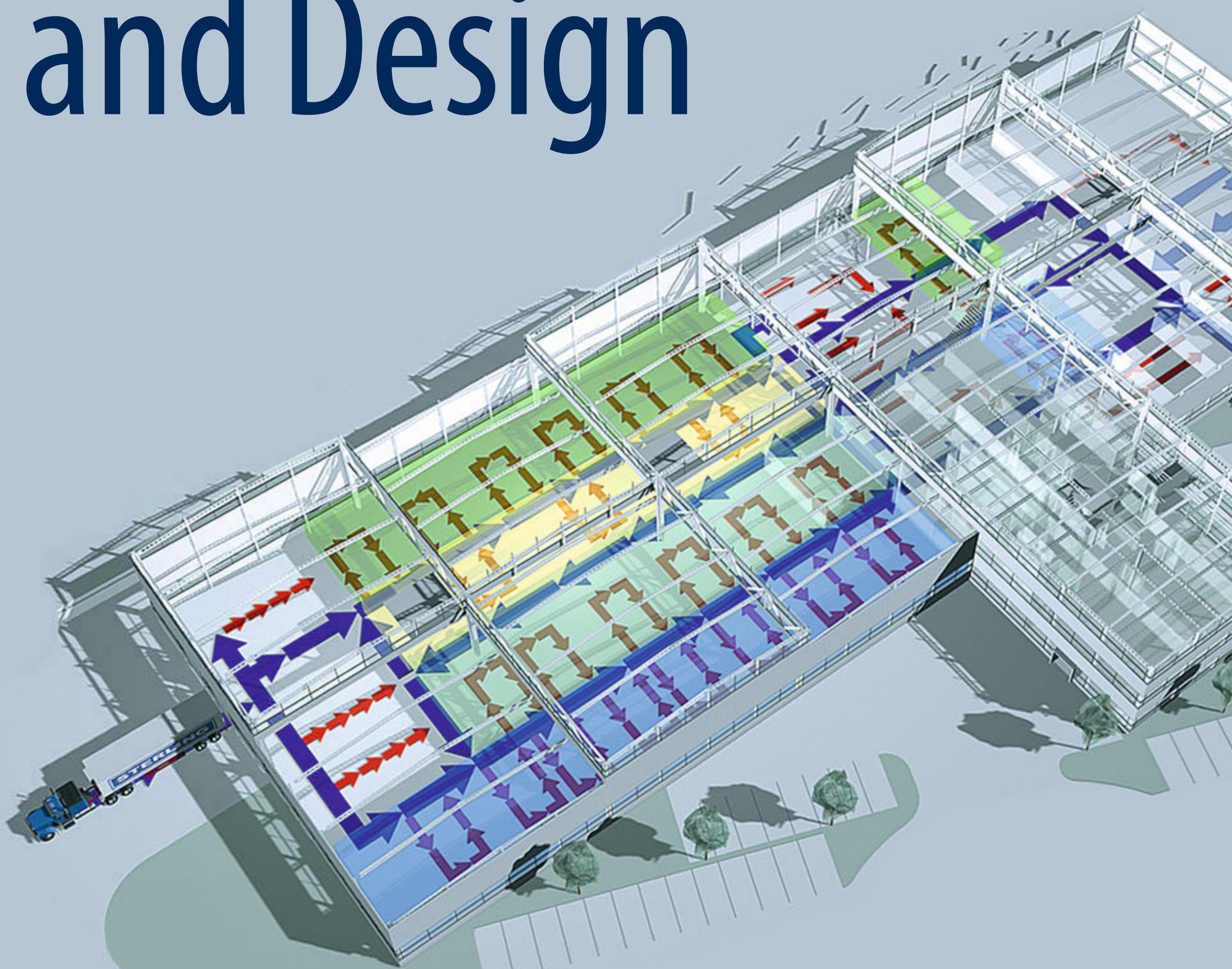
Hans-Peter Wiendahl · Jürgen Reichardt
Peter Nyhuis

Handbook Factory Planning and Design



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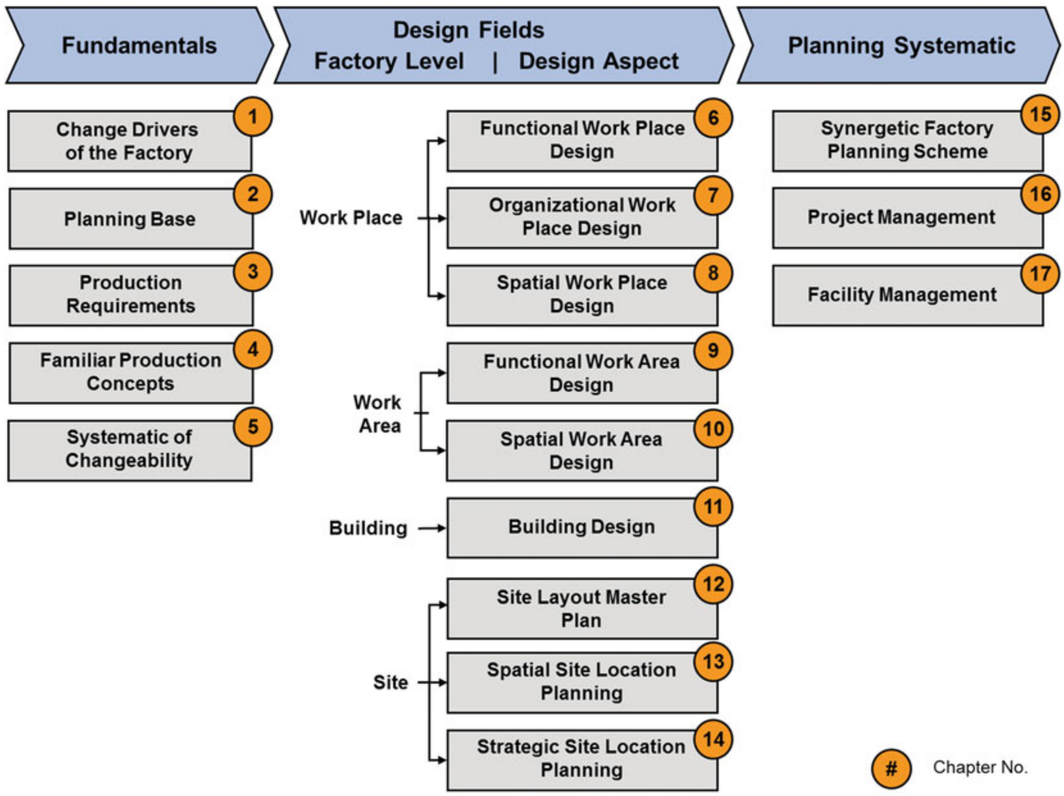

