1 Introduction

Manufacturing sciences are part of the technical sciences that's history as a standing discipline is still young. But in search for competitive excellence manufacturing research has received much attention during recent years, has made big steps forward and has offered huge solution potential to practitioners. Especially since the 1990s, manufacturing science and -management have become more formalised, manufacturing matters and its research have become more conceptual and the product of principles and a number of excellent practices together were seen as new approaches; Lean Production and the Fractal Company are cases in point. Moreover, in the early 1990s, a plea for empirical research based on quantitative analysis emerged, inspired by a social science perspective to arrive at theory; a re-iteration of this position came regularly about and proved popular for advancing operations management science, followed by the case study research methodology, which has been picked up strongly in the beginning of the 2000s. A case in point is the broadening of all technical transformations up to the total organisational design of manufacturing companies by establishing the Tayloristic thinking that could be later embedded into General Systems Theory. New ways of modelling, e.g. by interpreting technical transformations as inputs and outputs, allowed deeper insight into the logic of manufacturing organisations and its implications to the integration of more aspects, and decompositions for analysis and appropriate control mechanisms. The resulting thoughts actually are indispensable constituents of most current manufacturing systems' outlines. Optimising manufacturing systems definitely has to regard the total value transformation, and this view will guide this outline completely. Following this line, a formal core for manufacturing set ups is given, as a solid ground for the following outlines of factory operations, factory planning, resources' organisation and cyber manufacturing, which highlight holistic views.

Varying perceptions of manufacturing systems are regularly inducing paradigmatic debates e.g. pointing at social, resources, or technological dimensions that should be included stronger and hence demanding to widen up the scope and to embrace larger contexts or outside knowledge. A prominent example is e.g. the best practice concept of Lean Production being extended along the Theory of Constraints, Agile Manufacturing, recalling old principles of nature or again the Fractal Company, relying on principles of geometry. These developments led to taking best practices as a source for network oriented manufacturing approaches. In manufacturing, respective outcomes have resulted in quite often unnoticed, but brilliant implementations. In spite of their rather sketchy documentations, they experience largely high levels of credibility and acceptance by both, researchers and managers. The appearance of novel ICT low cost devices able to identify, to position, and to track any manufacturing item anywhere and anytime, on one hand, also smart enough to communicate, to act, to negotiate and even to decide on the other, is actually about to accelerate the shift towards manufacturing networks methods and tools. As manufacturing increasingly involves smart resources inducing decentralisation and atomisation of processes, units and procedures and their virtualisations are progressing and fully imposing network principles on all levels. As a consequence, it has become more commonly accepted that outside disciplines, such as complexity theory, are seen to be helpful to directly face the recent network challenges for manufacturing and its management.

With this volume, I take the challenge to cover selected chapters of established manufacturing planning as well as of these new manufacturing approaches, and to capture possible future developments. A main concern of these notes is the proposition of holistic approaches coined by state or transition descriptions, embedded into a general systemic modelling world, including all its formal parts. Moreover, I lay ground to strongly encourage interdisciplinary work already on the master's studies level. In order to properly succeed, higher abstractions and, in some cases, generalisations have to be introduced. In the search for a common denominator embracing all the fields addressed and synthesising the various-based approaches in this volume, the pivoting points are certainly the interfaces between the covered fields that have to be viable and offer seamless transitions between objects areas. For keeping all viewpoints compatible, established standards and traditional methodologies offer excellent grounds for designing harmonized fold/unfold or aggregation/dissolution options. Looking from a very abstract viewpoint, all taken up fields are just different descriptions of one and the same object: The Manufacturing System.

An extended approach captures all items from the system's as well as from the network view. For linking these, generalisations and abstractions on one side and hierarchisation on the other are the guiding principles in industrial practice and thus for structuring of the lecture matters. Narrowing down to the areas of interest, I can posit that all addressed application fields have already been entrenched by respective granular thinking. Independent from each other, but obviously in intensive exchange, even widespread standards have been established for defining adequate aggregation- and dissolution levels that perfectly harmonise for putting all chapters on a unified base.

In Factory Operations, for corresponding material flow designs, levels of detail along (VDI 3300) are standardised as Material Flow orders, along the facilities planning objects' classification:

- 1st order Material flow is capturing the transports between sites and suppliers as well as customers
- 2nd order Material flow is capturing the transports between sites on the factory level
- 3rd order Material flow is aimed at transportation and handling on the area on a site as well as between different organisational units and buildings.
- 4th order Material flow is the movement and handling between departments' shop floors, assembly areas and groups of machines.
- 5th order Material flow then represents process steps within or on a workplace, including handling.

In Factory Planning and Material Flow Design, levelled standardisations of objects and flows are common, which apply predefined granularities as well; the respective levels here are (VDI 3300):

1. Enterprise network's or site level – including all the suppliers' sites
2. Master plan level, including arrangements of buildings, hangars, storage areas, structural units as production halls, storage areas, and administrative buildings
3. Layout planning level with arrangements of departments, machine units, production areas, buffer areas for raw materials, parts and finished products
4. Work places with single machines, comprehensive work places, handling and processing points, as all fold and unfold items, Layout planning may be done in layers of detail.

A 5th break-down level, capturing e.g. parts of machines or other details, has not been in the focus for facilities planning so far, becomes highly relevant now as a consequence of the novel smartness of objects.

