*ncremental discount* means that the units beyond a specified quantity threshold, called the breakpoint, can be purchased at reduced price. In this case, the full price is applied to one part of the order (the units below the quantity threshold), and the reduced price is applied to the other part of the order (the units above the threshold).

- **Uncertainty of demand**. In real life, it is not known in advance how much the demand will be. The adverse effect of demand uncertainty, namely the risk of shortage, can be mitigated by increasing the inventory level by what is known as *safety stock*. In such a case, management typically specifies an acceptable level of shortage, the level of service, and accordingly determines the required size of the safety stock.

4. THE BASICS OF PRODUCTION ECONOMICS

Production economics deals with the most important issues of measuring and evaluating the resources used in production. It examines the options of measuring resources in natural (kilogram, litre, piece) and economic (euro, HUF) units. It also analyses the relationship between the planned and the actual resource use. This management field investigates the possible causes of regularities and discrepancies between costs and production processes, as well as the managerial aspects of cash flows related to production.

Since production economics deals with the economic issues of production and service processes, it is necessary to clarify the concepts of cost, expense and revenue:

- *Cost* is the monetary value of resources used for the operation. In business, "cost is usually a monetary valuation of (1) effort, (2) material, (3) resources, (4) time and utilities consumed, (5) risks incurred, and (6) opportunity forgone in production and delivery of a good or service." (Business Dictionary, 2019)
- An *expense* is "money spent or cost incurred in an organization's efforts to generate revenue, representing the cost of doing business. Whereas all expenses are costs, not all costs (such as those incurred in acquisition of income generating assets) are expenses." (Business Dictionary, 2019)
- *Revenue* is the monetary consideration of products or services derived from the company's core business. Revenue is "the income generated from sale of goods or services, or any other use of capital or assets, associated with the main operations of an organization before any costs or expenses are deducted. Also called sales, or (in the UK) turnover." (Business Dictionary, 2019) Unit selling price multiplied by the amount of sold products gives the amount of the revenue.

4.1. Classification of cost types

One of the factors determining the competitiveness of modern companies is the appropriate information available at the right time, including costs and the cost structure of the company. Most important goals of the development and operation of enterprise cost accounting systems include to support business decisions and to help managers work quickly with accurate information. This might seem simple in the first approach, as the corporate accounting system contains the necessary basic data. However, the same elementary information should be grouped and used in different ways in different decision situations, taken into account or, on the contrary, ignored. For example, it is necessary to know the cost of producing a product or operating a plant, various performance and efficiency indicators, the cost of building, maintaining and operating capacities, the total cost of a particular activity. Therefore, the methods of collecting and analysing costs were already characterized by a multi-faceted approach at an early stage. (Kaplan and Atkinson, 2003)

1. The primary form of the appearance of costs in the life of a company is the classification by the *nature of expenses*. This grouping is used by practically all companies. The Accounting Act distinguishes between three types of expenses: *material expenses*

(material costs, cost of used services), *personnel/staff expenses* (wage cost, wage rates, other payments of a personal character) and *depreciation*.
The first two categories are relatively straightforward, but the meaning of depreciation is less well known. Depreciation is used to account for the cost of acquiring assets that serve the company on a long-term basis. The cost of purchasing equipment (machinery, buildings) used over a number of years should be allocated to the years in which the equipment is expected to be used. Therefore, depreciation is the amount of these assets recognized as an expense in a given year (Sztanó, 1991).
This type of cost classification is primarily based on the reason for the costs incurred and not on their purpose. It does not facilitate in-depth economic analysis but serves as a basis for other grouping and analytical methods.

