Chapter 1
Introduction

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1.1 The Cluster of Excellence "Integrative Production Technology for High-Wage Countries"

Manufacturing is fundamental for the welfare of modern society in terms of its contribution to employment and value added. In the European Union almost 10 % of all enterprises (2.1 million) were classified to manufacturing (Eurostat 2013). With regards to the central role of manufacturing, the European Commission (2012) aims to increase the share of manufacturing from 16 % of GDP (2012) to 20 % by 2020.

Manufacturing companies in high-wage countries are challenged with increasing volatile and global markets, short innovation cycles, cost-pressure and mostly expensive resources. However, these challenges can also open up new business opportunities for companies if they are able to produce customer-specific products at mass production costs and if they can rapidly adapt to the market dynamics while assuring optimised use of resources. Today, the two dichotomies behind those capabilities are not yet resolved: Individual products that match the specific customer demands (scope) generally result in unit costs far above those of mass production (scale). Moreover, the optimisation of resources with sophisticated planning tools and highly automated production systems (planning orientation) mostly leads to less adaptability than achievable with simple and robust value stream oriented process chains (value orientation). Together, the two dichotomies form the polylemma of production (Fig. 1.1).

The research within the Cluster of Excellence aims to achieve sustainable competiveness by resolving the two dichotomies between scale and scope and

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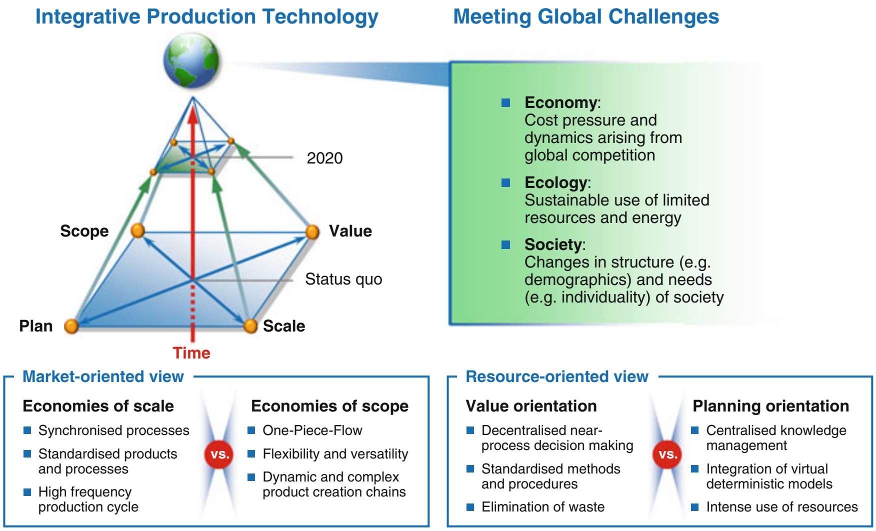

Fig. 1.1 Meeting economic, ecological and social challenges by means of Integrative Production Technology aimed at resolving the polylemma of production (Brecher et al. 2011)

between plan and value orientation (Brecher et al. 2011). Therefore, the cluster incorporates and advances key technologies by combining expertise from different fields of production engineering and materials science aiming to provide technological solutions that increase productivity, adaptability and innovation speed. In addition, sustainable competiveness requires models and methods to understand, predict and control the behaviour of complex, socio-technical production systems. From the perspective of technical sub-systems the complexity can often be reduced to the main functional characteristics and interaction laws that can be described by physical or other formal models. These deterministic models enhance predictability allowing to speed-up the design of products and production processes.

Socio-technical production systems as a whole, however, comprise such a high complexity and so many uncertainties and unknowns that the detailed behaviour cannot be accurately predicted with simulation techniques. Instead cybernetic structures are required that enable a company to adapt quickly and robustly to unforeseen disruptions and volatile boundary conditions. These cybernetic structures start with simple feedback loops on the basis of classical control theory, but also comprise self-optimisation and cybernetic management approaches leading to structural adaption, learning abilities, model-based decisions, artificial intelligence, vertical and horizontal communication and human-machine interaction. The smart factory in the context of "Industrie 4.0" can be seen as a vision in this context (Kagermann et al. 2013). One of the keys for practical implementation of the smart factory will be the understanding and consideration of human factors in production systems (Chap. 14—Brauner and Ziefle).