Because manufacturing organisation has traditionally engaged a number of IT solutions, addressing different corresponding enterprise areas, important models are already available, ready to interact on a base of harmonised granularities. Therefore, for ICT applications too, the existence of wide spread standards supporting corresponding level logic is crucial, which ensures adequate descriptions of all units and networks on corresponding levels of detail. For industrial automation, too, operations of equipment, processes or systems are hierarchically displayed for global suitability of components progressively linked via wired and wireless ICT. A well-known level view incorporates logics of equipment and units' control, which means that processes are identified by a hierarchy of devices and interfaces. This industrial automation set up has been cast into the international standard ISA-95, frequently referred to as the automation pyramid. Hierarchical levels there focus on the stages where control decisions are taken. They root in the production process, and go all the way up to the enterprise management level via intermediate levels.; if the given decision range is not sufficient, next higher decision levels are activated. Supporting systems are complementary, in line with the manufacturing operation management model (DIN EN 62264). This ISA95 automation pyramid unwraps as follows:

Enterprise Network or Extended Enterprise level (ERP): In a manufacturing network, which usually involves complex supply chains, the main concern is related to the integration of all members of the supplier and distribution chains, which share a common goal of obtaining market shares through the product realisation.

Factory level (MES): Manufacturing Execution Systems consist of a set of integrated software and hardware components that provide functions for managing production activities from job order launch to finished products. According standard VDI 5600, this level corresponds to the enterprise control level, generally supported by Manufacturing Execution Systems.

Shop Floor level (SCADA): For optimizing configurations and considering alternative process plans for shop floor execution. Using current and accurate data, SCADA, Supervisory Control and Data Acquisition, initiates, guides, responds to, and reports on production activities as they occur. SCADA provides production activity information to other engineering and business activities in the enterprise and its supply chain via bidirectional communications.

Fieldbus level: Low level configurations have traditionally been accommodated in IEC 61131-type programs in response to commands from a higher-level controller.

Sensor and actuator level: Includes all process near components as elements of Fieldbus solutions and of SCADA setups.

The levels of detail chosen and the adequate granularity to be addressed depends on the item to be treated, e.g. a machine, an assembly line, or a factory; respectively a flow of products should be presented on the parts' level for the machine, on an order level for a line, or the lot size level for a factory. Each level embraces specific attributes; information exchange is easiest on corresponding levels of units. The top level is represented by the Extended Enterprise Network (ERP), for planning decisions taken for entire companies, fully engaging manufacturing organisation principles or supply network wide ERP implementations. It is followed by the Business Process level, respectively treating company sites and Manufacturing Execution (MES) in manufacturing departments. Core processes, as production or assembly in a factory are embraced by the Supervising and Control (SCADA) level. Processes on the shop floors are orchestrated by field bus set-ups, which run sub-processes, communicating to and interacting with work places, supported by sensors and actors. The setup of this outline displays the fields of Manufacturing Operations, Factory Planning, Manufacturing Enterprise Organisation and Cyber Production in full congruence with these standards for working out selected issues of manufacturing systems. The selection of matter does include portions from all levels, except for the most detailed one, which would lead into technical details; their profound discussion definitely falls out of the scope of this outline, but may seamlessly be added.

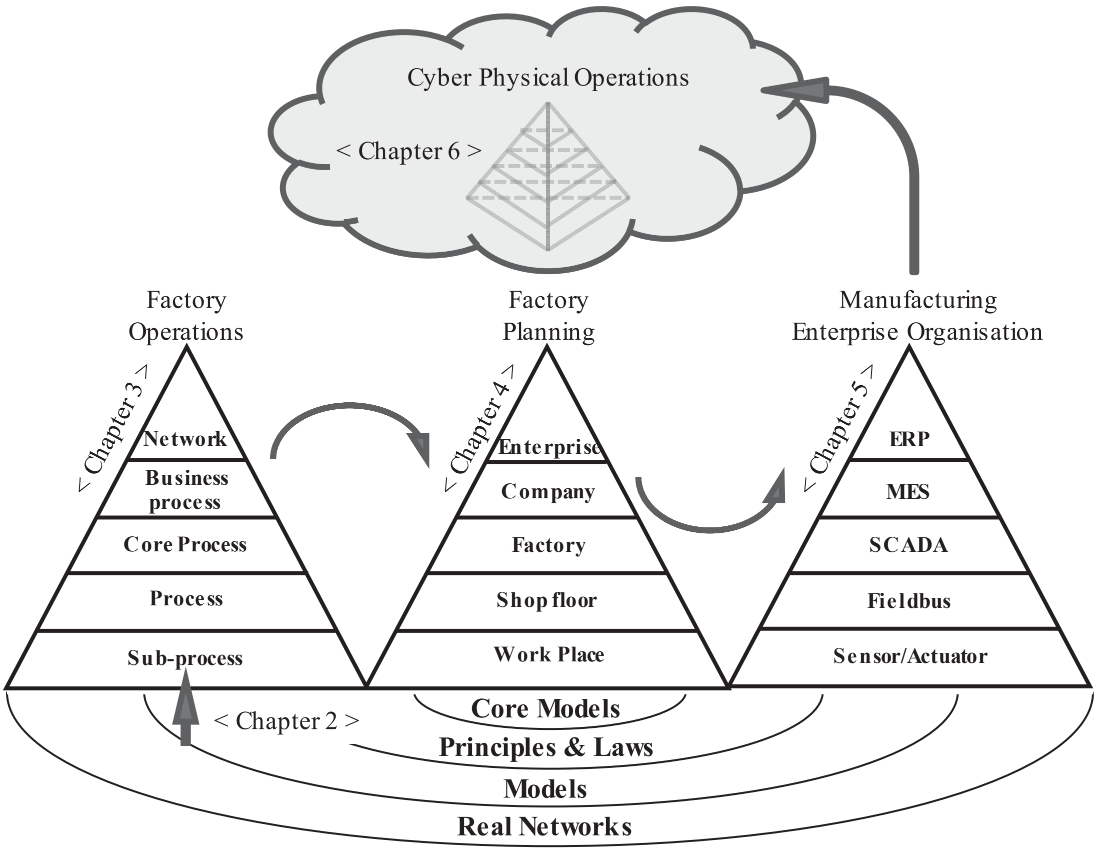


Figure 1-1. Framework and Chapters' organisation along Principles, Models and Granularities

In consequence, I organised this text in 6 chapters, including this Chapter 1 – Introduction. All chapters' first sections revisit relevant laws and principles, upon which selected matters are outlined and illustrated, laying ground for the subsequent detailing down to frequently used methods and model descriptions; key issues are underpinned by examples.

