

## Chapter 2

# Production System

**Abstract** This chapter aims at answering the question of what a production system actually is, what the characteristics of a system are, and why a systems perspective is useful when dealing with development and operation of production systems. Furthermore, different ways of classifying production systems are presented based on characteristics given by the systems perspective. The terminology related to production systems is presented, and different hierarchical levels and parts of the production system are described. As a conclusion the relevance of a life-cycle perspective on production systems is elaborated upon.

### 2.1 A Systems Perspective

During the 1990s it was generally observed that a holistic perspective on production systems was required (e.g. Rampersad 1994; Wu 1994; Bellgran 1998). Today, the need for a holistic perspective, or to regard the production system in totality, is generally accepted. A holistic perspective on production systems implies that systems should be designed with the technical and physical parts, the humans in the system, and the way to organise the work, taken into consideration (Bennett 1986).

One way to facilitate the use of a holistic perspective is to apply a systems perspective, based on system theory, to production systems. The importance of totality is emphasised when a system theoretical perspective is applied to the production system. With support from a system theoretical perspective all parts are taken into consideration and the interplay between the different parts of the production system is emphasised. A system theoretical perspective is also called a systems perspective (Lind 2001). A similar term is systems thinking, referring to how we regard the world around us, if we use the system concept to understand the complexity of reality (Checkland 1998).

The notion system has become more and more common to describe activities and phenomena in different situations (Lind 2001). Therefore, the notion system

often appears in combination with other words, as in our case production system, manufacturing system, and assembly system. Systems exist everywhere and despite differences all systems share some common fundamental structures. As a consequence the system theoretical perspective has developed as a way of explaining systems in a scientific way (Wu 1994):

“... manufacturing industries are now leaving one technological age which is characterised by machines, and are in transition to the age of systems.” (Wu 1994, p. 27)

One explanation of the statement above is that a systems perspective is useful for increasing the understanding of a complex production system. To successfully develop and operate production systems good understanding of the components of a production system and how these components interact is essential.

### ***2.1.1 Characteristics of a System***

Systems theory is based on the relations and interplay between different components in a system. The fundamentals of general system theory can be found in biology where von Bertalanffy had already described the meaning of a system in 1920 (von Bertalanffy 1972). However, the system concept is, according to von Bertalanffy (1972), as old as western philosophy; Aristotle said that the totality is more than the sum of the parts. A fundamental starting point of systems theory is the idea of synergy; meaning that totality is different from and hopefully larger than the separate parts, which can be exemplified as (Checkland 1998):

“The taste of water, for example, is the quality of the substance water, not of hydrogen and oxygen which is combined to achieve water.” (Checkland 1998, p. 3)

A system is an organised collection of personnel, machines, and methods required to accomplish a set of specific actions (CIRP 1990). Churchman (1968) includes the accomplishment of a set of goals in his definition, as does Wu (1994). A system can thereby be defined as a collection of different components, such as for example people and machines, which are interrelated in an organised way and work together towards a purposeful goal.

The system boundaries can be drawn at different levels, and everything outside the system boundaries can be considered the external environment (Wu 1994). A characteristic of a systems environment is that the environment influences the goals for a system but the system cannot influence the environment (Churchman 1968). On the basis of how the environment affects the system, the environment can be divided into different parts. The active (close) environment directly affects the system, whereas the passive (remote) environment has little or no effect on the system (Hubka and Eder 1988). Within system theory emphasis is placed on what are inside the systems boundaries.

Commonly a system is divided into subsystems, which provides a general view of a complex system. With a systems perspective the relations between the different subsystems are emphasised, and also between different hierarchical levels (Lind 2001).

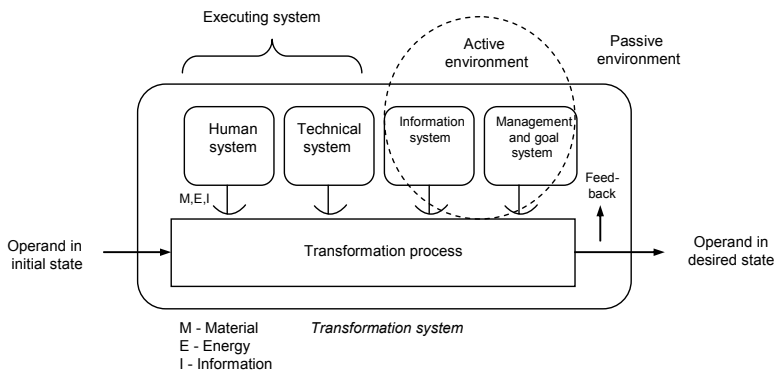
### 2.1.2 Production: A Transformation System

The function of a production system can be described as a transformation of input to output, see Fig. 2.1.