2. Some cost models try to categorize the corporate cost structure in terms of products and services. These models primarily examine how much it costs a company to produce a unit of a product or service. Taking into account the total costs of a company over a given period (typically one year), there are a wide variety of cost elements: wages, materials used, utility bills, consumables, rents, subcontracting fees, shipping, packaging, etc. Pricing should be stated based on these. It is necessary to determine the amount of each cost element per unit. On this basis, costs form two large groups.
   Direct costs can be linked directly to the cost bearer (product/service). It means that they can be easily traced back to the manufacturing of a particular good or providing a particular service. They include for example direct costs of materials or labour (wages) that are essential to a given product or service to be finished. *Indirect costs* may be needed for production but are not directly related to the production act. They are not only associated with the production of a single product, but also serve the purpose of producing more or all of the products or services. This is why they are collected at the place of occurrence (cost centres). Indirect costs include for example the materials and supplies needed for the company's day-to-day operations, depreciation of buildings, machinery, CEO salary, maintenance costs, etc.
   Product cost calculation methods, which are based on the division of indirect and direct costs, can determine how much a unit of a product (1 piece, 1 litre, 1 kg, 1 meter, etc.) will cost for a company (or an organizational unit). On the one hand, it is a good way of analysing the company's past performance under the right conditions, it helps management understand the company's business system and cost structure. On the other hand, it cannot be used in making economic decisions for the future, or can only be used with strong criticism due to the static nature of the calculation.

3. Costs can also be grouped according to how they are affected by changes in production quantity. Based on this, we can also distinguish between two major cost categories. Costs that do not respond to volume changes are called *fixed costs* and costs that respond to volume changes are called *variable costs*.
   - The amount of fixed costs is constant, at least within a certain range, irrespective of the quantity produced. This usually includes costs related to building the physical capacity of the company. These include for example rent for a site or building,

depreciation of buildings, machinery, salaries of monthly workers, etc., which are always the same regardless of the quantity produced.

Note that fixed costs can only be considered fixed within a certain range (relatively or quasi fixed cost). In order to produce a product in excess of the quantity of products determined by the current capacities, capacity expansion is required. This expansion entails a sharp increase in fixed costs, but at one stage remains constant until another expansion occurs.

- Within variable costs, depending on the rate of change in expenses relative to the rate of change in volume, three types of costs can be defined. Costs that vary in proportion to the change in volume are called *proportional costs*, costs that change less than the straight line are *degressive*, and costs that change more than the linear rate are called *progressive costs*.
  - Proportional costs typically include costs that are closely related to the production of the product, such as performance-related wages, material cost of the product and others.
  - Degressive costs are generally related to operation but are not as closely linked to the production of the product as the proportional cost. This includes, for example, the energy costs of a plant, the cost of maintaining a building or the operating costs of departments. One of the main characteristics of the degressive cost function is that, unlike the previous two cost types, it is no longer linear. Another important characteristic is that the function does not start from the origin, even though it is a variable cost.
  - Progressive costs may be incurred at a company partly due to necessity, and partly due to some malfunctioning or overexertion. For example, overtime or poorly organized, unscheduled operation can cause such a progressive increase in cost over normal operation.

Costs can be categorized in other ways, but in the following subsections we will use the cost types of the last mentioned group.

4.2. Cost-Volume-Profit (CVP) analysis

The amount of products sold varies dynamically from time to time. That is why it becomes an important question when analysing the costs of a company, how changes in the production volume affect the costs and the economic analysis of the company. The answer to this question is the result of the cost-volume-profit (CVP) analysis.

As described in Subsection 4.1, two major categories of costs, fixed and variable, can be distinguished based on their response to changes in volume. Within variable costs, depending on the rate of change in costs relative to the rate of change in volume, three types of costs can be defined, proportional, degressive and progressive costs. Figure 11 shows the four cost functions. Proportional costs vary in proportion to the change in volume. For degressive costs, the rate of change in cost is less than the rate of change in volume, i.e. a 1% change in volume causes a less than 1% change in cost. For progressive costs, the rate of change in cost is greater than the rate of change in volume, i.e. a 1% change in volume causes a more than 1% change in cost. The property of costs, which shows the extent to which a change in volume causes a change in costs, is expressed by the *cost variation factor* (reaction degree). In other words, the cost variation factor (δ) gives the degree of proportionality. In the case of fixed and proportional costs, this indicator is, respectively, 0 and 1. The cost variation factor for degressive costs is between 0 and 1, and for progressive costs is greater than one.

