Industrial production

Industrial production

The Manufacture of Mechanical Products

5th revised edition

Prof. dr. ir. H.J.J. Kals
Ir. Cs. Buiting-Csikós
Ir. C.A. van Luttervelt
Ir. K.A. Moulijn
Ir. J.M. Ponsen
Ir. A.H. Streppel

Boom

More information about this and other publications is available from www.boomuitgeversamsterdam.nl.

1st edition (Dutch) 1996
2nd edition (Dutch) 1998
3rd revised edition (Dutch) 2003
4th revised edition (Dutch) 2007
5th revised edition (Dutch) 2012
5th revised edition (English) 2016

Layout and design: Studio Bassa, Culemborg (the Netherlands)

ISBN: 978 90 244 0730 9
NUR: 173/950

Foreword

This is the first English translation of the text book Industrial Production, based on the fifth Dutch edition compiled by an editorial committee consisting of Prof. Dr. Ir. H.J.J. Kals, Ir. Cs. Buiting-Csikós, Ir. C.A. van Luttervelt, Ir. K.A. Moulijn, Ir. J.M. Ponsen and Ir. A.H. Streppel, all lecturers in production engineering. The final editing was done by this committee under the ultimate responsibility of the undersigned.

The book has already been used for a number of years by lecturers at the Delft University of Technology, University of Twente and many other institutions of higher education in the faculties of mechanical engineering, aeronautical engineering, industrial design and industrial engineering & management science.

This book finds its origin in the effort to improve the quality and effectiveness of education in production engineering at the university and university of applied sciences level. Another important objective of the book is to improve the image and profile of the broad field of production engineering.

During the compilation of this book, the following considerations played an important role:

– Providing knowledge at a level appropriate to students of technical universities and universities of applied sciences who have no prior knowledge of the field.
– Providing a context that expresses the importance of production engineering within the disciplines concerned with the design and manufacture of products.
– Presenting knowledge that takes into account the needs of the industry and devotes ample attention to decision making and other important aspects of technical management.

The book gives a broad and substantial introduction to the extensive field of production engineering and covers fundamental subjects in the areas of manufacture, assembly, materials, material treatments, production machines, quality, costs and the most important aspects of technical and organisational management in an industrial environment. It also contains an introductory chapter on product and production development, with special attention paid to material and process choices.

A series of authors contributed to the book's contents. In addition to the members of the editorial committee itself, the following authors contributed in their specific fields of expertise: Dr Ir. J.P. Baartman, Dr. Ir. J.H. Dautzenberg, Ing. F. Langereis, Ir. Th. Luijendijk, Dr. Ir. D. Lutters, and Dr. Ir. M. Tichem.

The content of all delivered manuscripts has been thoroughly reviewed by the editors and, where necessary, adapted and expanded. During the preparation, much attention was devoted to the aligning of the content, but also to the presentation of the separate texts and chapters. The same applies to the figures, the presentation of which was arranged by Ir. A.H. Streppel and Ir. Cs. Buiting-Csikós. The responsibility for the preparation and content lies entirely with the editors of the final draft.

In addition to the authors and the members of the editorial committee, many others have contributed to this book. My special thanks go to Prof. Dr. Ing. Habil. B. Karpuschewski, Prof. Dr. Ir. R. Akkerman and Ir. P.J.M. Wentzel.

The editors welcome any comments and suggestions that may lead to the improvement of future editions. The address of the editorial committee is:
Redactie Industriële Productie, p/a Ir. Cs. Buiting-Csikós, TU Delft, Faculteit Industrieel Ontwerpen, Landbergstraat 15, 2628 CE Delft, the Netherlands.

Enschede, the Netherlands, March 2016

Prof. Dr. Ir. H.J.J. Kals

Reader's Guide

This book was developed through a collaboration of lecturers from Delft University of Technology, the University of Twente and the Engineering Department of Inholland University of Applied Sciences in Haarlem. Within these institutions, instructors felt a need for a book to support the introductory lectures and practicals in the area of production engineering.

The design of the book included consideration of the industry's growing need for recent engineering graduates who are both experienced in solving problems in the field of design and production and who have knowledge of the integral process of product manufacturing.

The book is limited to the production technologies used in the production of **discrete products**: these are distinctly separate and countable products that are separately distinguishable (whether already assembled or not) and which have a functionally recognisable geometry. Products of the chemical industry (e.g. gasoline) or the food industry (e.g. sugar) are not considered here. Another characteristic of discrete products is that they are movable. Therefore, construction works of any kind also fall outside the scope of this book.

As a result of trade and competition on a global scale, the importance of production engineering as a multidisciplinary field has significantly increased over the past decades. At the same time, the fierce competition has led to extensive reorganisations of large businesses in particular, which aim at reducing scale (business units), outsourcing and achieving 'flat' organisations (lean production). When outsourcing production, it remains important that product designers have and maintain a good knowledge of the possibilities of production technologies and the requirements to be imposed on the product design based on those possibilities. Smaller businesses are especially confronted with the increasing importance of technological knowledge.

A consequence is that the demand for engineers has shifted significantly from large companies (which previously hired the vast majority of recent engineering graduates) to medium-sized and small companies. At the same time, graduates need to have an increasingly broad education because there are fewer opportunities for education and training within companies. This explains the growing demand for recent engineering graduates with sufficient operational knowledge of the field and a good understanding of the needs of the industry.

The increasing relocation of production activities from the traditional industrial countries to emerging industrial countries does not diminish the need for production engineering education in the former countries. New products, manufacturing technologies and means of production are still mainly developed in the traditional industrial countries and the need to educate future designers and business experts in this field is only increasing.

This book is intended to offer a broad overview. Given the nature and scope of the field, it is impossible to achieve any form of completeness in a text book. The broad scope includes subjects such as important manufacturing technologies, along with a discussion of subjects such as the most common processes for material processing and assembly or tooling. It also discusses related aspects of technical production, such as quality, costs and the organisation of production. The connection between product development and production development is also discussed extensively. In addition, the book focuses on issues of decision making in a production environment.

The book is primarily aimed at students of mechanical engineering, aeronautical engineering, industrial design and related disciplines taught in higher education. It is also suitable for other disciplines, such as technical business administration and business information technology, where a basic grasp of manufacturing and production processes is essential.

In addition to the material offered here, it will be necessary to elaborate on one or more of the covered subjects, depending on the field of study or specialisation. For disciplines such as Industrial Engineering and Management Science, the depth of the material related to the technical subjects will be sufficient. It is also possible to skip particular parts, either because they are considered less important, or because they will be discussed in more detail later in the course.

Apart from its use in education, the editors see possibilities for using the book as a reference work for designers, structural engineers and production engineers who, in addition to their business-related knowledge and experience, demand a general and structured overview of the field and the technologies applied in that field.

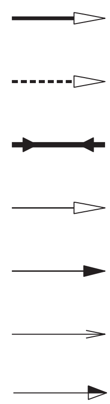
How to use this book

The book is suitable for self-study. To that end, quite a few practice questions are included. Some of these questions are designed to encourage students to become actively engaged with the subject and are therefore less suitable as examination questions. The answers given to these questions are not the only correct ones, but provide an indication of the right line of thought. Other questions would qualify as examination questions.