This description is according to the *black-box* principle (Wu 1994). The transformation constitutes a black box which we cannot see the contents of. The transformation can for example consist of machining or assembly. The major elements of a transformation system are a process, an operand and the operators (Hubka and Eder 1988), see Fig. 2.2. The arrangements and relationships of the elements form the structure of the system.

A transformation system usually has a defined goal; to perform a transformation on an applied operand, from an existing state to a desired state. Driving and guiding the process is the task for the operators, consisting of the human system, the technical system and the active environment. The function describes the purpose of a system, what it does or is intended to do. With the terminology from systems theory we can refer to the technical system and the human system as the executing system, and the information system and the management and goal system as the active environment. The relation between these subsystems together contributes to the transformation of input to output. One example of a transformation system is a production system.

**Fig. 2.1** Transformation of input to output



**Fig. 2.2** A simplified model of the transformation system (Hubka and Eder 1988)

The transformation can be regarded as a change process. To meet the requirements of the change, the operand gets added values. These values can be different qualities which makes the operand fulfil the requirements after the transformation. For example, there is a demand for pressed sheet instead of raw steel. In this case the steel (the operand) should be given these qualities, the added values, through the transformation process. The transformation affects the operand through changing its structure, location (for example through transportation) or time dimension (for example through stock-keeping). The structure of the system is described by the different elements, which are parts of the system, and the relations between these elements.

The function describes the purpose of a system, what it does or is intended to do (Hubka and Eder 1988). When the transformation system is a production system the function is for example to transform raw material into components or complete products. Transformation of raw material into components or products can be achieved in five fundamentally different ways (Mattsson and Jonsson 2003), see Table 2.1.

The transformations described above can also be combined. A production system often uses several different value-adding processes to transform raw material into the demanded form and if necessary complete products. The result (output) from a production system can therefore be input to another production system. As one example, in the USA about 20% of the steel production and about 60% of the rubber production went straight into the automotive industry during the 1990s (Wu 1994).

**Table 2.1** Five fundamentally different transformations

| Transformation     | Description   |
|--------------------|---|
| Separating         | Essentially one item that is the source of several items from the production system, e.g. production of petrol and paraffin oil from crude oil. |
| Putting together   | Several items as input and one item as output, e.g. production of machines.   |
| Detaching          | Change of form of an item through removal of material, e.g. production from shaft turning.  |
| Forming            | Change of form of an item through reshape, e.g. rolling of ingot into steel profiles.   |
| Quality adaptation | Change of qualities of an item without changing its form, e.g. surface treatment.   |

### 2.1.3 Classification of Systems

Depending on the purpose of a description of a system, different classifications can be used. Here we present some classifications relevant for a production system. Systems can be described from functional, structural, and hierarchical perspectives (Seliger et al. 1987), see Fig. 2.3.

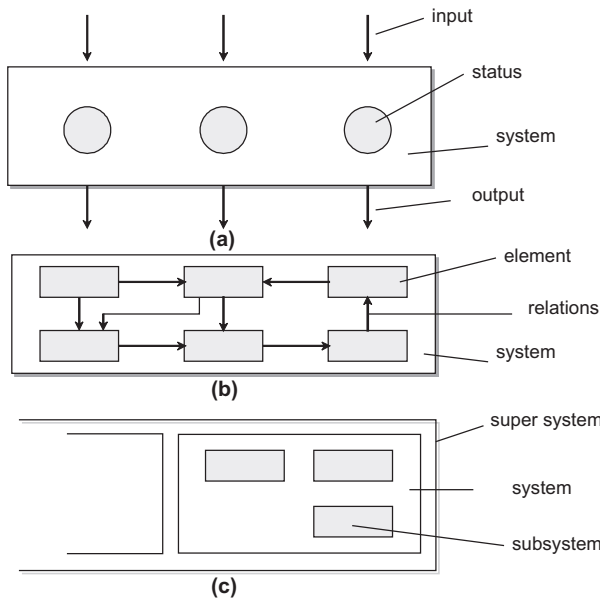
The functional perspective (Fig. 2.3a) describes the system as a black box transforming input to output. The structural perspective (Fig. 2.3b) is a way of describing the system in terms of its different elements and the relations between these elements. The system can also be regarded from a hierarchical perspective (Fig. 2.3c) which implies that one system can be a sub system within a larger system. With the hierarchical perspective the relation or position of a system is described in relation to other systems, as for example sub systems or super systems.