Structure of the Book

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Handbook Factory Planning and Design

Springer

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Preface

The 1990s saw the rapid development of both the Internet and business logistics. Less than two decades later, the globalized economy was a reality. Nowadays, sustainability and resource efficiency are guiding principles to run a factory. The digital communication of orders, processes, and resources is the next foreseeable development step in manufacturing.

Enterprises now frequently distribute their productions over several sites in a number of countries, and their productions are usually subject to strong fluctuations. Individual sites thus have to be highly reactive and changeable. This in turn necessitates a paradigm change; generally speaking, we need to invert the way we have traditionally considered a factory. Whereas previously, the primary task of a parent company was seen as developing a product, producing it and processing orders, while procuring and distributing finished goods to customers were secondary, today's priority is reliably supplying globally distributed markets from the most advantageous sites. Instead of central factories with a broad manufacturing depth, transformable or even temporary production sites located near the individual markets are now essential.

With this in mind, we realized that a critical look at factory planning up until now had to be undertaken. In gathering information from numerous research projects and industrial-based projects conducted in various branches, it became clear that in addition to the customary primary goal of being as efficient as possible, additional demands have arisen:

- Depending on the impulse for change, a factory needs to be able to adjust itself within a suitable time period with regard to both production technology and spatial demands on each of the impacted factory levels.
- Manufacturing and assembly systems need to take into consideration local perspectives concerning know-how, wage costs, and required value-adding (i.e., local content).
- Production facilities and buildings need to be designed so that they conserve resources and are energy efficient.
- The external appearance of the factory needs to represent the corporate identity of the enterprise, while the internal appearance needs to meet the claim of the product.
- The spatial design of production sites needs to provide comfortable workplaces, thereby expressing the company's high regard for its employees.

In consideration of all this and over a number of years, we have developed the tri-fold structure of this book. It is based on the second edition of the German "Handbuch Fabrikplanung" (Handbook Factory Planning), published in 2014 by Hanser Verlag Munich.

The first part of the book consists of five chapters and begins by developing a deeper understanding of the drivers behind factory changes and the resulting planning basis including future demands. Following that, we review existing production concepts and conclude by deriving various characteristics of what we refer to as a 'site's changeability'.

In the second part of the book, we describe the planning and design process of a production site from the level of individual workstations to the level of various sections, up to the levels of the building and location itself. Depending on the level, we discuss strategic and functional planning aspects as well as aspects pertaining to the actual organization of work—all with a special emphasis on changeability. Describing the spatial specifications of these levels plays a central role in directing the factory planner's view to the notion that form not only follows function, but also follows the performance of the buildings and the building services they are equipped with.

With three chapters in the third part of the book, we focus on the systematic factory planning process with respect to these new requirements. The center of our discussion is the synergetic factory planning model. In seven stages, it describes the creative interplay between production planning and spatial planning based on a continuous 3-D-modeling starting with the goal-setting right up to the ramp-up. The second chapter takes a look at project management, including the aspects of forming a project team, the responsibilities or team tasks, as well as a brief overview of digital tools for planning a factory. In view of the frequent changes of use, it becomes all the more important to efficiently use real estate properties; the last chapter of the book is therefore dedicated to facility management.

Our goal with this handbook is first and foremost to provide a comprehensive, methodical, and practical support for the management of production enterprises as well as for planners and designers of production sites. The same applies to architects and construction planners who design and realize industrial buildings. Moreover, this handbook is also intended for those studying production technology and industrial logistics from the perspectives of both engineering and management, and for architecture and building construction students.

Before delving into our subject matter, we would like to thank first of all Mrs. Rett Rossi, our most valued translator, who went deep into the complex subject and delivered a perfect performance. Next to thank is Jens Lübkemann from the IFA Institute of Production Systems and Logistics Leibniz University, Hannover, for coordinating the work between the authors, our reviewers, and Mrs. Rossi as well as the preparation of the correct format of text and figures. Mr. Gerhard Hoffmann, CEO of IFES GmbH in Cologne, has contributed Sect. 11.3 and Detlef Gerst Chap. 7; to both, we have to express our sincere thanks. In addition, we are much indebted to Indranil Bhattacharya, from the architectural firm Reichardt–Maas and Associates (Essen/Bangalore), for energetically supporting Chaps. 11–14 on spatial

planning especially with regard to adapting it to international aspects as well as adding British building norms and quoting of English standard literature sources. Many thanks go further to our colleagues Prof. Hoda and Waguih ElMaraghy, University of Windsor Canada, and Prof. Neil Duffie, Madison Wisconsin University, for carefully reviewing several chapters. Last but not least we would like to thank the members of the Scientific Publishing Services in Chennai, India for the excellent preparation of the final book lay out. This concerns mainly Mr. Udhaya Kumar P. and Ms. Shilpa Soundararajan.