Only start answering the questions when you have a thorough grasp of the subject. First try to answer them without referring back to the text in the book. If you fail at this repeatedly, you have not sufficiently mastered the material. Study the text further and try to imagine which questions you can expect. Then try to answer the questions again. After answering, go back to the text to check whether you got it right. Only use the answers in the back of the book to confirm your conclusions. In addition to answering the exercise questions, it is strongly recommended that you practise making drawings (a skill that every engineer must possess).

Nowadays, in all kinds of project-based education, there is often a need for much more information on particular subjects than is presented in this book. To meet this need, carefully selected literature references have been included in each chapter. References to specialist literature have been left out intentionally. It is recommended that educational institutions include the works from these reference lists in their libraries.

Various types of arrows occur in the drawings, each with their own meaning:



tool movement

setting motion

parting line in a mould

workpiece movement

force

dimension

arrow to indicate plane of cross section

Technical terms are printed in bold typeface in the places where they are introduced. A list of keywords can be found at the end of the book.

Note on the decimal point

To maintain conformity of the equations and numbers in the Dutch and English editions of this publication, this English edition uses decimal commas instead of decimal points, and full stops (dots) as grouping separators. For example, two thousand is printed as 2.000 and two and a half as 2,5.

The editors wish you the best of luck in studying this book and hope that the knowledge you acquire will contribute to a greater interest in the field.

The editors

Content

1 Introduction

This chapter describes the close relationship between the technologies for the manufacture of products and the different disciplines in the manufacturing enterprise. It explains why product designers also require an understanding of the specialised field of production engineering. It also gives an overview of the most important aspects of production and the topics covered in the following chapters.

1.1 The development of industrial production

Industrial manufacturing engineering came about towards the end of the eighteenth century. A good illustration of this is the steam engine (see Figure 1.1), which was commonly used to extract water from coal mines. The rise of the steam engine marks the time when people were in a position to apply the principles of physics, mechanics and production engineering to the design and manufacture of functional and profitable tools. This development is also generally considered the beginning of the rise of the mechanical industry.

An essential condition for building steam engines was the availability of knowledge and means to manufacture cylinders and pistons with accurate shapes and dimensions. Accuracy requires machine tools, and those tools need sufficient energy to drive them. The steam engine supplied energy at a central point and that energy had to be used on the spot (see Figure 1.2).

The availability of very large quantities of energy in a single location marked the first industrial revolution. This was characterised by the rise of large **industrial enterprises**, which replaced the small craft-based enterprises from the time of windmills and watermills. One of the most important characteristics of industrialisation is bringing together production resources such as labour, machines and tools in an organised context. These industrial manufacturing companies had a much larger capacity than craft-based companies. The rise of railways and steam navigation made it possible to supply raw materials and other supplies over great distances and to distribute products over a large sales area. This in turn stimulated the machine industry and the building of civil works such as railway lines, bridges and waterways.

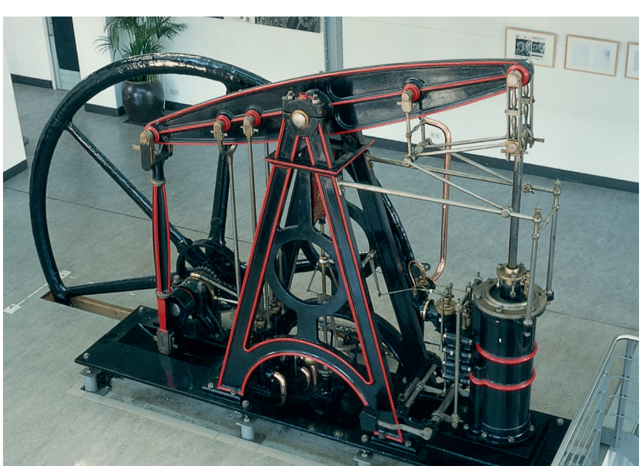


Figure 1.1 Steam engine from 1843 (Techniek Museum, Delft)

Figure 1.2 Central machine shop of the Technische Hogeschool Delft from about 1938. The machines were originally driven by a steam engine via drive shafts and pulleys

The development of industrial businesses brought with it considerable social problems. The massive population shift to the industrial cities, the resulting housing problems, dire poverty and inhumane working conditions are inextricably linked to the industrial revolution. From the end of the nineteenth century, some 100 years after the industrial revolution began, improvement came gradually through the rise of parliamentary democracy and the trade union movement.

One of the first signs of mass dissatisfaction among workers was the riot around 1815 of the Luddites, English textile workers led by Ned Ludd who destroyed the new looms for fear of losing their jobs.

Background: The looms in question are the precursors of today's production machines. The pattern to be woven was created using a series of punched cards (see Figure 1.3). The hole pattern in the cards determined the weave pattern. The information about the product and production process was input in code with an easily exchangeable data carrier. This information allowed for the production process to take place wholly or largely automatically. Aside from the punched card or punched tape, this description still applies to the modern numerically controlled (or computerised) machine tools. Numerical control is generally indicated by the abbreviation NC. This subject is discussed in Chapter 12.

The Luddites have their modern successors: in the seventies of the twentieth century the introduction of a levy was proposed in Dutch politics to curb automation and thereby preserve jobs.

Other problems that arose with large scale production were a shortage of capital and a trained workforce, the distribution of tasks and the required specialisation. As a consequence, organisational complexity increased and communication between the different departments within enterprises became ever more difficult.

In the beginning of the twentieth century, new important developments followed: the rise of the electrification, automobiles, aircraft, radio and television and finally, after the Second World War, space travel, micro-electronics and information technology. Here too technical breakthroughs were always necessary in order to facilitate the application of technological principles that were already known. Examples: no aircraft without a light combustion engine, no space travel without micro-electronics.

Figure 1.3 Jacquard-loom from the beginning of the 19th century. The weave is being controlled by a punched paper card

The clearest and most important trend over the previous century is, however, the enormous increase in accuracy allowing very diverging manufacturing machining operations and material treatments to be carried out. This has been the driving force during the previous decades behind a form of product renewal that can best be called miniaturisation. It thus becomes clear that manufacturability forms the greatest hindrance for product renewal. The current developments in the field of **microtechnology** (the design and manufacture, as well as the manipulation, placing and measurement of products on a sub-100 micrometer scale), and the related production possibilities in micro-electronics, stem from the growing requirement for miniaturisation. These developments focus mainly on precision manufacturing, with which new products can always be brought on the market in a technically and economically attractive way. This applies, for example, to the automotive industry: for the more expensive types, the added value of micro-electronics with its associated sensors and actuators already counts for over half of the added value.

The newest challenge is biotechnology. For the time being, this technology focuses especially on new materials and shows a large involvement with physics and chemistry. From a mechanical viewpoint, **nanotechnology** (the design and manufacture, as well as the manipulation, positioning and measurement of products at sub-100 nanometer scale, < 0,0001mm) are considered a logical continuation of microtechnology. When it comes to industrial production, the manufacture of nanoproducts will therefore frequently require the help of the mechanical and micro-electronic disciplines on account of the required production equipment.

1.2 Organisation and communication

Craft-based firms, founded by an owner – simultaneously product developer, technical expert and seller, sometimes assisted by apprentices – grew into industrial companies with many employees, each with their own task. The changes that brought about this growth have been described in the previous sections. The further growth of companies and progress of technical development was accompanied by a growth in the complexity of products and processes.