Other examples of classifications relevant to the production system are (Wu 1994):

- physical and conceptual systems;
- continuous and discrete systems; and
- stochastic and deterministic systems.

Systems can be divided into real systems or models of systems (Arbnor and Bjerke 1994), which can also be referred to as physical and conceptual systems (Wu 1994). Physical systems consist of real objects such as machines and equipment whereas conceptual systems can consist of diagrams, charts, verbal descriptions, etc. The production system can be both physical and conceptual, depending on which phase of the system's life-cycle is considered. A conceptual system can be found during the production system design phase and a physical system after the implementation phase.

Continuous and discrete systems belong to a category of dynamic systems, which are defined based on how the system variables change over time. System



**Fig. 2.3** System from a functional perspective (a), a structural perspective (b), and a hierarchical perspective (c) (Seliger et al. 1987)

variables in a continuous system change continuously over time, whereas system variables in discrete systems change step-by-step. How variables change over time is for example of interest when simulating production systems. In a discrete system separate activities can be discerned, which for example is in congruence with the flow of material in production systems (Wu 1994).

Going through further classifications, relevant for production systems, systems can either be deterministic or stochastic (Wu 1994). Deterministic systems have a cause-and-effect relationship between input and output, for a given input the system always responds with the same output. Stochastic systems are characterised by random properties; the input, process and output can only be statistically analysed (Wu 1994). However, the possibility to discuss deterministic and stochastic systems depends on whether the system can be classified as open or closed.

### 2.1.4 Open System

An open system depends, unlike a closed system, on its environment. In an open system, the relation to the system's environment is studied, which is not the case in a closed system. A production system is an open system that depends on and is affected by its environment. Open systems maintain a dynamic relation with the environment, which is essential for production systems. Production systems have to be adaptable to changes in the environment and the competitive market.

An open system is among other things characterised by the following attributes (O'Sullivan 1994):

- an open system is *goal seeking* and *hierarchical* where different subsystems have various degrees of importance in the goal fulfilment;
- an open system is an inseparable entity, it is *holistic*; and
- open systems are characterised by *equifinality*; goals can be reached in a number of different ways.

Equifinality needs explanation. It was mentioned above that in closed, deterministic systems it was possible to predict the output based on the given input. Cause-and-effect relationships prevail in closed systems, which is not the case in

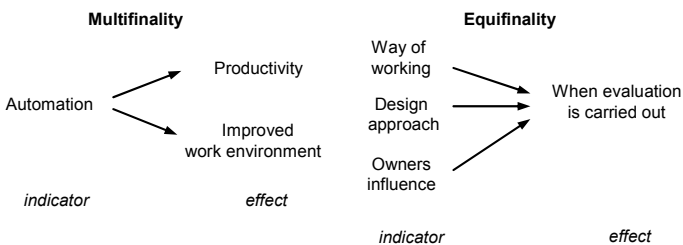


Fig. 2.4 Different types of finality relations: multifinality and equifinality

open systems. In open systems there are several factors that might affect the output. To describe this, the term finality can be used (Arbnor and Bjerke 1997). Another term for finality is indicator-effect relations, see the example in Fig. 2.4. One indicator can give several effects (multifinality), and several indicators can reach one and the same effect (equifinality).

The development of the theory of open systems has, among other things, contributed to the development of the socio-technical school. However, the input-output nature of the traditional system theory cannot fully describe the socio-technical parts (Hubka and Eder 1988; Karlsson 1979). The system theory treating human beings in an organisation as components does not suit the socio-technical system, according to Karlsson (1979). Two different tracks have developed within systems theory; a classical system theory and a so-called soft system theory. The latter is closer to the socio-technical school, and thereby provides better possibilities to describe socio-technical systems (Checkland 1998).

## **2.2 What Is a Production System?**

The previous chapter was devoted to definitions and descriptions of systems in general. Since the focus in this book is on production systems it is appropriate to also explain the meaning of production. Moreover, a more thorough analysis and description of production systems is needed, which is provided here through descriptions of the components of the production system, its relations and hierarchical nature.