In Chapter 2, I compile a theoretical core. This core constitutes the formal tool box for the text; by putting the set-up into an onion-like pattern, it is expressed, that very abstract models can have very concrete expressions in real cases. The systematic build-up of knowledge may work also in the opposite direction. Real case knowledge may feed more general models that are vice versa applied for describing real manufacturing systems. Chapter 2 takes up all important core models traditionally being used and applied on the fields, as the base for all subsequent chapters. Some models have been extended into principles and general laws that coin production systems and manufacturing networks. I can easily demonstrate that traditionally used models and methods keep their important role within their frames of validity, i.e. systems, which may gradually be expanded into the manufacturing processes dominating network world or virtualisations, which may easily be captured by embedding all applied models into a more general topological space with its attached tangent- (cyber) spaces.

In Chapter 3, I take up the systems decomposition thinking by constituting six partial systems (the 6-Pack), emphasising the systems' aspects when representing manufacturing systems on all levels of detail. Self-similarity perfectly supports linking of units and subsystems on all levels of detail, keeping open separate studies and designs while maintaining all the systems aspects thoroughly. Moreover, every aspect exposes specific disciplines' peculiarities, so the setup is perfectly designed for all kinds of interdisciplinary studies and solutions. In this sense, every aspect additionally exhibits specific laws and principles in line with the general "onion" set up. They constitute solid bases for further detailing the Six Manufacturing System aspects in parallel on a holistic base. The focus is to firstly treat all the aspects; later aspects' interactions are addressed. The layer systematic has well proven to be useful for analyses as well as practical implementations of best practice manufacturing systems, like fractal factories or lean manufacturing implementations with hundreds of market leaders and world-class companies demonstrate. Chapter 3 consequently details relevant manufacturing systems aspects in order to embrace important factory operations methods and tools. Between and within the aspect layers, mutual influences are given as well as the hierarchical context. The cultural layer of the company determines the basics of strategy, which may mean that the technically feasible is not the economically desirable and may not even be socially accepted. Cultural and economic premises all limiting entrepreneurial actions. Social informal and economic financial aspects will have impact on information flow and material flow. The information flow surrounds the material flow and acts as input and control at the same time. This results a predominance of layers from top to bottom, which also means that there are impacts across several layers. The strategic level influences directly and strongly the Process and material flow layer. The chapter picks up the material flow layer and works consecutively through all layers up to the cultural layer. Easily, the layer stack allows to compose process- and value chains on all levels of detail, as the 6-Pack is encapsulated on all levels.

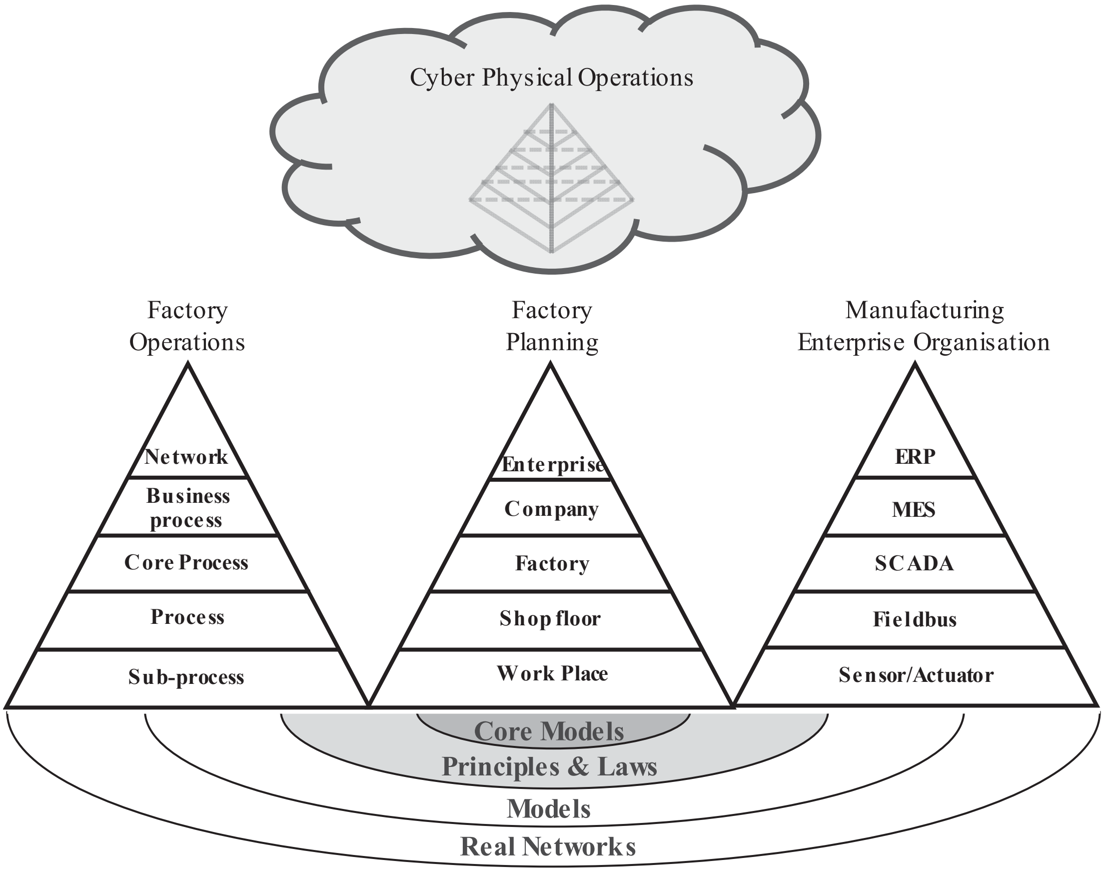
Manufacturing Systems Design, Factory Planning and decisions, including site allocations as well as factory master plans and layout developments, are covered in Chapter 4. Factory planning and design is characterised by taking into account large volumes of data and information defining the quality of all decisions. Factory planning and design is a wide and complex area, always involving high investment sums and a variety of tools and methods. This text, detailing factory planning and design from the modelling viewpoint, emphasises decision preparations depending on the model systems available for decision procedures. The model portfolio developed in previous chapters strongly recommends differentiating two configurations of process/object models. The respective decision modes can be outlined as common practices. In Chapter 4, I combine grown and traditionally proven knowledge and methods for factory planning including the respective methods and tools. Efforts, necessary for providing modified and updated data have considerably gone down with efficient use of ICT, i.e. CAD, virtual reality (VR), multiple realities (MR) as well as advanced simulation tools. I take into consideration that a number of planning procedures have evolved from the strict top-down modus (with occasional bottom-up corrections) towards arbitrarily bottom-up, top-down and cross-checking activities, continuous adaptations and frequent redesigns. So, from site decisions, over master plans down to shop floor details everything is covered, key methods are detailed and examples given. I draw special attention to the key norms and standards, traditionally used in German industry (DIN, VDI) on the field, some have recently been updated others have remained unchanged since years; these norms and standards fully embrace decades of professional experience and constitute a valuable body of knowledge in Manufacturing Systems planning and design.