In the first half of the twentieth century this led to a distinction between the different **business functions** and even to a distinction within the business functions. This was very clearly evident with the production function. Especially in mass production, the successive operations were split up into simple, recurring actions that are each carried out by an employee. In this way, productivity could be raised significantly and the work left to untrained or undertrained and low-paid workers. The film "Modern Times" starring Charlie Chaplin shows by means of caricature where this can lead. Similar tasks were brought together in separate organisational units in the business. In today's companies, such separation can still be found in business functions, namely sales or marketing, product development and production. This "natural" division is most clearly seen in the construction industry, where the broker, the architect and the building contractor often operate as independent companies.

As an enterprise grows, task allocation goes ever further. Figure 1.4 shows the four primary tasks in the generation of a product, that are often handled as separate business functions. The business functions must support each other and to that end **communication** is necessary. The function-based structure makes it quite difficult to avoid communication problems and barriers between departments. If the communication between the business functions does not work properly, it is almost impossible to meet all the requirements specified for the product (quality, lead time and cost).

Communication requires in the first place the readiness to engage in consultation with people from other specialisations. This is often found to be much more difficult than first expected. A commercially minded person has a different way of thinking and reasoning than a designer. He has his own jargon, his own priorities and expects an immediate reply to questions a designer would first have to consider for a time.

The same applies for the communication process between designers and the personnel in the workshop. This also requires a readiness to listen to each other, to grasp each other's problems and to look for a solution together. But all too often the attitude "that isn't my problem" prevails, and product designs are pushed to the workshop before designers have asked themselves adequately how the product is to be made (Figure 1.5).

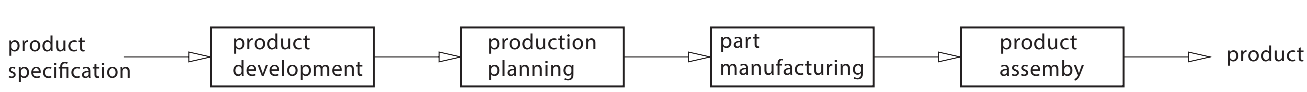


Figure 1.4 From product specification to product

Figure 1.5 Communication

Figure 1.6 shows the result of various investigations carried out in industry. It includes the share in the costs of product development, production planning, part manufacturing and assembly. It also shows where these costs are determined. The share of the design costs is limited, but the designer determines to a large extent the production methods and consequently the cost of the product. An unfavourable design from the viewpoint of costs can therefore never be compensated by an efficient production method.

Consequently, good consultation is of vital importance for the continued existence of the enterprise. In addition to the readiness to communicate, fruitful consultation also calls for an adequate measure of expertise. In addition the employees involved must have the required data or have access to the communication channels. The designer will need an adequate knowledge and understanding of the production techniques to be able to elaborate sound proposals independently.

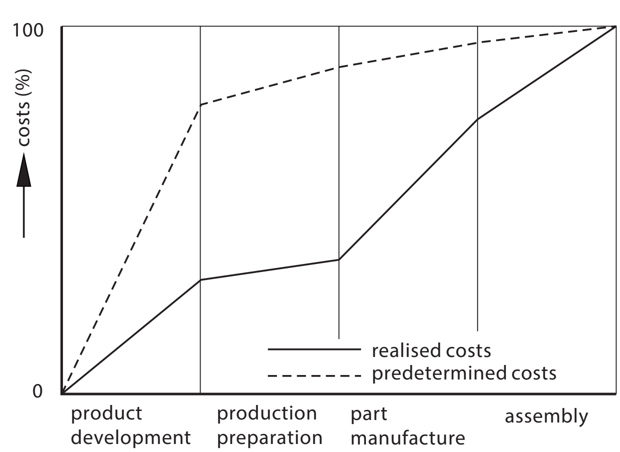


Figure 1.6 Schematic cost structure

Communication media

The growing complexity of business processes also increases the need for good communication. The oral communication in the craft-based enterprise has led to different communication media.

The manual sketch gave way to the **technical drawing**, which established the geometrical and, at a later stage, the **tolerance aspects** (i.e. permissible deviations from the nominal dimensions and of shape and position) of a design. Nowadays this is referred to as the **geometrical product specification** (**GPS**). In the course of more than a century, an increasingly refined system of ISO standards has been developed for the GPS that determine the execution and interpretation of drawings. Additional information such as required quantities, delivery dates and required materials was documented on forms. These were developed on the basis of the required information flows.

Initially, the transfer of information from drawing to product took place by the manual setting and operation of production machines and later, in the case of mass production, also by controlling the machines using mechanical means such as gauges and stops. The rise of computer-controlled machines made it possible to provide the control system with workpiece programs containing geometrical and **technological** information (information concerning the machining operation) using easily exchangeable data carriers. This led to the possibility of automating the manufacture of products on a smaller, batchwise scale. Nowadays the geometry of a workpiece is usually documented in a 3-dimensional computer model. This model can serve as a starting point for designing the workpiece program and facilitates the development of these programs, producing them faster and especially much more reliably. This technology is known as **CAD/CAM** (Computer Aided Design/Computer Aided Manufacturing).

For other communication flows, there is a growing trend to use computer networks. This takes place increasingly on a worldwide scale between companies involved in product development and manufacture.

1.3 Product examples and key figures

In this book, the subject matter is illustrated with practical examples taken from the field, which relate, as far as possible, to the same example products.

The chosen example products are:
- A stapler (Figure 1.7). This simple article is an excellent example of the division of the production techniques and the choices a product designer has to make.
- A shaver (Figure 1.8), an apparently simple product but for which very advanced manufacturing methods are applied and that is made in very large volumes – up to a few million per year for a single model.
- The front fuselage of a passenger aircraft, the Fokker 100 (Figure 1.9). The focus here is a very complex product of which only 20 to 30 units were made per year. Due to the low volume alone, the manufacturing processes are completely different than for a mass product.

These examples could be supplemented with others to treat the whole range of production processes between mass-produced and one-off products.