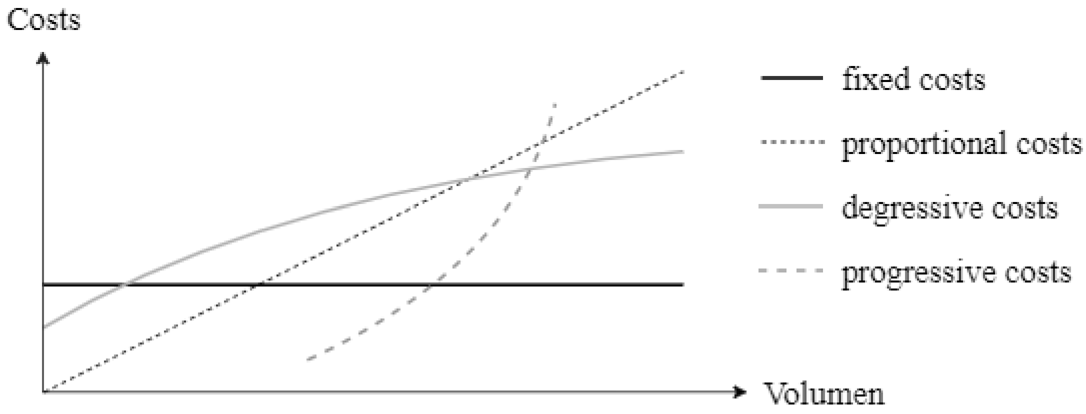

Figure 11 Cost functions as a function of volume

Knowing the cost variation factor, *cost type reduction* can be performed, which means breaking down degressive costs into a fixed and a proportional part. As a result of the cost type reduction, degressive costs (in their original form) are eliminated and we calculate a so called reduced proportional cost (C_{pr}) and a reduced fixed cost (C_{fr}). Let's take an example. If the cost variation factor for a plant's maintenance cost is $\delta = 0.65$ and the plant's monthly maintenance cost is 2 million HUF, then by definition of the cost variation factor, 65% of the 2 million HUF can be considered proportional and 35% fixed. Thus, in our example $C_{pr} = 2 \times 0.65 = 1.3$ million HUF, $C_{fr} = 2 \times 0.35 = 0.7$ million HUF.

After completing the cost type reduction, the cost structure of a company can be characterized by linearly variable (fixed and proportional) costs (CVP analysis does not take into account progressive costs, since they are not determinative under normal operation). Adding the reduced fixed costs (C_{fr}) to the original fixed costs (C_{fo}) gives the total fixed cost (C_{ft}) of the company. By adding the original proportional costs (C_{po}) to the reduced proportional costs (C_{pr}) the total proportional costs (C_{pt}) of the company can be computed. Thus, from now on, we only have to consider fixed and proportional costs, which greatly simplifies and clarifies the analysis (see Figure 12).

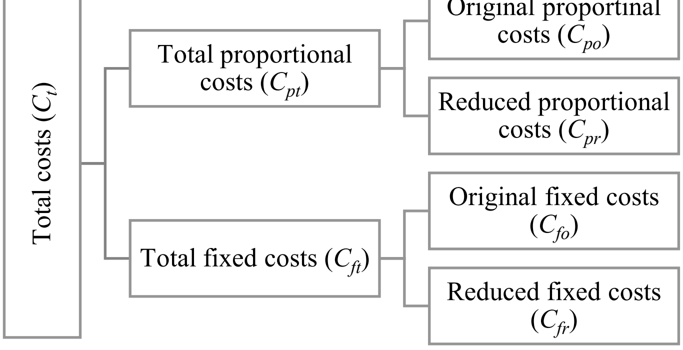

Figure 12 Breakdown of total cost into fixed and proportional parts

4.2.1. Calculating the break-even point

In addition to costs, CVP analysis takes into consideration revenue, profit and contribution as well. *Contribution* (abbreviated as *Cont*) is the difference between revenue and total proportional costs. In accounting, contribution is the "amount left over after variable costs are deducted from the sales revenue. Also called gross income, this sum pays for fixed costs and contributes to net income (profit)." (Business Dictionary, 2019) Consequently, the difference between the contribution and the fixed cost is the profit. Thus, in a managerial point of view, maximizing the profit or the contribution of the company results in the same result regarding production volume.