To the traditionally strong and globally known achievements of manufacturing organisation, including their management and control methods, I devote an entire chapter, Chapter 5. It covers all fundamentals and basics of manufacturing companies' organisation up to the latest manufacturing philosophies, including the process control procedures for ERP and for company networks. Chapter 5 comprehensively discusses all matters around manufacturing process modelling and optimisation. I recall basic techniques to set up organisations, to assign favourable forms of grouping manufacturing tasks and I discuss advanced concepts. In order to capture all process organisation procedures, as applied in Production Planning and Control software in a very concentrated manner, I have established an overall mathematical description allowing evaluations, comparisons and verifications of the philosophies behind. For sharply capturing all logics and procedures, this mathematical model involves operators and pointers that formalise all established procedures, such as MRP, Statistical Inventory Control, or Kanban. The addressed levels of detail harmonise with the automation pyramid set up with a strong focus on ERP- and Manufacturing Execution Systems (MES).

Transposing Manufacturing Systems design issues into the next generation networked cyber production world points at Smart Manufacturing topics as driven forward in the contexts of Industrial Internet and Industry 4.0. For embracing both, systems and networks, I embedded all studying objects into a general concept of topology. The proposed framework easily allows me to directly address all currently upcoming fields, as Cloud Manufacturing, Cyber Physical Production Systems, and Virtual Machines on a uniform base in the final Chapter 6. Shortly I revisit important manufacturing fundamentals with the aim of listing all the latest ICT and network novelties with so far unseen potential for manufacturing. Full monitoring of all assets and processes as well as instant localisation options of all items, enabled by wireless LAN, RFID and smart objects are game changing for manufacturing; they bring up manufacturing units' smart properties enforcing extended manufacturing principles and laws, exhibiting flexible decision procedures and gradually evolving network optimisations. In the age of computers, the control issue in manufacturing systems remains extremely important, so I discuss it three times, once in Chap. 2 as general control loop, in Chap. 4 more formally, production control specific and again in Chap. 6 under the new principles. The smart equipment effects for manufacturing systems is fully taken into account by extension of the lecture body into the digital twin (virtual) world, which upgrades manufacturing units by extended properties. Cyber physical systems, now permeating the manufacturing world, have become the decisive game changers in Manufacturing Systems Design and – Operations, engaging all digitalised models that have been established, in a different manner (CAD, CAM, Simulation, Decision support systems). Manufacturing companies may no longer solely be envisioned as process executing systems, rather as being parts of complex evolving value networks. Therefore, I have expanded the guiding laws and rules in manufacturing onto, by what I call, Concurrency Principles (e.g. behaviour, iteration). Planning and control modes change and logical compatibilities of all units become utmost important. Information at the points-of-creation on all levels of detail has to be accessible and at all addressed points-of-action for decision making; all processes may be logically monitored, (real-time) information may be acquired by (e.g. for ERP) programmable logic controllers (PLCs), radio frequency identification (RFID) chips or transponders and adequately processed and presented for decision-making. Big Data and Cloud Computing provide for the necessary processing capacities to handle all resulting data streams. I included a case example that displays some of the ground-breaking shifts in views by highlighting an important future research slot: Interactive man-machine (hybrid) decision making.

This text is not intended to be self-explaining, it imperatively assumes skilled University Lectures, Seminars and Exercises in the first place for being fully understood. Home studies are viable alternatives; selected Bibliographies for this purpose, preferably focussed on classic titles and key references, round up all the Chapters.

2 Fundamentals of Factory Operations



Designing and optimising manufacturing has to regard the total value transformation, and this view will guide this outline completely. With this aim, a formal core of the factory and the factory organisation will be suggested, which prepares holistic views. It comprises states and transitions' descriptions, enabling to model the complete chains of value creation as well as deriving functionalities and activities' attributes by differentiation. These two modes of detailing are equally viable; they may be retrieved from the formal description of transformations and states as well as state transitions with time descriptions. Formal models will be illustrated by frequently used models as well as concrete examples of manufacturing companies, enterprises and shop floor cases. The main concern of these lecture notes is the introduction of holistic descriptions; the state transition descriptions are embedded into a general systemic modelling world, including all formal parts. On the background of a plethora of studies, model buildings of manufacturing organisation and shop floor designs, the verification base is strong enough for justifying this approach. The formal base is not just systems analysis, but also the formal systems and network theory. Also for other disciplines, as control theory and information theory, specialisations of formal systems theory have contributed descriptions and formalisms. Improved empirical base and better data, made possible by the increasing power of computers, give additional impact to the approach. Beyond the extensions of all frequently applied instruments, the extension of the formalisms results in enlarged description fields for manufacturing networks. Descriptions of all so far known approaches and issues may easily be embedded as specifications.