Figure 1.7 Stapler

Figure 1.8a Philips shaver

Figure 1.9 The front fuselage of a passenger aircraft, the Fokker 100

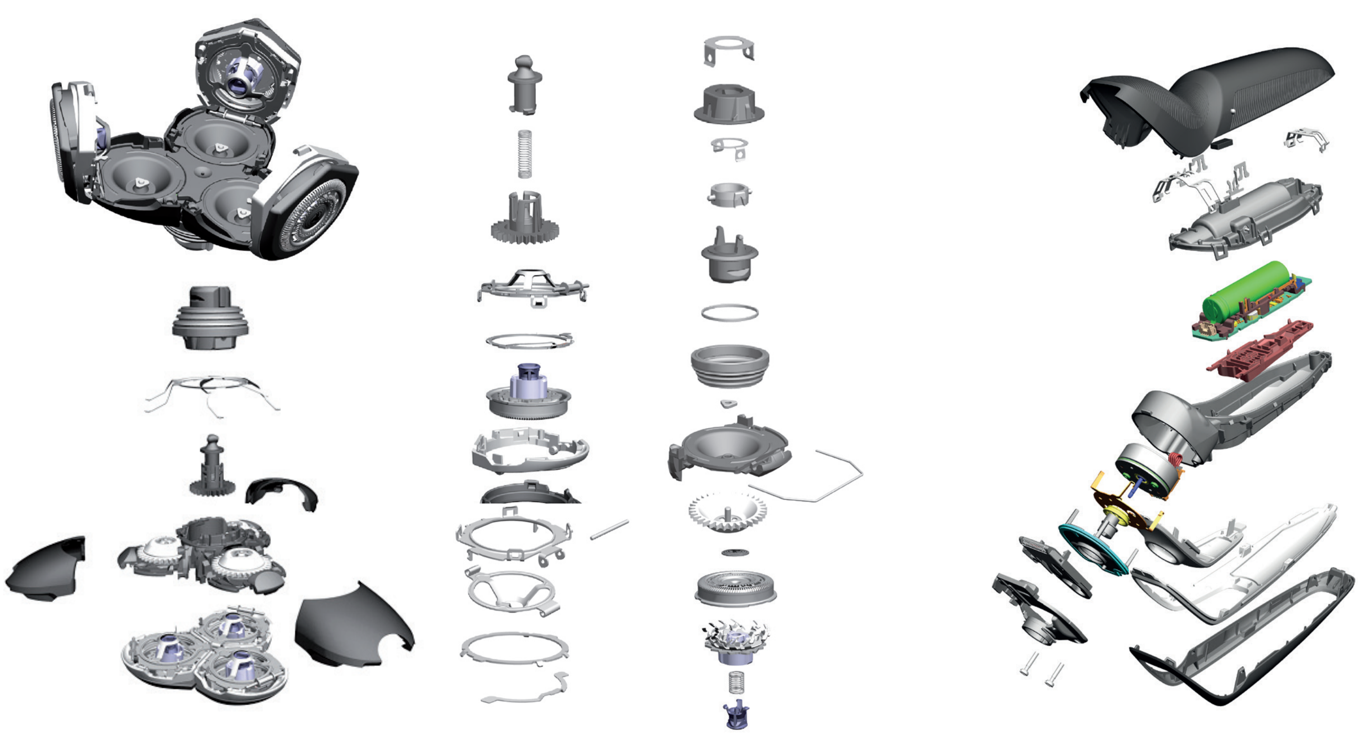


Figure1.8b Partial exploded view of a Philips shaver

Product	Total series	Product lifecycle	Development time	Product lifetime	Number of components
shaver	10^7	1 year	1 year	5 years	50
car	10^6	5 years	5 years	10 years	10.000
airplane	10^3	25 years	7 years	25 years	100.000
yacht	10^2	5 years	1/2 year	30 years	1.000
dredger	10^0	building time	1 year	15 years	50.000

Figure 1.10 Examples of products and their production characteristics

Figure 1.10 shows a number of characterising quantities for a set of products that are typical examples of mechanical production. The examples cover the whole area from mass production to the production of a single unique product. The product volumes have a large influence on the design and manufacturing processes at a production plant. The total production volume indicates the order of magnitude of the total number of units that is produced of a single model (including variants). The numbers apply to products that may be considered a commercial success.

The **product life cycle** is the duration in which a product can be sold successfully. Striking are the very short product life cycle of consumer products and the very long product life cycle of aircraft. The Fokker F-27 (Figure 1.11a), direct predecessor of the Fokker 50 (Figure 1.11b), was first made in 1955. The latter remained in production until the year 1996. This is followed by a **product lifetime** of approximately 25 years.

The **development time** is the duration of the development process to a ready-for-production design. The product lifetime is the average lifetime of the product. The total production volume is the most important factor in the design of the production method. The product life cycle and the development time determine the course of product development. The product lifetime determines the efforts required in the field of service provision and the archiving of data. The number of components is an indication of the complexity, both of the product development and of the manufacturing process.

Choice issues in the design

Designers are continuously concerned with issues of choice. The choices they make influence both the design and the manufacturing method. Two alternative designs for a stapler provide an example of this (Figure 1.12). The designer must make consistent choices with regard to:

- material,
- design,
- manufacturing process,
- producing in house or outsourcing.

The choices are determined by factors such as:

Function:
Functional requirements specified for product components are strength, rigidity and accuracy.

a

b

Figure 1.11 Prototype Fokker F 27, first flight in 1955 (a). and Fokker 50, produced 40 years later (b)

Aesthetic requirements
This concerns the desired external appearance of the product. This may have to be adapted so that the product fits within a line of related products (punch, staple remover) or fits with office furniture, for example. Another consideration could be the demand for a certain look: businesslike or fashionable.

Considerations for the possible combinations of material selection and manufacturing methods are:

Cost
In this case, the batch size, the variants to be expected and the number of components are determining factors.

Lead time
A mould for the injection moulding of a plastic product implies a relatively long lead time.

Available production techniques
The question whether the required technology is available within the enterprise, and whether one is prepared to outsource or to do everything in house, means either a significant broadening or a limitation of the options.

Suppliability
It must be possible to acquire the base materials (sort, shape and quantity) within the required time frame, not only in present production scenarios but also in the future.

Maintenance
The product must be easily accessible for maintenance. The use of product-related tools for this purpose should be avoided as much as possible.

Recycling
The product must be easily dismanteable and the material re-usable.

1.4 Classification of the manufacturing processes

The manufacturing processes considered comprise the manufacture and joining of components. We will use the stapler again to illustrate this, in a version that is made primarily from steel plate (Figure 1.12a, b).

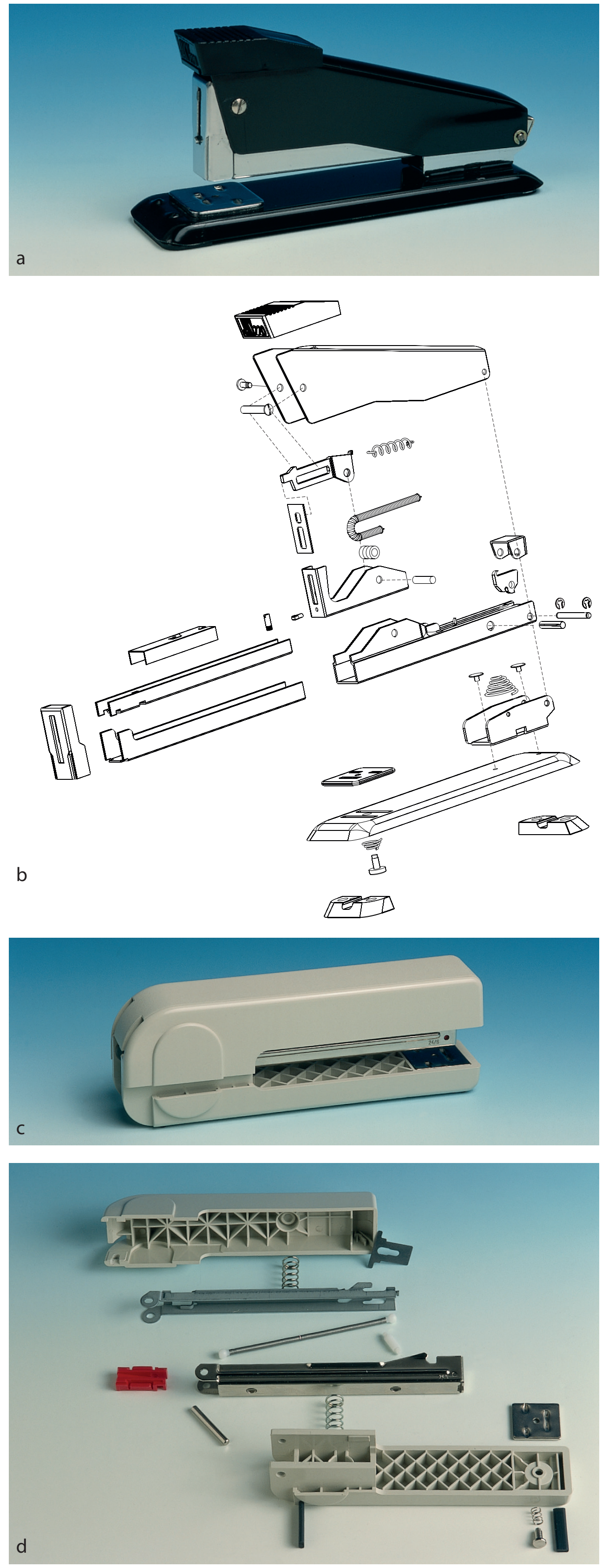


Figure 1.12 Stapler made of sheet metal (a) in exploded view (b) and polymer stapler (c) in exploded view (d)