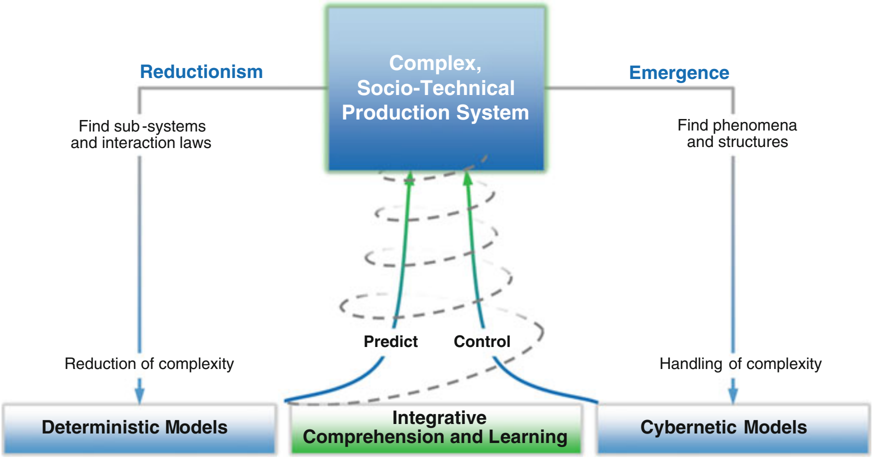

Fig. 1.2 Combining deterministic and cybernetic models

A holistic theory of production to predict and control the behaviour of complex production systems combines deterministic and cybernetic models to enable an integrative comprehension and learning process (Fig. 1.2), e.g. cybernetic approaches that integrate deterministic models or deterministic models that are improved by the feedback within cybernetic structures.

1.2 Scientific Roadmap

To resolve the dichotomies a scientific roadmap with four Integrated Cluster Domains (ICDs) has been defined at the start of cluster in the year 2006 (Fig. 1.3). The research within the domain Individualised Production (ICD A) focusses on the dichotomy between scale and scope. Thus, the main research question is, how small quantities can be manufactured in a significantly more efficient manner by reducing the time and costs for engineering and set-up (Fig. 1.4). A promising approach in this context is Selective Laser Melting (SLM), an additive manufacturing technology that has been significantly advanced within the cluster (Chap. 5—Poprawe et al.). By applying a laser beam selectively to a thin layer of metal powder, products with high-quality material characteristics can be manufactured without tools, moulds or machine-specific manual programming. On this basis individuality can be achieved without additional costs allowing new business models different from those of mass production (Chap. 4—Piller et al.).

While additive manufacturing will be beneficial for certain applications, it will not replace established mould-based technologies. Rather, the aim is to efficiently produce small batches under the constraint that each batch requires a custom mould or die. Time and costs for engineering and set-up can be reduced by applying