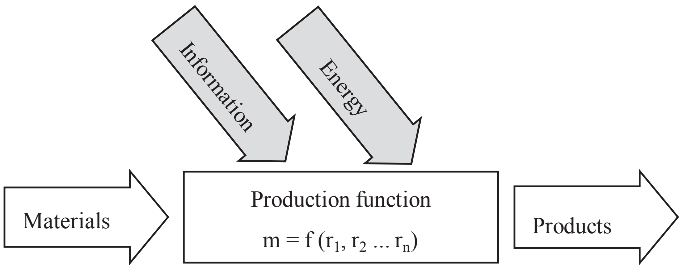


Figure 2-1. Production as transformation process, formally represented by the production function

2.1 Manufacturing as system

Manufacturing aims at providing for artefacts, services and objects to satisfy societal needs. More generally speaking, manufacturing is any value adding combination of production factors. For a first approximation and preliminary discussions, manufacturing is addressed as transformation producing objects on the base of energy, material and information. The process of transformation is called manufacturing or production, and the result is called product or output (Figure 2-1Figure 1-1). Sometimes the terminology production is replaced by fabrication, which is derived from the French word Fabrique, that had been used in the 17th century for a definition of the shop floor, where motions have been operated. Organisational units in this context, especially as buildings, are the factories. The term of the factory appears as key term also for manufacturing, production and all activities within a factory. Frequently, the term factory operation or factory organisation is used for describing an organisational unit and defining purposes to the factory. Factory operation, as used here, is the planned and organised synthesis of production factors. Especially production factors as human labour, means of manufacturing and materials are summarised in this sense with the aim of generating goods, objects and services. In this sense, factory operations are summarised into corporations, - economic units characterising value creation. Frequently, the term industry is also used in this context even synonymously with the term industry unit or industry plant. The term "manufacturing system" does not just address a single workstation or an individual production department (e.g. foundry, turnery), but also a complete enterprise or a group of enterprises. Accordingly, manufacturing is not only the process of making goods, but also the entirety of all relevant technological, economic, and organisational measures directly connected with the processing of materials, i.e. all functions and activities directly contributing. In Europe the term "Production" is often used as an umbrella term, which includes manufacturing. Accordingly, production technology consists of manufacturing engineering (pieces of goods), process engineering (raw materials to products) and power (energy) engineering (in German: Fertigungstechnik, Verfahrenstechnik, Energietechnik, respectively). Central view point of manufacturing engineering is the huge body of standards, released the German Institute of Standardisation e.g. determining manufacturing in DIN 8580, which defines manufacturing main processes (German: Fertigungsverfahren) as: primary forming, reshaping, separating, adding, coating and material properties changing, and which considers manufacturing as specifics for processing, and not for the whole enterprise. Elsewhere, manufacturing is defined as the transformation of materials and information into products for human satisfaction needs with several constituent parts:

- Processes, where the form, the shape and/or the physical properties of a given material are changed,
- Equipment used to perform processes that – in combination with humans – represent Manufacturing systems, and
- Interfaces and design, for example, CAD files.

An industry unit may be defined as an operating unit generating goods, artefacts and objects by the prevailing use of machines (press work) and by exploiting the principle of labour division (line). In this sense, an industry unit is almost identical with the definition of a factory operations' unit. In focus are the machines, the labour division driving value creation and the resulting dimensional transformations of objects. A manufacturing unit is therefore an economic unit executing transformation with the aim of value creation. In this context, transformations of objects and goods are subject to changes that make them have higher value. This value is determined by the choices of utilisation of the transformed objects as well as the esteemed utilisation possibilities by other players (exchange value). Transformations in manufacturing are generally executed as part of longer sequences of steps and changes (Figure 2-2).

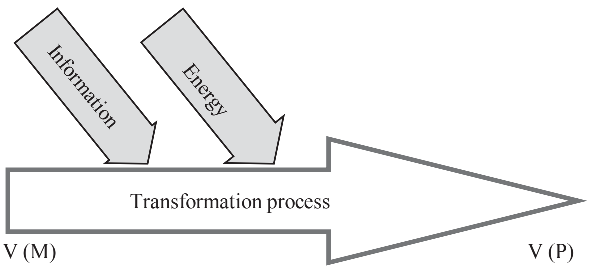


Figure 2-2. Manufacturing as transformation process

Introducing formalisms to these basics, the values V may be formalised, so value indicators may be assigned and compared. In economics, uniform value scales are current. Of course, manufacturing or production will naturally and rationally aim at V (P = product) to be larger than V (M = material). For start, a very simple definition of a system shall be given as a base, which may be easily applied to the manufacturing context: A system may be defined as the total of elements and the relations between these elements. More generally, a system may be defined as a structured whole, e.g. a figure being separated from its environment by limits and being configured by a set of elements linked via relations, according to DIN 19266.

Thus, a system is a very general and formal object, that's context for manufacturing and for the involved production units still must be defined. First specifications for general attributes of the system may be given as the openness towards the environment (open system), opposite to the closeness of a system (Figure 2-3).

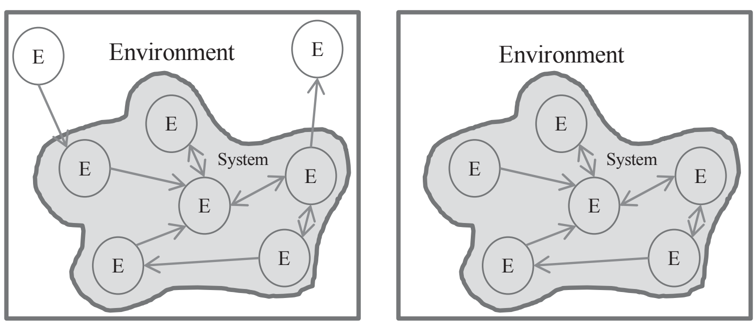


Figure 2-3. Open system (on the left), and Closed system (on the right)

Most real systems are envisioned as open systems. Relations between systems and environment may be very generally given as input and output, dependent on the direction of the relation. Linked to the model of a manufacturing unit, the input-output system expression is useful for analysing, when focusing on products and supply. Manufacturing transformations appear as black boxes. Elements and relations of manufacturing systems are not yet regarded in this kind of view. Manufacturing units, therefore, may simply be regarded as open systems, and already this simple interpretation allows quite a number of valuable conclusions (Figure 2-4).