Garbsen, March 2015	Hans-Peter Wiendahl
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Hans-Peter Wiendahl born in 1938, studied Mechanical Engineering at the RWTH Aachen and at MIT USA and worked after that as junior researcher for 4 years at the WZL Laboratory for Machine Tools and Production Engineering in University of Aachen. There, he received a Doctorate in Engineering in 1970, and in 1972 he graduated as lecturer (Dr.-Ing habil.). From 1972 to 1979, he moved to a large machine building company working in different management positions. From 1979 until 2003, Wiendahl was appointed Full-time Professor and Director of the Institute of Production Systems and Logistics at the Leibniz Universität Hannover (www.ifa.uni-hannover.de). Prof. Wiendahl is full member of the German Academic Society for Production Engineering (WGP) and Emeritus Member of the International Academy for Production Engineering CIRP. He has authored more than 10 books and over 300 articles in the field of Factory Planning, Assembly, and production logistics. He received three doctorates of honor from the Universities of Magdeburg, ETH Zurich, and Dortmund and the SME Golden Medal.

Jürgen Reichardt born in 1956, studied Architecture at the University of Karlsruhe and the Technische Universität Braunschweig. From 1988 to 1995, he worked as project manager for design and implementation of complex industrial buildings at Agiplan AG in Mülheim/Ruhr. In 1992, he founded his office Reichardt Architects with a focus on planning of industrial plants and logistics centers at home and abroad. Since 1996, he is Professor in Industrial Construction at the Muenster school of architecture (https://www.fh-muenster.de). In 2006, he founded the office Bhattacharya Reichardt Architects & Engineers in Bangalore (BRAE), India, and operates since 2008 its German office as RMA Reichardt–Maas–Associated Architects GmbH & Co. KG in Essen.

Peter Nyhuis born in 1957, studied Mechanical Engineering at the Leibniz Universität Hannover. He received his Ph.D. in 1991 after his time as junior researcher at the Institute for Production Systems and Logistics. In 1999, he was graduated as lecturer (Dr.-Ing. habil.). From 1999 to 2003, Professor Nyhuis worked at Siemens AG in SPLS Supply Chain Consulting, an in-house consulting entity. In 2003, he was appointed as Full-time Professor and Managing Director of the Institute for Production Systems and Logistics at the Leibniz Universität Hannover for the topics factory planning, production logistics, assembly planning, and Industrial Engineering. Since 2008, he is also Managing Director of the Institute of Integrated Production Hannover (IPH). Prof. Nyhuis is full member of the German Academic Society for Production Engineering (WGP), Associate Member of the International Academy for Production Engineering (CIRP), and member of the International Federation for Information Processing (IFIP) (Working Group 5.7: Production Control). He is author of several books and book chapters on production planning and control, logistic curves, factory planning, and procurement logistics.

1 Factory Change Drivers

1.1 Introduction

Due to the variety and speed at which factors influencing a factory change, a factory can quickly lose its competitiveness. The main reason for this is the factory's inability to adapt its facilities and organization fast enough. When strategically planning a factory for long term use it is therefore essential to bear in mind the change drivers that have impacted factories in the past and present and will impact them in the future. In this first chapter we will consider the symptoms of a change resistant factory, describe the basic stages of developing a modern factory and outline the first approaches of a competitive manufacturing enterprise.

1.1.1 Stagnant Factories

Since the beginning of the 1990s the role and significance of production has been intensely discussed in Germany both in research as well as in the practice. Computer Integrated Manufacturing (CIM), developed in the 1980s, had failed to provide the anticipated success in countering high labor costs world-wide. Moreover, the illusory outlook following German reunification belied the increasingly obvious weaknesses of Germany as a location for productions. A study conducted by the Massachusetts Institute of Technology (M.I.T.) about the automobile industry in Japan, the United States and Europe was the first to suddenly make it clear that German industrial enterprises in particular were on the verge of losing their competitiveness with regards to productivity, delivery times and quality [Wom90]. The main cause of this was identified as the enterprises' insufficient ability to innovate and adjust to the massively increasing dynamism of markets and technology. We refer to this weakness, which is primarily due to poor management, as a *stagnant factory*, the characteristics of which are outlined according to four main criteria in Fig. 1.1.

In a stagnant factory, a *complex organizational structure* has been developed over the course of a long business tradition. Numerous sections are strictly structured in five to seven hierarchical levels with precisely defined tasks and competencies. Employee participation is not desired and remuneration is based on output rather than on results. The emphasis is on functionally optimizing marketing, design and production processes. As a result, decisions cannot be made quickly and the responsibility to customers with respect to the processing of orders is widely spread.