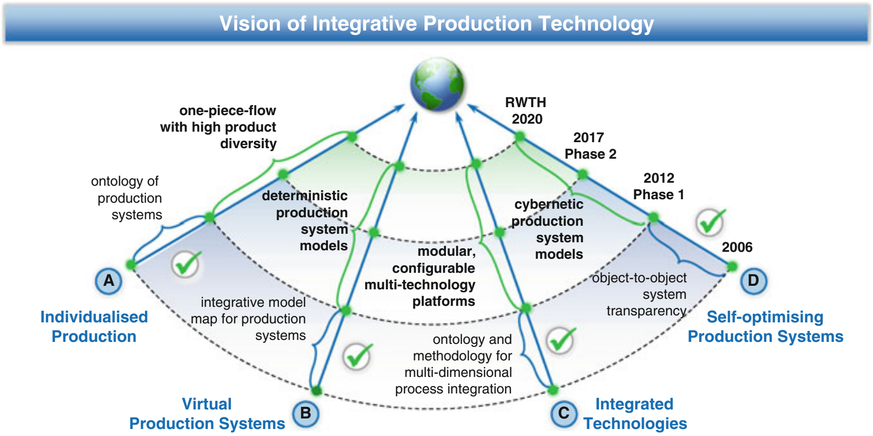

Fig. 1.3 Scientific roadmap for Integrative Production Technology

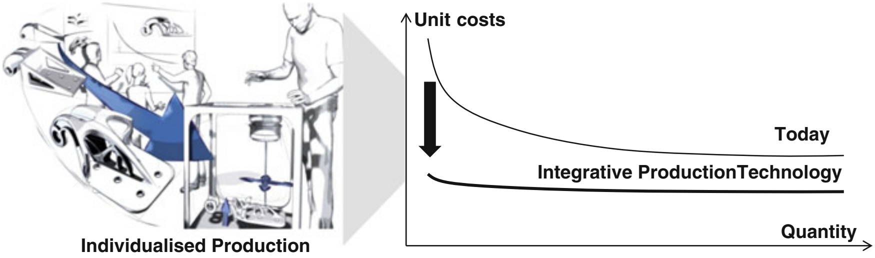

Fig. 1.4 Objective of Individualised Production (Brecher and Wesch-Potente 2014)

simulation-based optimisation methods, instead of being dependent on multiple run-in experiments and expensive modifications (Siegbert et al. 2013). Further, modular parts of moulds or dies can be manufactured by SLM allowing a direct realisation of the results from topology optimisation.

Virtual Production Systems (ICD B) are a prerequisite not only for Individualised Production (ICD A), but also for the design of Integrated Technologies (ICD C) and for the "Intelligence" within Self-optimising Production Systems (ICD D). The research in the field of ICD B addresses the dichotomy between planning and value orientation by developing methods that increase innovation speed and allow a fast adaption to new requirements. Integrative Computational Materials and Production Engineering (ICMPE), for example, provides a platform that can significantly reduce the development time for products with new materials (Chap. 7—Bleck et al.). To fully leverage the potential of simulation-based approaches, concepts for information aggregation, retrieval, exploration and visualisation have been developed in the cluster. Schulz and Al-Khawli demonstrate this approach using the example of laser-based sheet metal cutting, where the dependencies within the high dimensional parameter set are aggregated in a process map (Chap. 6—Schulz and Al-Khawli). On factory level, dependencies are modelled with ontology languages (Büscher et al. 2014) and visualised with Virtual Reality (Pick et al. 2014).

The research within the area of Integrated Technologies (ICD C) aims to combine different materials and processes to shorten value chains and to design products with new characteristics. Integrating different technologies leads to greater flexibility, more potential for individualisation and less resource consumption. Considering production systems, hybrid manufacturing processes enable the processing of high strength materials, e.g. for gas turbines (Lauwers et al. 2014) (Chap. 8—Lauwers et al.). Within the cluster a multi-technology machining centre has been developed in a research partnership with the company CHIRON. The milling machine that is equipped with two workspaces integrates a 6-axis robot and two laser units, one for laser deposition welding and hardening and the other for laser texturing and deburring. Both can be picked up by the robot or by the machine spindle from a magazine (Brecher et al. 2013b). Research questions comprise the precision under thermal influences, control integration, CAM programming, safety and economic analysis (Brecher et al. 2013a, 2014). Hybrid sheet metal forming, as another example for integrated technologies, combines stretch-forming and incremental sheet forming allowing variations of the product geometry without the need for a new mould (Chap. 9—Hirt et al.). Multi-technology production systems facilitate the production of multi-technology products that integrate different functionalities and materials in one component. Examples that have been developed within the cluster include microstructured plastics optics, plastic bonded electronic parts and light-weight structural components (Chap. 10—Hopmann et al.) (Fig. 1.5).