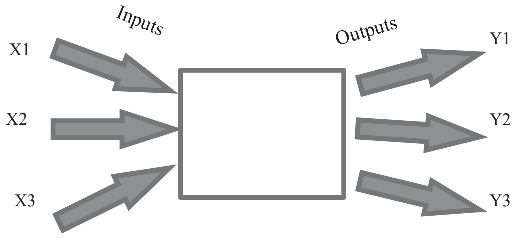
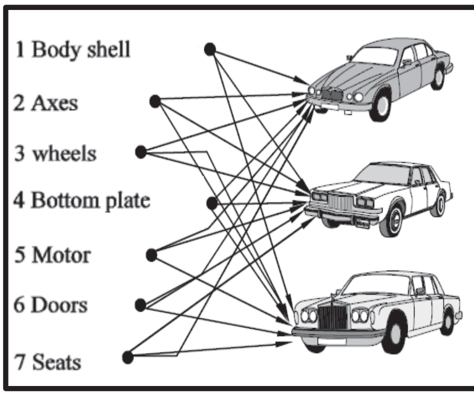


Figure 2-4. General I/O system

2.1.1 System in a manufacturing context

The generation and transformation of different states in the chorus of manufacturing processes is tightly linked to the use of technology. The qualitative statement of availability of technology means that the respective states are attainable by the manufacturing units in focus. It is the knowledge of the process planers to assign the available technology units in a factory or a company that are necessary to provide for the targeted states and transformations. The respective information and the related knowledge is translated into bills of operations (BOOs). Technology may be engaged in different stages, combined or assorted with various resources, with tools for set-up states and certain programming states for instance. Whenever entire process chains are addressed, tool thresholds, equipment supplies, NC programs and transportation or storage functions may be involved. Mostly, the focus is put on the technology itself, not upon the resulting transformation states.

For illustration, some frequently found transformations and states shall be taken up. These are transformations and states, which can actually be found within value creation as intermediate results, parts or final products. In specific operations, these (as intermediate results, parts or final products) are the states, which can also be found in the documents about the value creation, as e.g. bill of materials (BOM), bill of operations (BOO) or design sheets. That is not only focusing on inputs and outputs of the manufacturing systems, but also on linking specific states, so the context is created, where interlinked production functions can be represented analytically i.e. in the form of a production function or, if appropriate, in a number. This can be done as a forced coupled transformation process (as chemical reactions or coupled production) or by discrete manufacturing (assembling of parts). Dependent on this context, manufacturing functions may be of integer or rational value. The view may be extended to intermediate states by regarding functions and aggregates of product groups representing the whole manufacturing systems apparatus. Output objects may illustrate the context more clearly, using nodes and arcs. Product graphs of this kind are also called Gozinto graphs. Documents, such as the bill of material, that are in daily use, may therefore be levelled into different granularities. This representation can be extended to the full or to parts of the production program (Figure 2-5).



		gradual heck	hatchback	touring
1	Body shell	1	1	1
2	Axis	2	2	2
3	Wheel	4	4	4
4	Bottom plate	1	1	1
5	Motor	1	1	1
6	Door	4	2	4
7	Seat	4	2+2	4

Figure 2-5. Knock down example of finished product variants

2.1.2 Functions in the system view

Another very important description of the manufacturing unit describes the manufacturing transformation as fulfilment of tasks. Any transformation within a manufacturing unit is perceived and assigned as a manufacturing task. In the case of industry and manufacturing, enterprise tasks are comprehensive and extensive. They may only be achieved via task partition, e.g. dividing the total enterprise- and company tasks into subtasks and sub-subtasks, and subsequently by synthesising and accumulating repetitive sets of tasks. The task is divided into subtasks and single tasks, so the single tasks are defined in a feasible way, adapted to technical capacity and resource availability, so task execution is object of an individual task. Executions leading to transformation results are called functions. In the context of the manufacturing unit, such functions are called operations functions; mostly they are simply referred to as functions, to be fulfilled. As such, every task in manufacturing may be interpreted as a part of a task fulfilment situation, which is intended to provide the material resources used for the fulfilment of tasks as well as the interdependencies to other task fulfilment contexts. By definition of industry, it is assumed that in industry the principle of labour division into small tasks is the rule.

2.1.3 Process

Manufacturing makes products and services with the aim of satisfying demands. More generally speaking, manufacturing is therefore a value adding combination of production factors, as labour, material or energy. It may be envisioned as a sum of transformations resulting in products by means of these resources i.e. of energy, materials and information. Manufacturing objects consequently may also be seen as being subject to transformations of adding value. The value is determined by the demand and possibilities or options to draw advantages of the use of these objects. Transformations are usually done in larger sequences of technological steps.