1.4.1 The main groups

DIN 8580 gives a classification of the manufacturing processes, based on the changes in the cohesion of the workpiece material. In this way the following main groups have been formed:
– primary shaping,
– material forming,
– dividing and material removal,
– joining,
– modification of material properties,
– coating.

All manufacturing processes fall into one of these main groups. There are cases in which a combination of two or more main groups is involved. The manufacture of a product from fibre-reinforced plastic, for example, involves primary shaping, joining and modification of material properties simultaneously.

1.4.2 Descriptions, applications, examples

Primary shaping, processes for shapeless materials

The most important processes in this category **are those which convert shapeless** materials directly into a clearly defined shape. In by far most cases, the starting material is in a fluid state; one then speaks of **casting**. This involves pouring liquid material in a mould. After solidification – or curing in the case of some plastics – a dimensionally stable product is formed. A second option is to start with material in powder form that is compressed in a mould under high pressure and then heated to temperatures near the melting point. This last step is called **sintering**. This is another way to obtain a coherent component. For the processing of metals or metal alloys, the term **powder metallurgy** is used.

Additive manufacturing processes represent a family of methods that also come under processes for shapeless materials. The component is built up from a shapeless material without the necessity of a shaping tool, for example a casting mould.

Any materials that are not used in the form in which they naturally occur (e.g. wood and stone), come about through a primary shaping process, possibly in a number of steps. In the case of casting, it is possible to distinguish between the casting of starting material for making semi-finished products, such as plate, rods or sections, and the direct casting of components to be used as such.

Example of casting:
The push-button of the stapler is made by injecting liquid plastic under high pressure into a metal casting mould; this process is called **injection moulding**. The same applies for most components of the plastic stapler.

Primary shaping is discussed in Chapter 3, the additive manufacturing processes in Chapter 7.

Forming

Forming relies on the ability of materials to undergo permanent deformation under the influence of forces. The cohesion of the material is retained and its mass and volume remain constant.

The forming processes can be divided into two groups: bulk deformation and the forming of sheet metal. **Bulk deformation processes** may involve subjecting the material to major changes of shape in all directions. The required forces are large in comparison with the forces that occur during the forming of sheet material. In the **forming of sheet metal,** deformations perpendicular to the plane of the sheet are of less importance for the forming of the component.

Example of bulk deformation:
The stapler is largely produced from steel sheet. Steel sheet is formed by reducing a cast block of steel in thickness in a large number of steps by means of rolling. This is a bulk deformation process.

Example of forming sheet metal:
A number of components of the stapler is made from flat sheet material by means of bending.

The forming of materials is discussed in Chapter 4.

Dividing and material removal

During these machining operations, the cohesion of the initial material is broken. The product comes about through the removal of superfluous material. As a rule, the superfluous material remains usable as such during the **dividing process,** for example in the case of shearing a wide sheet into narrower strips.

In the **process of material removal,** the superfluous material is finely distributed or even chemically bound, so that no usable material remains. In the production of certain aircraft components, around 95% of the starting material is converted by cutting into chips that can only be reconverted into usable material by recycling. A dividing machining operation can in itself be a material removal operation, for example the sawing of a long rod into discs. Sawing is an operation involving the removal of material. The end result is a number of usable material parts and a limited number of chips.

Example of dividing:

Before forming the sheet metal parts of the stapler, a sheet part must be made with the correct circumferential shape: the **blank**. The sheet is first sheared into narrow strips. A punch tool then punches out the blank – containing any required holes – from the strip. Sometimes the waste material can still be used for other parts.

Example of material removal:

The spherical ends of the hinge pin (Figure 1.13) are made by the removal of superfluous material by turning. This also applies for the grooves with which the fixing plate is fastened. The chips of course have no further use.

A general characteristic of mechanical removal operations is that the shape of the product is obtained by the movement of a **universal tool** (not intended for a particular product) along the product. This is referred to as **generating** the shape.

With primary shaping, forming and dividing, the shape of the end product is generally established in a **product-related tool** (specially intended for that product). This involves **reproducing** an already existing shape. As a rule, reproducing is much faster than generating and therefore generally preferable in the manufacture of products in large volumes.

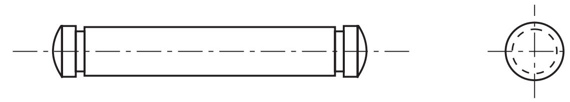


Figure 1.13 Hinge pin of the stapler in figure 1.12a,b

The dividing operations are discussed in Chapter 5, the material removal operations in Chapters 6 and 7.

Joining

In **joining processes,** components are assembled into one rigid whole. Roughly speaking, the joining techniques can be classified into five main groups:
- Pin-hole connections, further subdivided into detachable and undetachable joints.
- Joints that come about by bringing the material of the components to melting point (welded joints).
- Joints using an intermediate layer (glued and soldered joints).
- Forming joints where the joining is accomplished by the forming of one or more of the components.
- Joints by elastic deformation, such as shrink and press connections, where the mutual shifting of parts is impeded by friction.

None of the joints from the latter four groups can be taken apart without damaging the parts.

Example of joining:

The sheet metal parts of the stapler are permanently connected with rivets (non-detachable pin-hole connections).

The joining processes are discussed in Chapter 8.

In all the above-mentioned manufacturing processes, the aim is to achieve the desired geometry of the workpiece. In the following two main groups, the aim is to modify the material properties.

Modification of material properties

Modification of material properties relates primarily to the thermal treatment of metals, a subject within the field of materials science. The modifications can concern the volume of the workpiece (or a large part of it), bulk treatment or a thin layer on the surface of the workpiece (**surface treatment**).

The material properties are modified:
- to obtain desired properties of the end product, for example wear resistance,
- to be able to machine the product better, for example to improve formability.

Modification of properties can also occur as a consequence of the manufacturing process.

Example of desired modification:
In the manufacture of sheet, a combination of rolling and heat treatments produces sheets with the desired thickness and mechanical properties.

Example of undesired modification:
In the conversion of a semi-finished product into a component, strain hardening can make material hard and thereby difficult to deform.

The modification of material properties is discussed in Chapter 9.

Application of coatings

A large variety of coating techniques exist. They can be distinguished according to:
- function (improvement of durability, embellishment),
- applied materials (organic, metallic, ceramic),
- applied processes (chemical, electrochemical, physical).