Similar to cost functions, this analysis also can be illustrated graphically (see Figure 13). The total cost (C_t) function starts from the fixed costs (C_{ft}) and increases with the slope of the proportional cost (C_{pt}). The revenue (R) line start from the origin and grow at a slope corresponding to the unit price of the product. In order for a company to be profitable, the revenue line must grow more steeply than the costs, i.e. the product has to be sold at a higher unit price than the unit proportional cost. In order to pay the fixed costs, contribution must be positive. At the break-even point shown in the figure, revenue is equal to total costs, thus, profit (net income) is zero.

Break-even point is the point at which a company, a product or a project becomes financially viable. It means that at production volumes lower than the break-even quantity revenue is less than total costs. Consequently, production is loss-making at this stage. But after reaching the break-even point, profit is gained. Until a company reaches the break-even point, the contribution covers only the fixed costs, and above that, it generates a profit. The production quantity at the break-even point is called *critical volume* (V_{crit}). Therefore, in order to become profitable, the company must achieve at least this output.

Let us see an example for calculating the break-even point. Assume that the total fixed cost of a company is HUF 10,000,000. The total proportional cost as the function of the quantity produced (volume, V) is C_{pt}=5000V. The revenue function is R=9000V.

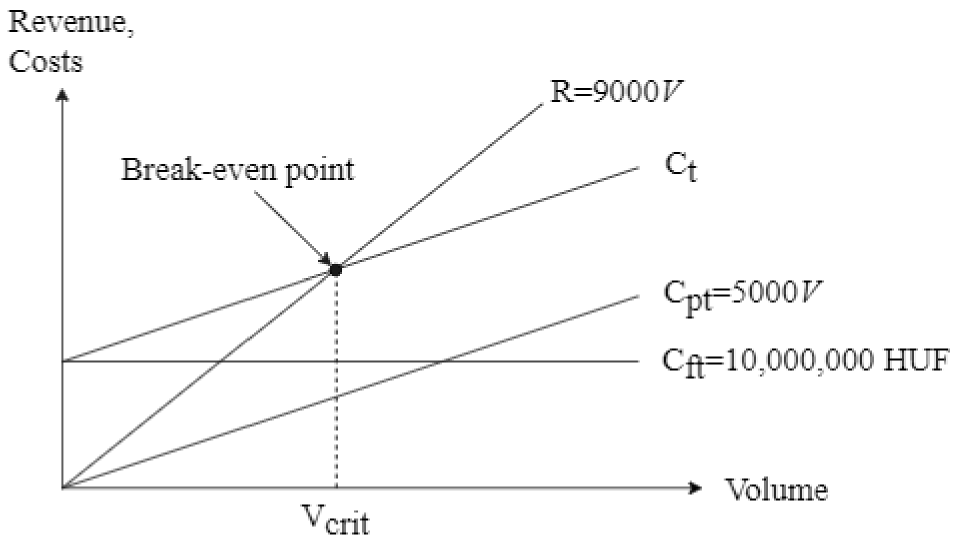

Figure 13 Break-even calculation

First, let's determine the critical volume belonging to the break-even point. As we already know, at the break-even point revenue and total costs are equal. We also know that the total cost consists of proportional and fixed cost components. In our example revenue and the proportional cost functions are given, also we know the amount of the fixed cost. We can easily calculate the critical volume based on these data:

$$R = C_t = C_{pt} + C_{ft}$$

$$9000V = 5000V + 10{,}000{,}000$$

$$V = 2500 \text{ units}$$

According to our results, we have the critical volume at 2500 units. This means that less than 2500 units sold will produce a loss for the company and more than 2500 will yield profit to the company under the given conditions.