2.1.4 Manufacturing as orchestration of organisational units

As the context is frequently discussed in terms of manufacturing units, an interpretation of manufacturing may also be given as the overall manufacturing unit, uniting a number of organisational units in an adequate manner. This definition emphasises that a manufacturing unit may be synthesised by the unification of the given units into a coherent organisation structure or body. Here, the term organisation is to be defined as: a system of formal and informal rules as preconditions for the fulfilment of tasks in a working system comprising the respective functions; under the term of labour organisation, all measures and methods concerning space and time are summarised as well. Any execution of work functions resp. working tasks is always done under consideration of all technological restrictions and the related work order is seen as consequence of:

- Division of working tasks
- Work labour division between persons
- Labour division between persons and machines

- Form of collaboration between persons
- Assignment of tasks to hierarchy levels of the total organisation
- Assumed working calendars and working hours in money and incentive system

It should be noted that the above-listed points are not necessarily fully complete. They are rather understood as a framework for respective rules in the context of labour organisation, involving such criteria. When detailing work organisation and also respective work systems according to the system concept, the “systems’ language” may be used as the common terminology. For factories, the context of manufacturing operations’ design is a well-established field. Smooth and efficient operations are decisive for prosperous business developments. Sophisticated and effective planning therefore focuses on sequences of operations, which take up resources, time, space and expertise in order to efficiently produce the intended output. Such sequences of operations, called the manufacturing processes, include all activities of analysing, controlling, implementing and improving e.g. by harmonising sequences of operations (batch or flow mode) with capacities within arrangements of machines and equipment, so useful results of elaborate process planning are generally based on detailed and precise work flow design.

2.2 Laws and Principles of Manufacturing

Manufacturing principles describe the sum of technological processes to be applied for a variety of parts/objects with focus on sequence and geometrical arrangements of the equipment involved. Small and medium series production most frequently apply the shop floor principle also referred to as function principle, that emphasises geometrical arrangements concentrating all resources with identical or similar tasks or technologies e.g. milling, drilling, coating. Resulting arrangements are due to technological properties. Characteristic for the line is the arrangement of work stations and equipment along the sequence of the prevailing manufacturing steps to be executed for product supply. The overall structure is product/object oriented; therefore, the term product/object principle is used as well. The basic idea dates back to 1913 when Henry Ford introduced this principle first using the term labour division. This means the partition of task volumes onto a number of workers evoking high specialisation of individuals for small tasks and increasing effectiveness in total. Nests cover complete sets of functions and technological processes necessary for the production of product/parts clusters by contracting all machines and equipment and assigning it to an organisational unit. Nest tasks will be enriched by control, planning and handling activities. Small control loops replace enforced labour division, resulting in higher flexibility more transparency and shorter lead times. Workers have to have higher qualifications and multiple skills; better motivation and more responsibility are expected. On single work places a number of different function and processes are possible without the objects transporting to other places.

The law of diminishing return is an economic model establishing relations between input and output, studying behaviour in cases where one factor is modified while maintaining all the others (partial factor variation). It had originally been articulated for agriculture to define harvest expectations: increasing on the respective service of soil the invested work intensity, the harvest will quickly go up to become saturated in later phases and eventually decrease. We can find the validity of this law also in industrial manufacturing as well as in other fields. There is some similarity to the law of diminishing returns also in industrial manufacturing, regarding the total characteristic, as it may also be extended to cases of full factor variations. The tipping or turning point from increasing to decreasing returns reappears as turning point also in manufacturing where it represents an important level for further decisions or break even situations.

As a formal description, the manufacturing unit has been formally introduced as:

$S = \{X, Y\}$ with inputs X and outputs Y.

Of course, transformations exist in manufacturing, where quite a number of relations between inputs X and outputs Y are involved. The context is described by the way of the involved transformation (physical, chemical and biological) on one side, and by the addressed laws and rules on the other. If exclusively physical transformation takes place in a manufacturing unit, mass (M) continuity is an important characteristic: $M(X) = M(Y)$.

Derived from this equation, materials, parts and project demands may be broken down, dependent on the expected output. Subsequently, the production function is given as a formal description of the I/O context (Figure 2-6).

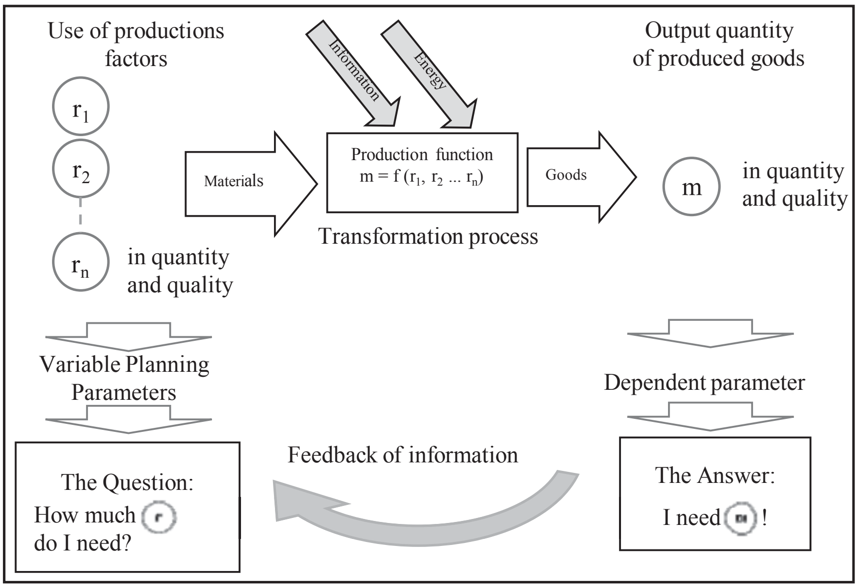


Figure 2-6. Systems notation in the manufacturing context with involved question and answer cycles

The starting point of process modelling considerations may be the abstraction of a production process on enriching the input-output relationship – also known as black-box representation by parameters of states. For further detailing, the estate mapping is used that extends the black box into the state parameterisation (X, Y, Z, λ), with the following representations:

X…Input
Y…Output
Z…States
λ…Mappings of States

State parameterisation (X, Y, Z, λ) defines the sets of inputs X and outputs Y for a given state Z. Different states of the same system may result in a different outputs Y with the same inputs X.

$\lambda: Z \Rightarrow \lambda\ (X \bullet Y)$

Besides the relations between input and output, more attributes may be introduced and compared. This may include time spans, and value comparisons (V) around the basic term $V(x) < V(y)$ and $V(y) - V(x) > 0$. Due to the different natures of these attributes, they may be differentiated into transvariables and intervariables (Figure 2-7), depending on, if this is a comparison between system inputs and outputs, a transvariable, or a linking input and output elements, as intervariable.