Examples of coating:
The sheet parts of the stapler have been partly painted, that is, covered with organic material by means of spraying or immersion. Other parts have been chromium-plated, thus provided with a metallic top coat, applied through an electrochemical process. The sheet parts are cleaned prior to these treatments and chemically treated to improve the adhesion of the surface layer.

Example of an applied process:
Aluminium parts (that are not part of the stapler) are often anodised. This is an electrochemical process where the material on the surface is converted into a hard and dense oxide layer that counters further oxidation.

Coating is discussed in Chapter 9.

1.5 The mechanical material behaviour in manufacturing

The material properties that determine **machinability** – that is the behaviour of the material during the manufacturing process – differ strongly from the properties that are important for the functioning of the product. It is therefore necessary to take machinability into account when choosing the material in the design stage of the product, in conjunction with the selection of the machining process.

Material behaviour is determined by:
- the properties of the initial material, determined by the composition and the structure,
- the modification of the material properties during the machining process, depending on the process conditions, among other things through the stresses, strains and temperatures.

During some machining operations, the workpiece material undergoes major changes of structure and properties. In these cases, the process and the process conditions are not only partly determining for the material properties during the machining operations, but also for those of the completed product. This is very clearly the case in the manufacture of products from plastics, where the polymer structure is formed during the manufacturing process. Something of the kind occurs also with metals, where as a consequence of plastic deformation strain hardening occurs. This can lead to a considerable increase in the strength of the material, but also to cracking and breakage. In the latter case, the properties of the construction as a whole have deteriorated.

In some cases, the material must undergo a prior heat treatment to obtain the structure required for the machining operation. In other cases, the process conditions must be adapted in such a way that machining of the material is possible. An example of this is the preheating of the material to reduce the resistance against plastic deformation or the probability of cracking. At higher temperatures, most materials are easier to deform.

During almost all machining operations, heat is formed by the deformation in the material or through the friction between tools and product. Friction, however, can also be attributed to plastic deformation on a micro scale. Thus all energy fed to a mechanical machining process is converted into heat. In some cases, this heat is useful, as in the hot rolling process. As a result, the material remains at the correct temperature. In other cases, forced cooling is necessary to control the material properties and to prevent deformation and wear of the tools.

All factors that determine the conditions can be reduced to a few physical principles of which friction is the most important. This relates especially to friction between workpiece and tools. Some processes, such as rolling, are only possible due to the occurrence of friction between roller and material. In other processes, such as extruding, the friction forces between tools and workpiece material are precisely the restricting factor. In the case of rapid processes, such as cutting or milling of steel, friction leads to very high temperatures and consequently to intensive wear of the tools. The application of lubrication can limit the friction.

As a rule, the limits of the feasibility of machining processes are determined by:

– the occurrence of extreme thermal and mechanical load of the tools, leading to high wear and/or breakage.
– undesired deformation (for example with thin-walled products), cracking (at too large local deformation) and breakage of the product.
– limitations in the possibilities of machine tools due to the installed power, the permissible or limiting forces, and the rigidity, the latter in connection with accuracy and vibrations.

Because of these limits and depending on the type of material, each manufacturing technology has its limitations with respect to the achievable shapes, dimensions and tolerances.

Chapter 2 provides the elementary knowledge of materials science required for a proper understanding of the different machining processes in the following chapters.

1.6 Producing in an industrial environment

Assembling involves bringing together components by application of the joining processes, discussed in Chapter 8. Chapter 10 discusses the set-up and procedures of assembly shops.

Quality is the measure to which a product meets the expectations of the customer. **Total quality management** covers the whole manufacturing process from market exploration via design and production through to service provision. Many quality problems concern organisational rather than technical issues. With technical quality problems, especially in the manufacture of components, **workshop measurement technology** and **non-destructive examination play** an important role. Quality is the subject of Chapter 11.

Chapter 12 discusses the production machines and examines the automation of manufacturing.

The link between the design and the manufacturing department is the **process planning department**. This department establishes the manufacturing method on the basis of product design, and determines the required tools and work instructions. This is the subject of Chapter 13.

Chapter 14 describes the production company as a whole. This chapter examines in particular the organisation and the procedures which are necessary to integrate the separate activities and processes discussed in the preceding chapters.

Figure 1.6 shows that the designer is the major factor in determining the cost of the product. Chapter 15 discusses the relationship between the manufacturing method and the cost of the product.

Chapter 16 discusses **design for production (DFP)**. This is designing in such a way that the product can be produced as efficiently as possible.

Chapter 17 gives an overview of the processes that occur in the development of products and production methods. It emphasises the influence of the relationships between product function, geometry and the material of the product on the course of the development process.

The following sections give an introduction to a number of general subjects. Some of these will be discussed in greater detail in subsequent chapters.

1.7 Criteria for the assessment of manufacturing methods

It has been mentioned repeatedly that product design has a significant influence on the manufacturing method. A manufacturing method is understood to be the series of successive machining operations and treatments, starting from the rough material, that ultimately leads to components that meet the specification. Machining operations are necessary to achieve the desired geometry, possibly via a number of intermediate stages. Treatments are necessary to obtain desired material properties or a good external appearance of a product. A distinction is made between material treatment before and after a machining operation. Pre-machining treatment serves to bring the material into a suitable condition for machining, such as soft annealing before a forming operation is performed. Material treatment after machining is often performed to counter undesired consequences of a machining operation. An example is stress-free annealing after welding to reduce the internal stresses in the workpiece.

Before giving more detailed descriptions of the different manufacturing methods, a global overview of the aspects a designer should consider is given below.

The effectiveness of a manufacturing method can be assessed considering:
– production costs,
– production rate,
– flexibility,
– quality,
– environmental effects.

These criteria can also be applied to a complete production system.

1.7.1 Production costs

The costs of a product can be divided into one-off, repeat order and repeating and recurring costs. One-off costs are costs that must be incurred once to be able to manufacture the product. These costs are therefore distributed over the total number of products: the total production volume. Examples of one-off costs are:
– design and development costs,
– process planning costs, e.g. making work instructions,
– costs of product-related machines and tools.

Costs for **repeat orders** are the costs that must be incurred to manufacture a batch of products. Components of products that are built during a longer time, such as passenger cars, are manufactured in batches. The costs for repeat orders return with each **manufacturing order**, so that they are distributed over the number of products in the manufacturing order. Examples are:
– administrative costs,
– costs to set up a machine for the manufacture of the relevant product, the set-up costs.

Repeating or recurring costs are the costs that return for each product. Examples are:
– material costs,
– costs of using universal machines and tools,
– labour costs.

The choice of the manufacturing method consequently depends greatly on the size of the total production volume and the manufacturing series. The importance of the size of the series, the batch size, is a recurring theme in this book. The decrease of the cost with increasing product quantities is known as the **batch size effect.** Cost calculation is discussed in Chapter 15.

1.7.2 Production rate

A high production rate is almost always accompanied by low repeating costs. High-speed manufacturing processes are usually highly automated. This in turn means that the preparation costs and the costs for repeat orders are relatively high and that this kind of manufacturing process is therefore especially suitable for high product volumes. An equally important aspect of the production rate is the mutual coordination of the speeds of the different processes in a series of successive manufacturing or assembly processes. This is demonstrated most clearly in connection with assembly lines, discussed in Chapter 10.