The lack of proximity to customers is closely related to the *lacking market orientation*. Consequently, the functional organization is not centered on customers and fulfilling their wishes, but rather focuses on operational goals such as high utilization of machinery or manufacturing in 'economical lots'. However, in order to successfully act in a market an enterprise has to

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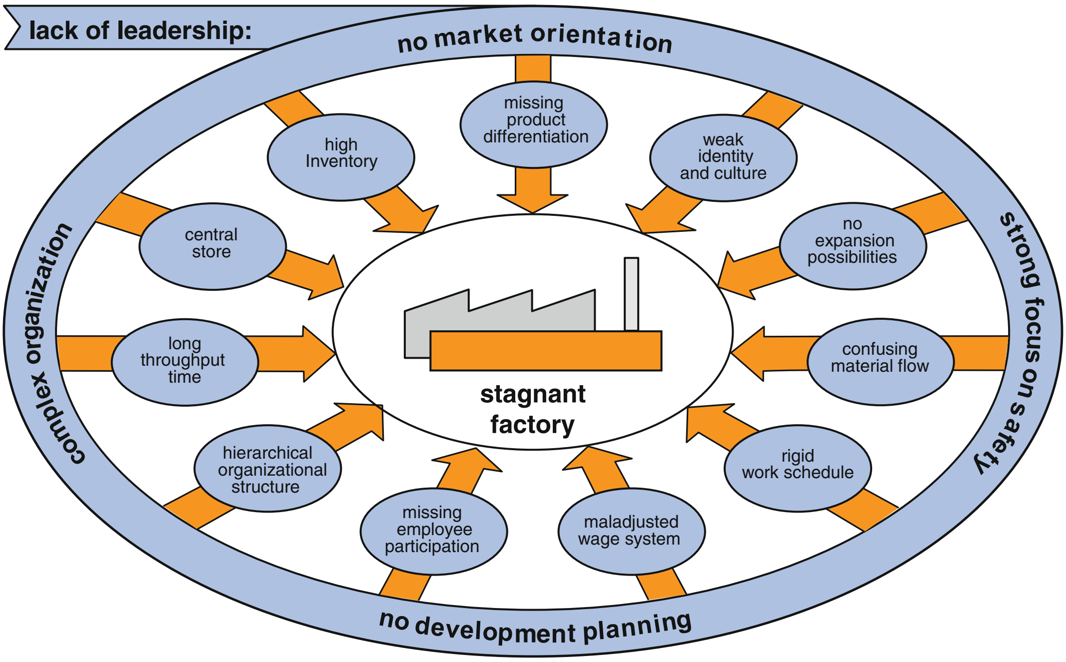

Fig. 1.1 Characteristics of a stagnant factory. © IFA G6181SW_Wd_B

follow the principle that everything that does not serve the customer is waste. Stagnant enterprises lack this orientation. They frequently fail to differentiate internally about their offerings according to customer groups or markets. Long throughput times, high inventories and central warehouses are visible signs of an enterprise that is wrongly oriented.

Moreover, a firm such as this frequently fails to have a guiding vision clearly mediating the business' fundamental operational goal to every employee. One of the dangerous results of this is the disappearance of the corporation's identity and culture. No longer able to identify with the enterprise and its products, employees see themselves as tiny pinions in a big gear box. To some extent they 'internally resign'; struggling day-to-day through the complicated organization, no energy remains for new ideas. Customers also sense this and rightfully complain about their partners lack of engagement.

Without such an overall goal, the *development of the enterprise* can also not be planned. The entrenched structures are mirrored in the unsystematic construction of the buildings, causing a disorderly material flow and long transportation paths. Considerable effort is required in order to quickly adjust sections (e.g., due to increasing production demand) because there are no possibilities for expansion nor are any planned. Unsightly buildings, unorganized spatially-scattered storage areas with raw materials, unfinished parts and accumulations of junk along with dirty, poorly lit workshops that impede a positive work attitude strengthen the cultural decay. No one wants to give customers a tour of the facilities, because the discrepancy between the production's claims and the appearance of the factory are too obvious.

Ultimately, the developments described here lead to a false sense of safety. Large inventories of raw materials, purchased parts, semi-finished products and end products feign a capability to react which the structure itself can no longer manage. Should non-routine orders be placed, long delivery times, rush orders and schedule delays arise. Furthermore, it is almost inevitable that ecological aspects such as conserving resources and protecting the environment completely fall into the background.

Figure 1.2 shows a typical example of stagnancy found in the industry. In the depicted production area, the strongly non-directional material flow is immediately obvious. Products manufactured here cover a distance of more than 1 km while being processed. This is one of the reasons that there are throughput times longer than four weeks when the actual processing time is only two days. The order throughput is also decelerated by long setup times and a high percentage of reworking. This structure was first questioned because of the need to integrate a new product into the production, for which there was an area deficit of 1400 m^2. A study showed that by rigorously orienting on three product groups (runners, repeaters and rarities), standardizing the work processes and introducing the pull-principle for controlling orders, it would be possible to reduce throughput times by 50 % and floor space by 40 %.

1.1.2 Previous Methods of Corporate Management

The developments outlined above have made it clear that previously successful maxims for managing industrial firms are no longer effective in view of an increasingly unpredictable environment. In particular, according to [Lut96, AbRe11] the following maxims have been followed:

- Plan and optimize all operational processes as much as possible especially in production. This was typically characterized by a large amount of work preparation and strong emphasis on time management.
- Clearly demarcate departments, specialized competencies and hierarchical responsibilities based on the division of labor. This was frequently documented by extensive organizational handbooks with precise descriptions of positions and processes.
- Equate specialized competencies with hierarchical positions. This traditional career path inevitably led to increasing hierarchy instead of decreasing.
- In-house solutions above all else. Supposed or actual company specific know-how was reluctantly passed on (i.e., in the form of outsourcing), resulting in an increasing number of parts and variants.
- Maximize the use of economies of scale. This typically, resulted in large lots being generated, orders being started too early or stock