The break-even quantity can be also easily calculated using the following equation:

$$V = \frac{C_{ft}}{p - c_{pt}},$$

where p is the unit selling price and c_{pt} is the unit proportional cost. Based on our data (p=9000, c_{pt}=5000) the critical volume belonging to the break-even point is the same as before:

$$V = \frac{10{,}000{,}000}{9000 - 5000} = 2500 \text{ units}$$

4.2.2. The effect of the cost structure

The economic characteristics of the company are well illustrated by the CVP analysis. It allows analyse the effect of product volume changes on profit. In many cases, companies are subject to quite different effects on the market due to their different cost structures, therefore, managing them well means different tasks for each of them. For example, the profitability changes of two companies that appear to be in the same economic position may differ significantly, even if they are subject to the same volume change (Ladó, 1981).

Both companies currently operate on the same level, they produce the same number of products and sell them at the same price, so their revenues are equal (HUF 100 million). They work with the same operating costs (HUF 90 million), thus, their profits are equal (HUF 10 million). We can structure the given data as shown in Table 2.

Table 2 Calculation structure for CVP analysis

	Revenue (R)
–	Total proportional costs (C_{pt})
=	**Contribution (*Cont*)**
–	Total fixed costs (C_{ft})
=	**Profit (net income) (*P*)**

According to the traditional view the two companies are in the same position since their most important economic indicators are even. However, the amount of the proportional and the fixed costs of the two companies is different within the total costs, and consequently, their contributions are different. Based on the CVP analysis of the two companies shown in the first two columns of Table 3, the difference becomes clear.

Table 3 Different cost structures

	Originally		**After change**	
	Company A (HUF million)	*Company B (HUF million)*	*Company A (HUF million)*	*Company B (HUF million)*
Revenue	100	100	90	90
Total proportional costs	80	10	72	9
Contribution	**20**	**90**	**18**	**81**
Total fixed costs	10	80	10	80
Profit	**10**	**10**	**8**	**1**

The data show that due to the different cost structures, the amount of contribution differs significantly between the two companies. Such a deviation also occurs in practice. A cost structure similar to Company *A* is typical, for example, of companies that process large quantities of high-value raw materials. The proportion of high fixed costs (Company *B*) is typical for companies with large plants and many buildings, typically transport companies.

Let's look at how the profits of the two companies change when the quantity produced and sold decreases by 10% (see the last two columns of Table 3):

- Due to the reduced sales volume, revenues of both companies drop by 10% to HUF 90 million.
- Proportional costs vary in proportion to the quantity produced: a 10% drop means an HUF 8 million decrease in costs for Company *A*; and a decrease of HUF 1 million for Company *B*.
- Correspondingly, the amount of the contribution is HUF 18 million at Company *A* and HUF 81 million at Company *B*.
- Fixed costs are unaffected by the volume change, they keep their original value.
- Thus, the profit of the companies decreases to HUF 8 million (Company *A*) and HUF 1 million (Company *B*).

The difference is significant. The profit of Company *A* decreased by 20% and that of Company *B* by 90%, following the same change. It can be realized that the management of the two companies have to take different decisions and steps in order to influence the development of the profit effectively.

4.2.3. CVP sensitivity analyses

The impact of a managerial decision (volume change, price change, development, investment, etc.) on corporate earnings depends on many factors, for example, on the cost structure of the companies, as shown in the previous subsection. The effect of economic decisions on profit can be demonstrated by CVP sensitivity analyses. These analyses can be used to determine the degree of change (in percentages) required from a component to a given change in profit (ΔP). This ratio can easily be determined if the company seeks to achieve the ΔP change in profit only by price or cost change.

A certain change in profit can be achieved by the same level of change in price or costs. Therefore, to perform a sensitivity analysis, only the magnitude of the change in profit needs to be compared to the value of the parameter being tested:

$$\Delta R = \frac{\Delta P}{R} \times 100 \quad ; \quad \Delta C_{pt} = \frac{\Delta P}{C_{pt}} \times 100 \quad ; \quad \Delta C_{ft} = \frac{\Delta P}{C_{ft}} \times 100$$