The process of creating goods and/or services through a combination of material, work, and capital is called production. Production can be anything from production of consumer goods, service production in a consultancy company, music or energy production.

There is a clear connection between production of goods and services. Consumption constitutes the superior driving force for all production. Produced goods must in some way be distributed for consumption. Production of goods is therefore often of no interest, if not combined with production of services, as for example within the area of logistics (Mattsson and Jonsson 2003). However, the specific type of production referred to in this book is industrial production. Our limitation is production of goods, where the transformation of raw material into products is carried out in a production system.

### **2.2.1 Terminology**

Production system is often used as synonymous with manufacturing system and assembly system. Other notions used to describe different types and sizes of production systems are line, factory, plant and workshop. The differences in notions

indicates that there actually *are* differences in what parts or to what extent a production system is referred to, but also that there are differences in how the different notions should be defined. The first issue to analyse is whether any of the systems is superior to the other, to look at the systems from a hierarchical perspective.

To elucidate how the different notions are used throughout this book a brief survey is required. In the further studies we start with the notions manufacturing and production.

#### **FURTHER STUDIES: MANUFACTURING VERSUS PRODUCTION**

The English notion *manufacturing* stems from the Latin *manu factum*, made by hand, and is explained as the making of articles or material by physical labour or mechanical power. The notion *production* stems from the Latin *pro ducere*, lead forward, and produce is explained as to bring into existence. CIRP<sup>1</sup>, which is an international research association within production engineering, gives the following definitions of *manufacturing* and *production*:

Manufacturing is:

“... a series of interrelated activities and operations involving the design, materials selection, planning, production, quality assurance, management and marketing of the products of the manufacturing industries”.

*Manufacturing production*, which most often is shortened to *production*:

“... the act or process (or the connected series of acts or processes) of actually physically making a product from its material constituents, as distinct from designing the product, planning and controlling its production, assuring its quality”.

As we can see *manufacturing* can be regarded as superior *production* (based on the definition of *manufacturing production*). In other words, according to the above given definitions *manufacturing* could be regarded as all activities within a company from design, material supply, planning and production, to quality assurance, distribution, management and marketing. In this case, *production* embraces the actual production process, the physical making of a product.

Sources: Hounshell (1984); CIRP (1990)

We consider the notion *manufacturing* as superior *production*. By way of introduction it was mentioned that production is the process of creating goods and/or services and we gave music and energy production as examples. This is also reflected in the definition provided by CIRP:

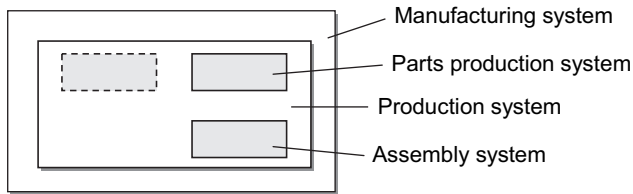
“... the result or output of industrial work in different fields of activity, e.g. agriculture production, oil production, energy production, manufacturing production.” (CIRP 1990, p. 736)

In that sense production, as a line of business or branch of industry, is superior manufacturing.

The observant reader might have noticed that the definition of manufacturing system, concerning the content, is similar to the definition of product realisation introduced in Chap. 1. A distinction that can be made is that product realisation refers to the *process* describing the design and realisation of a product, whereas manufacturing system refers to the actual system where the product is designed and

<sup>1</sup> CIRP = International Institution for Production Engineering Research, see <http://www.cirp.net/>





**Fig. 2.5** A hierarchical perspective on production system

realised. Thus, the difference is between process and system. The product realisation refers to the process, whereas manufacturing system refers to the system.

By way of introduction it was also mentioned that the chosen terminology also depends on what part of the production system is concerned. The next issue to elaborate is accordingly the different subsystems possible within a production system. A production system can for example embrace both the parts production and assembly, which means that the production system is superior to these subsystems. A hierarchical perspective of a production system is illustrated in Fig. 2.5.

The notion line is often used to denominate an assembly system. A workshop can refer to a subsystem of the manufacturing system, as for example the parts production system, or to a whole plant. Plant is often used synonymously with manufacturing system.