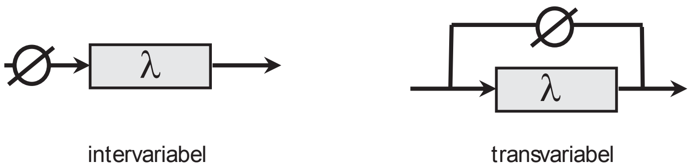


Figure 2-7. Systems and indicator measurements, two ways of gathering data

This differentiation corresponds to the system's notation in vector analysis, differentiating covariant (intervariable) and contravariant (transvariable) attributes. Mappings of such figures may be easily subject to stronger conditions resulting in (homo)morphisms for fold /unfold considerations according to the following assignments:

Intervariable (covariant): the relations between the transformations are described. Intensities will be detailed as well as transition times between the transformations steps.
Transvariable (contravariant): the transformations are in focus, so the resulting graph is basically representing time and loading evaluations.

In manufacturing sciences, this principle expresses other fundamental laws: structures and processes depend on quantities on one hand, and the less frequently manufactured varieties on the other, two modes of manufacturing that differ diametrically (Figure 2-8).

	Customer-independent order	Customer-related order
The overall objective	**Performance** (pieces per time)	**Time** (time per order)
Classification and measurement	Intervariable	Transvariable
Derived objectives (Examples)	Productivity Level of performance Reliability Error-free parts	On Time Delivery Rework
Parent resources	**Capacity** (time per resources) (time per employees)	**Reserve capacity** (resources per time) (employees per time)
Classification and measurement	Transvariable	Intervariable
Derived resources (Examples)	Headcount Technology	Budget
Constraints	**Utilization limits** (%)	**Flexibility limits** (%)
Classification and measurement	According to resources	According to resources

Figure 2-8. Mass versus Variety: Table of attributes and indicators – comparison mass vs. variety

Detailing quantities is being executed by intervariable (contravariant) views, whereas variants will be more likely to be observed in terms of time spans transvariable (contravariant).

The quality of these principles verifies the old management rule: Do not mix up high quantities and wide varieties in variants within the processes (stuck in the middle).

2.2.1 *Value stream analysis*

Value stream analysis, also known as value stream mapping or value stream design is a very good method to compare states and transitions respectively through the intended outcome and the actual parameters. Value stream mapping is designed in order to avoid waste in the value chain and to derive fields of action or to communicate disturbances. Value design is the mapping of the entire value stream by depicting all events (value creating or non value adding) characterizing the product flow from material to customer. The design includes process, material and information flows (Figure 2-9). Value stream design is the base for direct improvement activities; therefore, instruction elements may be introduced for the staffs.

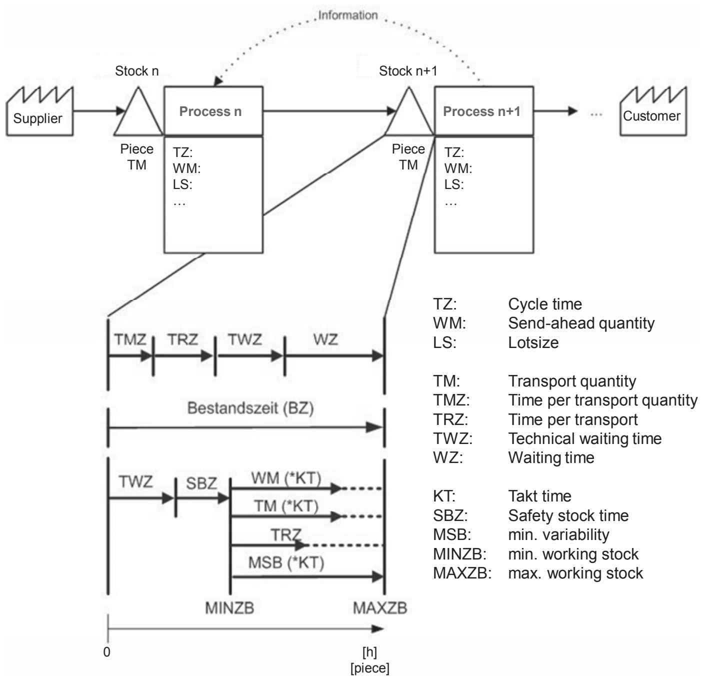


Figure 2-9. A sample of value stream design

2.2.2 Control of manufacturing processes

Control loops are key components of many systems, also for manufacturing systems. Control can be represented in two different modes:

- heuristically, by experimentation and trial and error choice of free parameters
- model-based, e.g. by measuring or calculating of model behaviour by applying this model

The second mode is the preferred way and therefore, applied in manufacturing contexts. In order to be able to execute systematic analysis and synthesis of control, the respective process has to be described formally by application of adequate models.

2.2.3 Production control

A control is generally called the way of impacting variable attributes of system's component by other systems components. Typically, the black box representation is used, where input y and output x will be regarded, and the mechanisms supporting the transformation may be ignored. Any output will be interpreted as functionally dependent on the input, influenced by disturbances z. As shown in the subsequent Figure 2-10, organisation units are represented by black boxes.

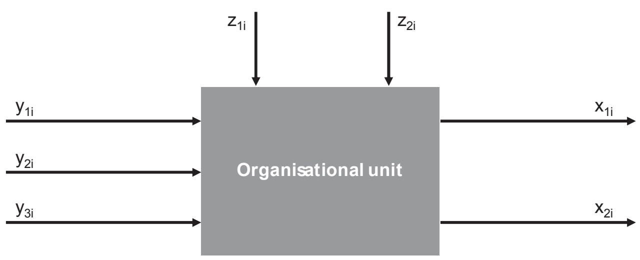


Figure 2-10. Input-output relations within stochastic manufacturing area