If we examine the correlation between changes in profit and volume, there is not such a simple relationship. As volume changes, both revenue and proportional costs change commensurately, so the contribution resulting from the difference changes as well. Therefore, to study the effect of a change in volume, the contribution resulting from CVP analysis is used:

$$\Delta V = \frac{\Delta P}{Cont} \times 100$$

By applying the CVP analysis, the effect of many changes (such as wage increases) and the magnitude of reactions to them (such as price increases, output increases) can be examined. Consider a company that seeks to determine its response to the effects of a wage increase through its CVP sensitivity analysis (based on Maczó, 1999). The company's annual sales revenue was HUF 250 million. The total annual cost of the business was HUF 200 million. The cost variation factor for the company is 0.6. Given this information, the company's break-even point can be easily determined, since with the help of the cost variation factor the total cost can be divided into proportional and fixed costs. Based on the relationships between the elements of the CVP analysis, the value of the contribution and the profit can also be calculated:

$$C_{pt} = \delta \times C_t = 0.6 \times 200 = \text{HUF}\,120\text{ million}$$
$$C_{ft} = (1-\delta) \times C_t = C_t - C_{pt} = 0.4 \times 200 = 200 - 120 = \text{HUF}\,80\text{ million}$$
$$Cont = R - C_{pt} = 250 - 120 = \text{HUF}\,130\text{ million}$$
$$P = Cont - C_{ft} = 130 - 80 = \text{HUF}\,50\text{ million}$$

As verification, the profit can be calculated as the difference between the sales revenue and the total costs (250-200), which results in HUF 50 million in this way as well. The CVP analysis is summarized in the second column of Table 4.

The company plans to raise salaries by 20% next year. This increases the proportional costs by 10% and the fixed costs by HUF 5 million. Thus, the total proportional cost increases to 120 × 1.1 = HUF 132 million and the total fixed cost rises to 80 + 5 = 85 million HUF. As a result of the wage increase, both the contribution (250 - 132 = 118 million HUF) and the profit (118 - 85 = 33 million HUF) of the company change, as shown in the third column of Table 4.

Table 4 Comparison of the CVP analyses (before and after pay-raise)

	Originally	**After change**
Revenue	250	250
Total proportional costs	120	132
Contribution	**130**	**118**
Total fixed costs	80	85
Profit	**50**	**33**

The company will suffer a loss of HUF 50 - 33 = HUF 17 million compared to its original profit as a result of the wage increase. The extent to which the company may compensate for this change in profit (ΔP = HUF 17 million) by price increases can be determined by sensitivity analysis:

$$\Delta R = \frac{\Delta P}{R} \times 100 = \frac{17}{250} \times 100 = 6.8\%$$

Thus, the profit before the salary raise may be achieved by a 6.8% price increase. Note that the word *may* appeared two times, as the company may not be able to sell the same amount of products or services at higher prices. Therefore, we need to talk about the result in conditional mode.

In many cases, however, market conditions do not allow for any price increases, for example when customers are easily tempted by the low prices of the competing companies. In this case, lost profits may be offset by increasing sales volume, if possible. The extent to which volume increases could compensate for lost profits (ΔP = HUF 17 million) can also be determined by sensitivity analysis:

$$\Delta V = \frac{\Delta P}{Cont} \times 100 = \frac{17}{118} \times 100 = 14.4\%$$

It means that if the company managed to increase sales by 14.4%, its profit would return to the original level of HUF 50 million.

CVP analyses after the 6.8% price change and the 14.4% volume increase are shown in Table 5. In the case of changing the unit price, revenue increases but costs remain unchanged. However, as volume increases, both revenue and proportional costs increase, but the amount of fixed costs, which is independent of volume, remains unchanged.

Table 5 Recovering the original profit using the two methods

	After price change (+6.8%)	**After volume increase (+14.4%)**
Revenue	267	286
Total proportional costs	132	151
Contribution	**135**	**135**
Total fixed costs	85	85
Profit	**50**	**50**

4.2.4. Measuring product profitability

CVP analysis can also be done at product level. In this case, *unit contribution* (*cont*) is determined and not the profit on a product – profit per unit never gets determined. The unit contribution is the difference between the unit price of the product (p) and the unit proportional cost (c_{pt}). The higher the unit contribution of a product, the more the product contributes to the total contribution and, at the same time (beyond the break-even point), to the generation of corporate profits. This type of analysis can be used for supporting management decisions about which product should continue to be produced and which should be stopped.