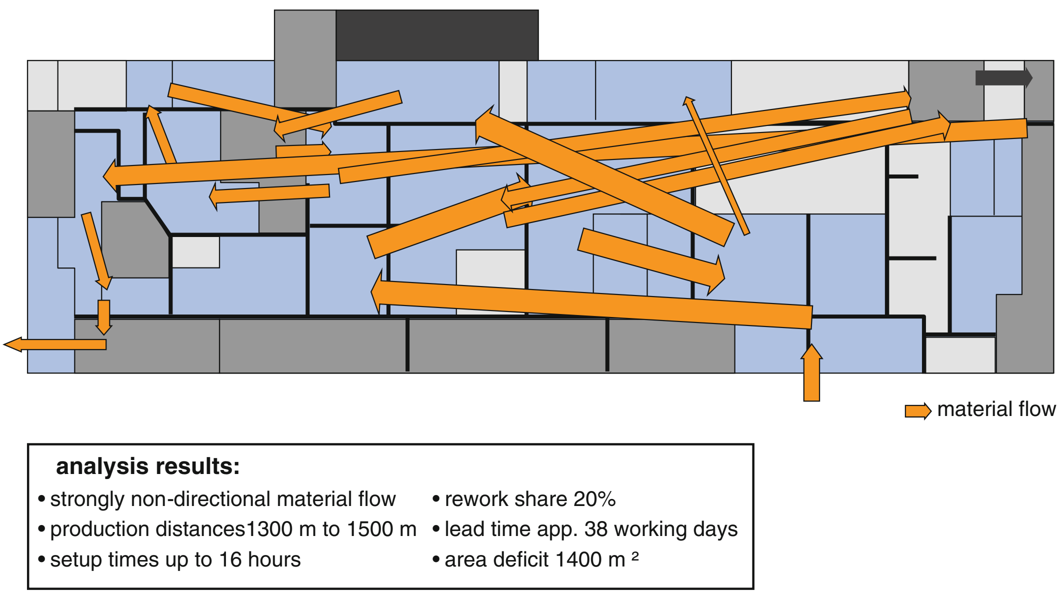

Fig. 1.2 Actual state of a production area. © IFA G3207SW_Wd_B

orders being released without concrete customer orders.

- Sustain a market position with incremental product innovation in the form of gradual improvements to an existing product. Subsequent to a dominant base product (frequently the invention of the company owner) strong customer loyalty could thus be attained over a long time.
- Develop new products as so-called 'breakthrough' innovations only occasionally and in order to exploit new markets. These innovations were rarely the result of researching customer needs (market pull), but rather developed from the potential of the enterprise's technology (technology push). In the favorable case scenario the product met existing customer need or triggered it.
- Focus investments and innovations on saving work force. Since the market was not yet saturated, the aim was to compensate for wages and ancillary wage costs along with continually greater overhead costs by disproportionally rationalizing the production process.
- When rationalizing, externalize as many costs and charges as possible. In particular this included costs related to the environmental impact and specific social costs e.g., operation related terminations or lay-offs.

The success of these principles was linked to relatively stable environmental conditions which, since the 1990s, have only been limitedly applicable when at all. Thus for example, changes in the sales market were usually predictable far in advance and the mid-range corporate planning range was typically three to five years. The number of competitors in these markets was also limited and both their strengths and weaknesses were known. Moreover, investment capital and resources could be raised at minimal cost and environmental impact played a subordinate role in the enterprise's success, just as the stock market price of the enterprise itself. Finally, highly motivated and well qualified workers were available everywhere [Lut96].

Since the start of the 1980s, these conditions have changed at a speed never seen before. The most significant challenge was the globalization of the goods and information streams, driven by the inventions of logistics and the internet. A wealth of products surged onto the world market from young aggressive industrial nations. Consequently, changes in the market became more and more difficult to plan.

Starting with Warnecke [War93] and Westkämper [West99] the term "turbulent environments" was coined to describe these phenomena. According to it, all of the parameters relevant to the production such as the product structure, competition, sales figures and available technology can vary quite quickly and suddenly. The predictability of changes in the industrial environment thus strongly diminishes. Indications of a turbulent environment include continually shorter lifecycles of products from their entry onto the market up to their discontinuation as well as the replacement of products with an ever greater number of variants.

An example of this is the growing number of niche vehicles—a typical lifestyle product. Figure 1.3 depicts the trend for these during the last five decades. Whereas there were only three categories (limousine, coupé and convertible/roadster) in the 1960s, in 2006 fourteen different segments were already known. Moreover, renowned automobile makers have already announced an increase of more than 40–50 models in the next decade.

Together with the variety of the product, comes the fast permeation of technological developments. Whether in the form of materials, manufacturing methods, information and communication technology, the internet or RFID (radio frequency identification devices) and virtual reality, they open up new possibilities for both the design engineer and factory planner.