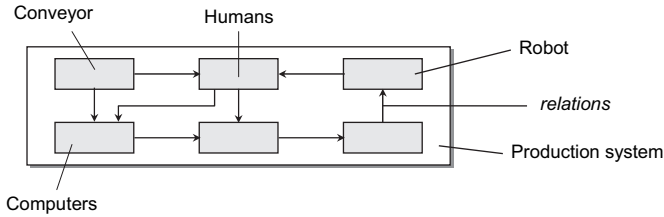
Production engineering and production development are two additional concepts which need clarification. Production engineering is here concerned with different manufacturing processes and rationalisation of existing production (Andersson et al. 1992). Production development concerns development and operation of production systems with a more long-term perspective.

The discussion concerning definitions might appear to be unnecessarily complicated, but aims at illustrating the need for a common terminology. No matter what definition you decide to use, most important is that the chosen definition is jointly defined among those working together within or around the production system.

### ***2.2.2 The Structure of the Production System***

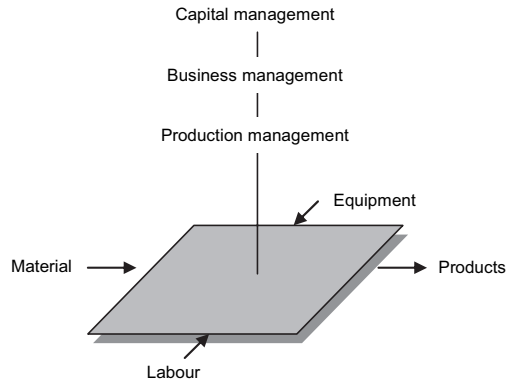
A production system comprises a number of elements between which there are reciprocal relations. Commonly mentioned elements are premises, humans, machines, and equipment (Löfgren 1983). Software and procedures might be added to the listed system elements according to Chapanis (1996). A structural perspective of the production system can be used to describe the different system elements and their relations, see Fig. 2.6.

Yet another dimension can be added to the description of a production system, the decision-making process. The decision-making process for a production system adds capital management (owners), business management and production management to the description of a production system (Sandkull and Johansson 2000), see Fig. 2.7.



**Fig. 2.6** Example of elements in a production system (a structural perspective)

**Fig. 2.7** Model of a production system including the decision-making process (Sandkull and Johansson 2000)



At the same time as each system component is an important resource, they are also potential sources of variation and disturbances which might be difficult to predict.

### 2.2.3 Life-Cycle Perspective

The main activities within a production system are often described based on the products life-cycle (Technical Foresight 2003):

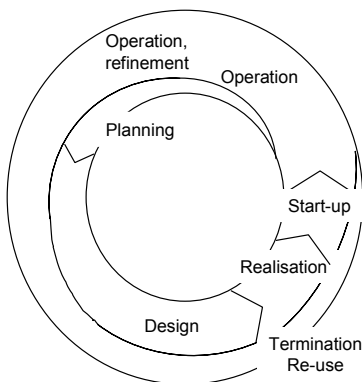
- the market activity places demands on the product delivered from the production system. It provides boundaries for how the system should perform when it comes to quality and productivity, and also provides prerequisites in terms of time for development, product qualities and cost;
- the engineering activity controls the product development, which is a prerequisite for the production system;
- the production activity creates the product in the production system;

- the distribution activity makes sure that the product is delivered under the right conditions to the customer;
- the service activity aims at removing and preventing defects which might appear in the product; and
- the recycling activity aims at saving resources and handles worn-out material.

The production system can also be regarded from its own life-cycle, from initial planning of the system design to phase-out. Increased environmental requirements, both from consumers and from legislation, place higher demands on re-use, not only of the produced products, but also of the production system. Therefore, it is relevant to plan for several product generations as well as system generations when designing production systems. The altered environmental requirements have contributed to a shift from a sequential to a parallel nature of the production system life-cycle, see Fig. 2.8.

New production systems are designed and realised in parallel with old systems still in operation, which provides good opportunities to make use of previous experiences. The nature of the production system varies during the different life-cycle phases, as do the requirements placed on the abilities of the system. Therefore, it is essential to be aware of the production systems current position in the life-cycle to know what requirements are reasonable.

Questions concerning manufacturing efficiency are also of interest when the life-cycle of a production system is considered. Manufacturing efficiency is commonly measured during the operation phase. If manufacturing efficiency is measured already from the start of the planning and design phase there would be obvious incentives to improve efficiency also during the initial development phases. All of a sudden it would be very attractive to improve the design process and to plan for efficient realisation and start-up. With this approach, manufacturing efficiency measured during the whole life-cycle of a production system, all phases could contribute to the achievement of total efficiency.



**Fig. 2.8** The life-cycle of a production system (Wiktorsson 2000)



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