Unit contribution of a product multiplied by the amount of product sold gives more information about the economic goodness of a product type than only the unit contribution. But why is that? Because it is in vain to have a high unit contribution if the product can only be manufactured and sold in small quantities. Furthermore, the ratio of unit contribution to unit price ($cont_i / p_i$) gives information on the level at which a given product can contribute to a firm's fixed costs or profit. Classification of product profitability according to the contribution ratio is summarized in Table 6.

Table 6 Profitability of a product based on the contribution ratio

$(cont_i / p_i) < 0$	A loss-making product
$0 \leq (cont_i / p_i) < (C_{ft} / R)$	The product is not profitable but contributes to fixed costs
$(C_{ft} / R) \leq (cont_i / p_i) < (Cont / R)$	Product contributes to profit (but not outstandingly)
$(Cont / R) \leq (cont_i / p_i)$	Product with above average profit

5. SUMMARY

This course material on the basics of operations management covered some important issues of running production and service processes. The word "basics" in the title indicates that the picture provided by this chapter is far from complete, but is limited to a few important principles and methods.

First, we reviewed the main tasks of operations management and the most common indicators of it; production volume indices, inventory indices and operating costs of production.

Then, the section on capacity analysis gave an overview of the most important short-term and long-term problems related to the capacity of resources used in manufacturing and service systems. First, four important capacity indices were introduced and applied. Then, short-term capacity planning methods, demand management and capacity management were discussed. After that, long-term capacity planning problems were introduced and three basic capacity expansion strategies were discussed.

Considering that the course material aims to provide insights into the basics, many of the methods and applications found in the literature of capacity planning are not described here. One important consideration, for example, can be the effect of the learning curve and its consequences for short-term capacity planning. The learning curve is based on the observation that operations become smoother and faster as the number of repetitions grows. (Wright, 1936) Therefore, the calculation of the required capacity should take the learning effect into account in order to take into consideration the possible time and cost reduction. The uncertainty of the data mentioned in connection with long-term planning problems has not been solved in this part, but among the methods found in the literature, the decision tree method should be listed and dealt with here. Decision trees are widely used for evaluating decision alternatives in many fields of management. Its theoretical background is detailed in the literature on decision theory and operations research. (Hillier, 1994)

In the next section an overview was given of the principles for answering the main questions arising in connection with maintaining an inventory system. We discussed the inventory control mechanisms, showed how to determine the amount to be ordered and the time to place an order. The answers to these questions are of relevance not only to inventory management but also to other aspects of operating manufacturing and service systems. The economic production quantity calculated on the basis of the assumed production rate affects the efficiency of the production process as a whole. Inventory management has influence on the economic efficiency of the entire material flow through controlling one part of that process.

The problems discussed in this section were often presented in a very simplified context. This does not affect, however, the general applicability of the results. The best example is the fixed order quantity system. It has been shown that placing orders of fixed size is optimal only under special conditions, yet this system is widely used in different circumstances. It is therefore necessary to add two comments to the results derived above. *First*, the principles presented in this section can also be used to find optimal solutions for problems that are more complex and realistic. *Second*, the results are often found to be applicable in practice even though the conditions are different from those the results were based on. In such cases, the additional costs of replacing an otherwise well-working near optimal solution with the optimal one does not outweigh the benefits.

Last but not least, we reviewed the basics of production economics. We defined related concepts as costs and revenue, then categorized costs, and based on production-related costs CVP analysis and its application were presented. We have shown that the cost structure of a company can have a strong impact on the effects of an organizational or external decision. The sensitivity analysis examples illustrated above showed how management can mitigate or eliminate these potentially unwanted effects.

Of course, production economics works with many other models and methods. For example, we could mention activity based costing (ABC) or standard costing. Due to the lack of space, these methods have not been presented, but readings about them can provide a good basis for deepening the topic (see for example Kaplan and Cooper, 2001).

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