Efficient operation of production systems in turbulent environments requires methods that can handle unpredictability and complexity. Self-optimisation

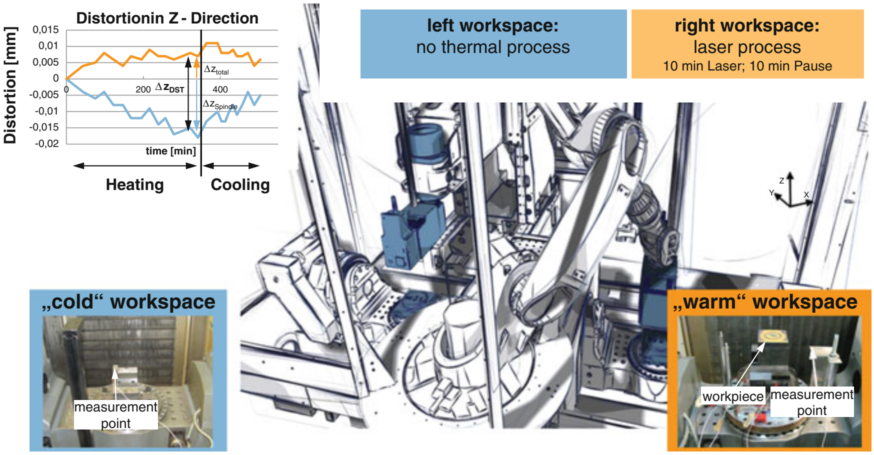

Fig. 1.5 Multi-technology production systems—thermal machine deformation caused by laser-assisted processes (Bois-Reymond and Brecher 2014)

(ICD D) allows dynamic adaptations at different levels of production systems. On the level of production networks the research within the cluster focuses cybernetic production and logistics management (Schmitt et al. 2011). Recent work in this area analyses the human factors in supply chain management (Brauner et al. 2013), an approach that requires the close collaboration of the disciplines engineering, economics and social sciences (Chap. 14—Brauner and Ziefle; Chap. 15—Schmitt et al.). On cell level, human-robot cooperation tasks are considered in a graph-based planner for assembly tasks (Chap. 11—Schlick et al.). To optimise manual assembly tasks with employee-specific support a sound understanding of physiological stress behaviour is required (Graichen and Deml 2014). Graichen et al. from Karlsruhe Institute of Technology (KIT) contribute in this context to the present volume (Chap. 13—Graichen et al.). From a technical perspective self-optimisation has been studied for a wide range of manufacturing processes within the cluster (Chap. 12—Klocke et al.), e.g. injection moulding (Reiter et al. 2014), laser cutting (Thombansen et al. 2014), milling (Auerbach et al. 2013), welding (Reisgen et al. 2014), weaving (Gloy et al. 2013) and assembly (Schmitt et al. 2014). With those practical applications it is demonstrated how self-optimisation helps to achieve cost-efficient production planning and manufacturing.

In addition to the research domains the cluster comprises Cross-Sectional Processes (CSPs) to consolidate the results and to achieve sustainability in terms of scientific, personnel and structural development. For personnel sustainability the CSPs focus activities in the fields of cooperation engineering, innovation management, diversity management and performance measurement (Jooß et al. 2013). For scientific sustainability the CSPs collect and consolidate results and cases from the ICDs for an enhanced theory of production (Chap. 2—Schuh et al.). To complement these results Becker and Nyhuis from the Institute of Production Systems and Logistics (IFA) contribute their framework of a production logistics theory to this volume (Chap. 3—Becker and Nyhuis). The technology platforms within the CSPs serve to ensure structural sustainability. To facilitate technology transfer a web-based platform has been established in the cluster that will in the long term also support bi-directional exchange with industry (Schuh et al. 2013). Stemming from successful collaboration within the cluster several new research centres have been established. A successful example is the Aachen Center for Integrative Lightweight Production (AZL)—funded in 2012—that aims at transforming lightweight design in mass production. Interdisciplinary collaboration between the material sciences and production technology enables the implementation of high-volume process chains. This is carried out in collaboration with the existing lightweight activities of the RWTH Aachen University, especially with the eight AZL partner institutes from RWTH Aachen (Brecher et al. 2013c).

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