A further, more structural development regards the diverging lifecycles of the technical factory elements i.e., processes, buildings and sites in comparison to the product. In Fig. 1.4, cited according to [ScWi04, p. 106], Wirth clearly illustrates these challenges. The *product lifecycle* (A) grows shorter and shorter last but not least due to the self-generated diversity of variants. In order to meet this development, the product is frequently divided into base modules

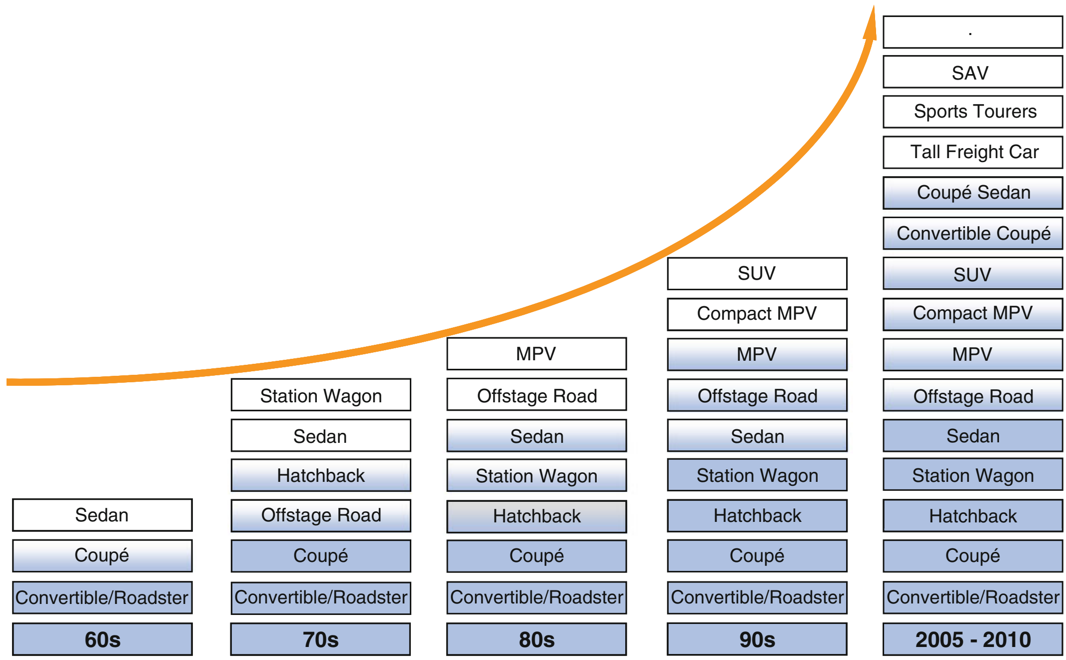

Fig. 1.3 Market trend for niche vehicles [Pol06]. © IFA 14.051SW_B

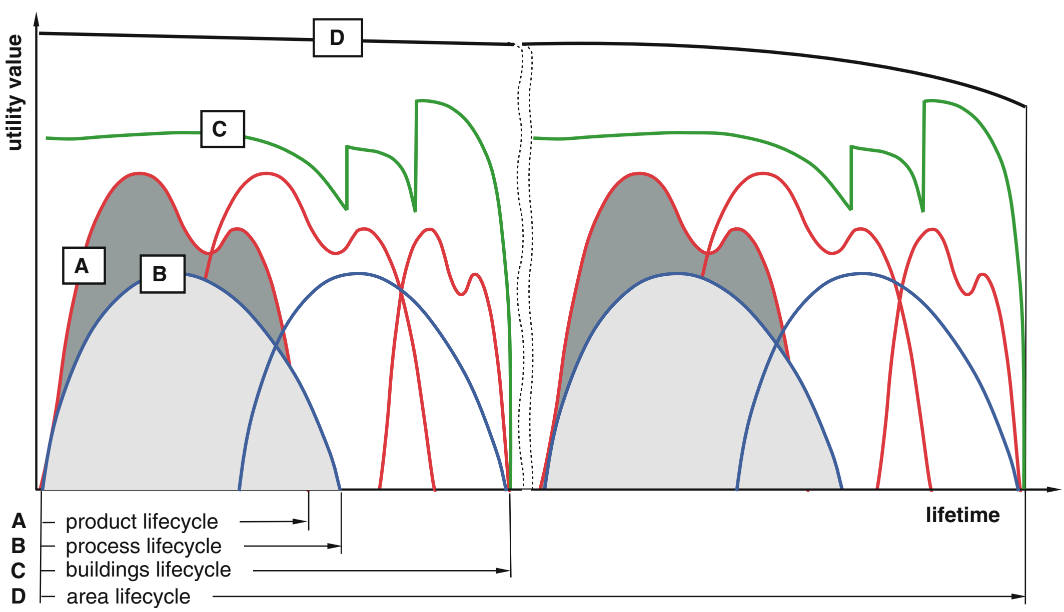

Fig. 1.4 Correlation between the product, process, building and area usage lifecycles (Wirth). © IFA 9901ASW_B

and variant dependent components. The base modules outlast a number of product cycles while the variant dependent components constitute the product's claimed innovation e.g., an additional function or a new design. The *process lifecycle* (B) is determined by changes in technology and their efficiency. Generally, the process lifecycle is longer than the product lifecycle and is applied to a number of product generations, if for no other reason than their depreciation value. With the *building lifecycle* (C) the structure of the building, which can last 30–50 years, has to be distinguished from the technical building services, which can be used for perhaps 10–15 years. Usually both cycles are a number of times longer than both the process and product cycles. Finally, the *area usage lifecycle* (D) is dependent on the location of the property and the related building rights. It is generally in the magnitude of decades and is longer than the use of the building. From this, Wirth deduces that sub-systems should be designed to be adaptable and harmonized temporally into the lifecycle of the entire factory [ScWi04, p. 107].