1.7.3 Flexibility

The flexibility of a manufacturing or assembly system is the measure in which the system can be adapted to new or changed products or to different product volumes. Over the past decades, the market for both consumer products and capital goods has developed in the direction of an increasing variety of products. There is also a demand for a larger measure of adaptation to the wishes of the customer and to shorter, but in particular more reliable, delivery times. Processes that are suitable for the production of very large volumes of identical products will generally produce very efficiently but have a low degree of flexibility. Chapter 12 gives a detailed discussion of this matter.

1.7.4 Quality

The product characteristics, the price to be paid, the lead time and the service together determine the quality of the product. Quality is thus not simply a matter of a high degree of accuracy or expensive raw materials. The quality of the product is determined by:

- the extent to which the product design conforms to the wishes or expectations of the customer,
- the extent to which the product corresponds with the product specification,
- the support for the product in the form of manuals, maintenance, spare components or parts supply and guarantee,
- the environmental impact associated with production, use and scrapping.

The product quality is the result of the design quality and the quality of the production process. In every machining operation or treatment something can go wrong so that workpieces fail to meet the quality inspection requirements. Quality control is an important aspect of production engineering. Inspection can lead to products being rejected. The **failure rate** f is an important criterion for judging the quality of production processes. The yield y ($y = 1 - f$), is also used. As a consequence we must start by making more components than strictly needed, in order to be able to finally deliver the desired number of correct components. The failure rate is an important measure of the reliability of production processes.

High quality does not always entail high cost. Chapter 11 shows that increasing quality often coincides with a lower cost!

1.7.5 Environmental effects

In the past and even today, activities for reducing environmental pollution were principally directed at removing pollution and at the responsible processing of waste. Nowadays there is gradually a more target-focussed approach, often indicated with the overarching term **environmental care**, aimed at preventing the creation of harmful substances and harmful effects. Here, however, the risk is that the old, known harmful influence is replaced by new, still unknown, effects. It is often difficult to understand the total effect of an environmental protection measure from beginning to end.

In production, the task is to limit the harmful environmental effects of the manufacturing processes as much as possible. In addition to the requirement that the environmental problem must be solved effectively, the technical result of the replacement process must be at least equivalent and that the process is practically feasible. If necessary, higher costs have to be accepted. Sometimes a replacement process involving lower consumption of energy and auxiliary materials may even result in cost reduction.

In general, design has the greatest influence on the environmental impact of the product. This applies both for the manufacture, and for the use and the end of the lifetime of the product. The design establishes the material used and so largely also determines the manufacturing method. For example, the manufacture of aluminium is energy-intensive. For a stationary construction, a less energy-intensive material may be preferable. With the use of aluminium in, for example, metro train-sets, the lighter weight can result in significant energy saving. When reuse is taken into account as early as in the design stage, the application of aluminium can be advantageous – from the viewpoint of energy consumption – in even more cases.

In the life cycle of products, we can distinguish four phases: product development, manufacture, use and disposal. The purpose of **environmentally-oriented product development** is the development of products that cause a minimum of environmental impact during their whole life cycle. The input of a production process consists of raw materials and energy, while the output consists of products, waste and emissions. For the study of environmental impact in product development, the following **MET factors** (material, energy, toxicity) are important:
- materials: economical and selective use of raw materials; reuse of raw materials as much as possible and at the highest possible use level.
- energy: energy extension of products through limitation of the energy content of products and the energy consumption during the use phase.
- toxicity: limitation of the release of waste and emissions.

Authorities are increasingly imposing legal requirements for products and production companies concerning the limitation of environmental impact. Of great significance is the international standard ISO 14001, which lays down rules for environmental protection systems.

1.7.6 Cohesion between the criteria

Figure 1.14 indicates that the aspects discussed here are inextricably linked. Choosing the best solution thus means weighing the effects of the five variables stated.

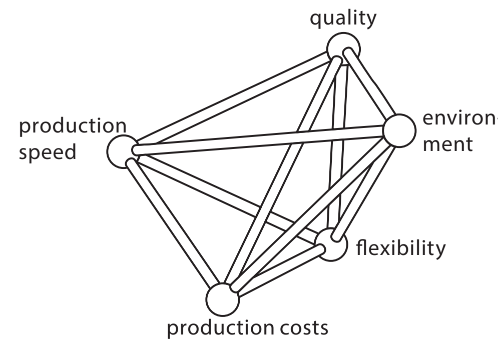


Figure 1.14 Relationship between the evaluation criteria

Figure 1.15 gives an overview of the valuation of the different machining processes with regard to the above-mentioned criteria.

1.8 Issues of choice

In the preceding section, assessment criteria were discussed that play an important role in industrial production. These criteria are not isolated but show a strong interrelationship. As the following chapters will show, sensible choices must often be made between the various available options. As a consequence, designers and production engineers often need to set priorities and make compromises when making choices. It is usual to refer to an issue of choice if a reasoned choice must be made on the grounds of different interests that have to be weighed against each other. The greater the range of possibilities, the more difficult the choice. Weighing up the various interests is a problem per se, especially with factors that are difficult to quantify. As far as possible, a goal must be established, but even when based on quantitative grounds this is not always easy, for example for safety or aesthetic reasons. The most

Evaluation criteria	Casting, powder processing	Deformation	Separating and material removal	Connecting	Changing of material properties
costs	tc: high	tc: high	tc: average	cc:low	cc: average to high
	lc:low	lc:low	le: high	le: high	ic:low
production speed	high	high	average to low	average to low	low
quality	average to low	average to low	average to low	average to low	high
flexibility	low	low	high	high	average to low

tc: tool costs le: labour costs cc: capital costs

Figure 1.15 Assessment of different manufacturing processes according to the evaluation criteria important characteristics of issues of choice can be summarised as follows:

- The goal – This can be single or multiple. Examples of single goals are: as quickly as possible or as cheap as possible. An example of a multiple goal is: quick and cheap. In almost all cases of multiple goals, the individual requirements cannot be met at the same time. It will then be necessary to set priorities and make considerations based on assigned weighting factors.
- The importance – Within the constraints of the desired quality and lead time of a product, the importance is often best expressed in terms of money (at the highest level in this field). Low costs are always an important competitive advantage. In an extremely short required lead time scenario, the total lead time of the order will play the most important role, with quality and costs ultimately forming the constraints.
- The constraints – It is crucial to establish beforehand within which limits a solution must lie. An important example are the allowable costs for the realisation of a product in view of the price of competing products.
- The familiarity – Some problems occur frequently on a daily basis; they are routine problems. Other problems occur much less often, but their solution is known. Then there are still issues of choice that are more or less rare and where many factors, of which little is known, are involved. Here, knowledge and the time necessary to choose play a large role.
- The complexity – The number of choice-elements that play a role in a selection process and the number of factors that must be involved when making the choice.
- The number of parties concerned – Issues of choice are frequently independently solved by production employees on a daily basis. Often this takes place without conscious effort, certainly if fairly unimportant or routine problems are involved. For important, complex and unknown issues of choice, cooperation with others – also from other disciplines – is frequently desirable. For exceptionally complex problems, long-term project groups are sometimes set up for resolving specific problems. Examples are the development of a new product, the purchase of a high-value machine and factory design.

At various points, this book discusses more detailed examples of simple issues of choice. The resolution of issues of choice lies at the heart of an engineer's work.