Despite the resulting, frequently interlinked, decision-making and execution processes when developing a product, introducing it to the market and processing orders, the time available for enterprises to react to changes in the environment decreases. The first basic reaction in response to this development seemed to be to reduce complexity. Driven by the concepts of lean production [Wom90] and business re-engineering [Ham93] five approaches arose:

- Products and production programs were broken down into components, modules and subsystems, and key competencies were concentrated on. In-house manufacturing was then drastically reduced by shifting required items to external suppliers. Consequently, the workforce was considerably reduced.
- The entire procurement logistics were restructured, differentiated and accelerated: components were delivered directly to the assembly line and relationships with suppliers for modules and systems were developed. The suppliers assumed responsibility for everything from the design up to integrating the modules/systems into the end product. A further example here is allocating the entire spectrum of C-parts (i.e., articles that are only worth 5–10 % of the value of a product, but make up 50–80 % of the volume) to a logistics service provider.
- The direct value-adding area of the manufacturing and assembly was fundamentally restructured into segments and decentralized. Based on the 1960s group technology [Mit60] and the 1970s/1980s manufacturing cells, the concept of modular factories [Wild98] and fractal factories [War93] were created. The general idea is to form groups of parts or components requiring similar manufacturing or assembly technology for a market segment with specific demands regarding delivery times and delivery reliability and to produce them in one segment. A certain part or component is then triggered by call-off orders and manufactured ready-to-install after their quality is tested and found to be 100 % faultless. All of the indirect functions such as the material and tool planning, scheduling, servicing and maintenance up to and including planning personnel and capacities are integrated into the segment. They thus appear as an in-house supplier.
- An alternative to relocating, which is receiving greater attention, is the integration into a network of enterprises. Here, companies join together into a virtual enterprise, appearing from the outside like a large enterprise and offering all of the services from 'one place'. In particular it allows small and mid-size enterprises to successfully bid and develop large projects with low overhead costs.
- In addition to these structural changes in the value adding chain, there has been an increased orientation on methodology since the 1990s. Based on the Toyota production system [Ohn88], which currently sets the standard for an efficient production (see Sect. 2.3.6), many enterprises have recognized that they have to orient all of their processes on preventing waste. The concept of lean production, brought into the forefront by Womack and Jones was initially understood as an instrument for downsizing personnel. However, since the start of the 21st century, it has been reassessed and has inspired the development of numerous 'holistic production systems' (HPS) [Spa03].

Within this context, value stream mapping, introduced by Rother and Shook [RoSh03], is a pragmatic approach to quickly analyzing wasted time, inventory, production areas and movements of material and staff. This approach has since lead to the concept of value stream factories [Erl10].

If we summarize the evolutionary stages of a factory together under the aforementioned aspects since the 1960s and strongly simplify them, four principle forms can be identified as shown in Fig. 1.5.

With a stable and predictable market, the *functional factory* was oriented on increasing efficiency by bundling know-how. The accompanying workshop principle with the workforce divided accordingly ensured that resources were highly flexible, nevertheless, at the price of high inventories and long throughput times. The need to more closely orient themselves on the markets and corresponding products led to the described *modular, fractal or segmented factories*. Order processing was then noticeably accelerated; facilities, however, were occasionally under-utilized. Personnel could only be fully utilized when they were cross-trained and flexible shift models were implemented. As the products and markets diversified more and more, the complexity also grew, so that with the aid of the described measures for reducing the manufacturing depth, especially in the automobile industry, strategic *supply networks* (also known as *supply chains*) were created. The enterprise responsible for supplying the end customer, now concentrates on their key competencies, in the extreme case only on the product design, final assembly and sales. Cost potentials are increased by resolutely outsourcing processes for everything from procurement, manufacturing and distribution up to and including development. Networks such as this are usually limited to the lifecycle of a product i.e., typically 3–5 years.

With increasing market turbulence and simultaneous demand for a faster and broader scope of goods and services, regional and national *production networks* visibly develop. They form production clusters which configure themselves very quickly with a high degree of innovation based on orders and dissolve just as quickly once the good or service has been yielded.

All of the factory forms outlined here have one thing in common—they all presume immobile resources (buildings, equipment and infrastructure) and sites. In Chap. 2, we will discuss the extent to which they satisfy already existing and foreseeable future demands. With the described concepts, production enterprises have quite successfully managed to take a first step in increasing

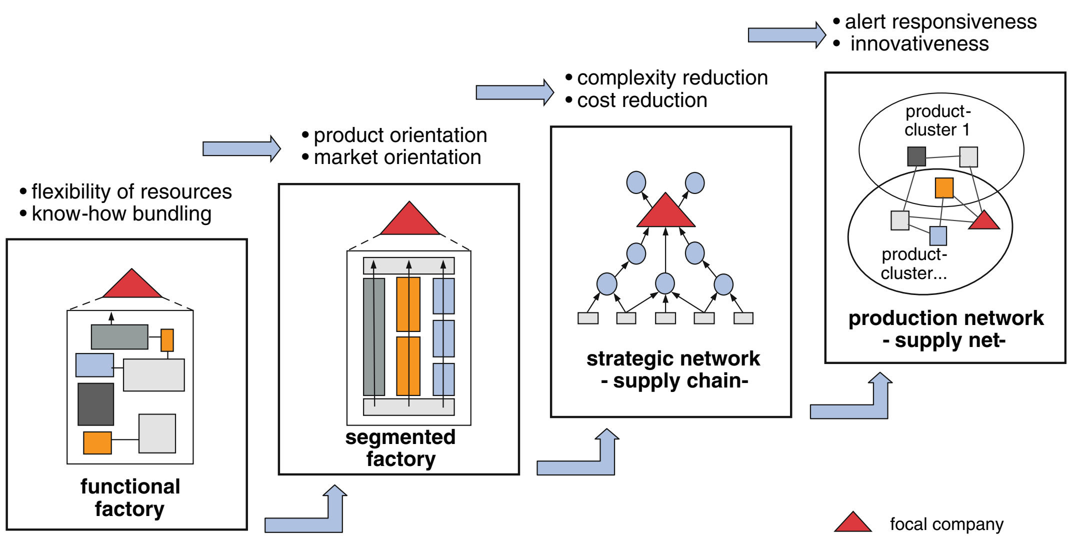

Fig. 1.5 From a functional factory to the location within a production network. © IFA G8147SW_Wd_B

their operational efficiency and responsiveness in order to match the challenges of a globalizing market. In doing so, the essential unique selling points have proven to be superior product functionality, punctual supply and high quality.