1.9 Knowledge: overview and detail

The specialisation of production engineering comprises a multiplicity of disciplines and techniques and can be approached from several perspectives. In this book some subjects are treated in greater detail, while others are discussed on a broader basis. An effort is made to provide an understanding and overview of the most frequently occurring, but also very divergent, methods and techniques that are applied in the manufacture of discrete products. (For the definition of this term see the "Reader's Guide"). Broadly speaking, the integration level of the subject matter under consideration increases and the details of the information used for description purposes decreases as the reader progresses further in the book. The book aims to provide a good overview of the field, as well as explaining fundamental principles.

The first chapters deal with materials (Chapter 2) and machining methods (Chapters 3 to 7) for the manufacture of components. The emphasis here lies on mechanical properties and material behaviour. In addition to the treatment of different basic forms of the processing and machining of materials, as well as the related important manufacturing aspects, subjects such as installation and the related joining processes are discussed (Chapters 8 and 10). The modification of material properties, for example for better machinability, and of surface characteristics, for a better functional behaviour of components, is treated in Chapter 9.

In the treatment of the most frequently occurring techniques for material machining, for example, the different types of tools and machining conditions play an important role. The treatment of the machining processes is of importance for the description of the different types of production machines in Chapter 12. This is a subject which is examined in less detail, because the design of these complex machines is beyond the scope of this book. The knowledge of machining and assembly processes, together with that of the production machinery involved, forms the basis for all other processes involved in the manufacture of discrete products.

To be able to make products of good quality at acceptable costs, the production process must be well prepared (Chapter 13), organised and monitored. In the execution of production processes, the control of the product quality and the production costs (Chapters 11 and 15) ultimately plays the most important role. Within a manufacturing enterprise, the integration of the total manufacturing process is ultimately the task of the technical management and the logistical organisation (Chapter 14). **Logistics** is about ensuring the availability of people, materials and means in the correct place, in the correct quantities and at the right time.

The highest responsibility for this rests with the business management. The relevant chapter describes, depending on the objective of a business, possible differences in corporate structure and the organisation of production processes and the related methods for the management and control of product flows in factories. Finally, and in a wide context, Chapters 16 and 17 discuss product and production development as a component of the total production process.

The higher the integration level of the subject matter under consideration, the greater the complexity of the relationship between the components. The greater the **integration** of functions and components during the stages of product and process design, the more difficult it becomes to maintain an overview and to choose the right solutions. A good overview of complex problems is only possible if sufficient relationship to detail is maintained.

Summary

This chapter has provided a brief outline of the role manufacturing engineering has played in the development of industrial enterprises.

As production processes become more complex, increasingly more communication and cooperation is required between various business functions and even between companies that supply each other. It is therefore necessary that designers also have an adequate understanding of these processes.

Characteristic production figures such as total production volume, product life cycle, development time, product lifetime and the number of components have a large influence on the nature and work procedures of a manufacturing company.

Design processes always involve making choices. Important choices are the choice of material and the physical design. The choices influence both the properties of the product and the manufacturing method.

The field of manufacturing techniques can be systematically categorised in terms of the main areas of shaping of shapeless materials (primary shaping), forming, dividing and material removal, joining, modification of material properties and coating.

Mechanical material behaviour in manufacturing is significantly determined by material stresses and temperature. Friction plays an important role in this regard.

During production in an industrial environment, the organisation and the work procedures are of great importance in carefully coordinating all required activities. Important factors are process planning and quality management.

The effectiveness of production processes can be assessed on the basis of criteria such as costs, production rate, flexibility, quality and environmental effects. Design and manufacturing involve many different issues of choice.

Literature

1.1 Jones, D.T., Womack, J.P., The Machine that Changed the World, Harper, New York, 2007. ISBN 978-0-7432-9979-4.

1.2 Kalpakjian S., Schmid S.R., Manufacturing Engineering and Technology, 6th edition, Prentice Hall, 2010, ISBN 978-0-13-608168-5. General Introduction. Part IX: Manufacturing in a Competitive Environment

Exercise questions

1.1 Why was the steam engine the starting point of the transition from the craft-based to the industrial enterprise? State a few areas of knowledge that were necessary to be able to build a usable steam engine.

1.2 State a number of characteristics in which craft-based and industrial enterprises can be distinguished from each other.

1.3 Which knowledge and technical means were necessary to cross the English channel with an aircraft driven by manpower? Remark: This flight took place in 1979.

1.4 Which conclusion do you draw from Figure 1.6?

1.5 Why is the product life cycle of an aircraft so long?

1.6 Define the terms shaping of shapeless materials (primary shaping), forming, dividing and material removal.

1.7 State and define four important joining techniques.

1.8 State a number of reasons for the use of coating.

1.9 Describe the difference between the classical and the new approach to the limitation of environmental impact.

1.10 Sum up the factors that must be taken into account when considering packaging milk in cardboard or glass.

1.11 A company produces office supplies, including staplers.
The staplers, manufactured from steel plate, have been soundly constructed and have been in production for many years. The steel stapler according to the latest design (smaller mass, easy filling, modern appearance) has now been in production for five years. Due to the smaller mass, the material costs have dropped to € 1.30 per stapler. Annually

380,000 pieces are sold. It is expected that this model will remain in production for two more years.

Based on the production capacity of the enterprise, the staplers can be produced in six months. To avoid having too many staplers in stock at the same time, the required staplers are produced in two batches per year. One batch is produced in the second quarter and the other in the fourth quarter. To keep hourly rates of the production machines sufficiently low (€ 110 for the whole line), other office supplies are produced in the other quarters on the same production line.

In the launch year, only 10,000 steel staplers were brought on the market. To this end, production machines that were still available were deployed; these were usually manually-operated machines. Production is now largely automated. Every 16 seconds a stapler comes off the production line. Three employees work on the production line (hourly rate of € 20) carrying out a number of assembly tasks and operating the line.

The design of the new steel stapler was completed in three months, while the design of the production facilities took two months. The design costs amount to respectively € 12,500 and € 9,000. The manufacture of the punching and bending tools (dies) cost € 15,000. Before steel staplers can be produced again, the correct dies must be placed on the machines and the machines must be set. These activities are carried out in half an hour by the foreman (hourly rate of € 42).

Determine the following quantities for the production process described: manufacturing series, total product volume, one-off costs, machine set-up costs, recurring costs, scale effect and product life cycle.

1.12 What is meant by flexibility? Why is the importance of flexibility steadily growing?

1.13 Define the term quality. State a few important aspects of product quality.

1.14 For the components of a steel and a plastic stapler, shown in Figures 1.12b and d, state the starting material and the manufacturing method.

1.15 1000 components of a particular type must be supplied. To this end, a manufacturing method consisting of six steps is required. Two different manufacturing methods can be applied, in which the fraction losses are as follows:

Step	Fraction loss Method A	Fraction loss Method B
1	0.003	0.013
2	0.005	0.011
3	0.007	0.009
4	0.009	0.007
5	0.011	0.005
6	0.013	0.003

The starting material (initial workpiece) costs € 1,00 per piece. Each intermediate step costs € 0,22. The residual value of a rejected product is € 0,18 and is independent of the manufacturing step that was reached.

Which manufacturing method gives the lowest costs? (When answering the question, the product quantities may be rounded off to whole numbers.)

1.16 What are the reasons why structures built up from several components are to be joined to each other? What are the consequences for the choice of the joining methods?

1.17 Assume you have developed an innovative product and now want to start a small factory to make that product. What questions should you ask yourself?