Since the 1990s, the relatively new field of *product integrated services* has also developed. These services encompass the entire lifecycle of the supplied product, beginning with supporting the customer in the planning and design phase and including everything from the assembly and ramp-up, to providing internet supported teleservices and replacement parts as well as return services. This approach has been further developed in *BOT models* (build-operate-transfer models). Here, the equipment or facility remains the property of the company that produces it and the customer only pays for the products actually generated. BOT models also represent an important contribution to sustainable development. The aim is to minimize the consumption of resources such as raw materials and energy by extensively reusing and recycling the product and thus keeping the impact on air, water and soil as low as possible.

Nevertheless, many enterprises also considered *relocating* part of their production to 'low wage countries' a solution because supposedly more favorable manufacturing conditions with regards to labor costs and work hours were to be found there. The Fraunhofer Institute for Systems and Innovation Research (ISI) conducts systematic investigations in respect to this in the German industry, the latest results of which are depicted in Fig. 1.6 for the two period's mid-2004 to mid-2006 and mid-2007 to mid-2009 [Kin12]. Generally labor costs, proximity to key customers and access to new markets are still the

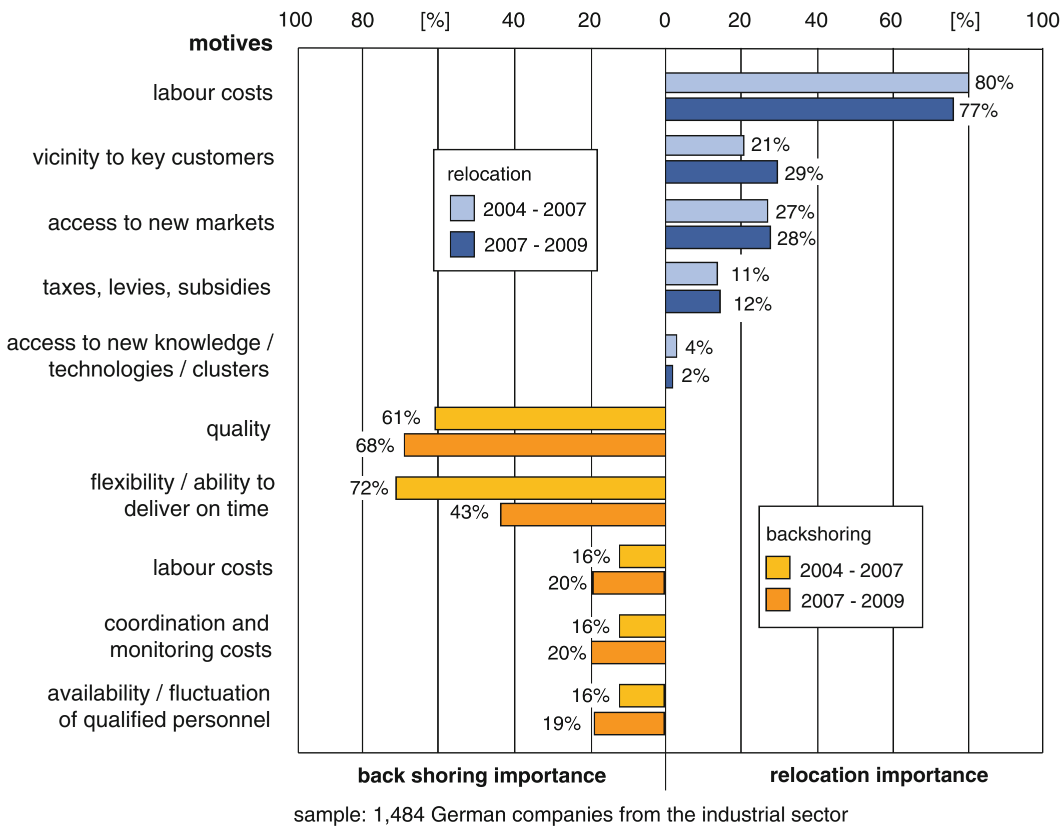

Fig. 1.6 Relocation and Backshoring motives in the German metal and electrical industry (per Kinkel). © IFA 14.663SW_B

dominating motives for relocating productions. The new Eastern European Community Countries, China and Asia are the main target regions.

Nevertheless, approximately one third of the firms that relocated have returned. The main motives for backshoring are insufficient quality, lacking logistic flexibility, rising labor costs and the problem of losing and/or finding qualified personnel.

In former studies ISI lists the basic reasons for the lack of success as follows:

- a lack of coherence between strategies and evaluation criteria,
- inadequately considering the potential for internal optimization,
- not evaluating network requirements at the respective site,
- gauging the site evaluation statically instead of dynamically,
- not weighing the ratings of individual site factors for the complete result,
- underestimating the start-up time required to ensure the process certainty, quality and productivity, and
- underestimating the costs of managing the foreign site.

On the one hand, it is indisputable that direct investments in other countries had a positive impact on employment in Germany. On the other hand, the study provides important impulses for more extensive approaches to improving the competitiveness of small enterprises in particular and to protect them from making rash decisions.

1.1.3 Competitive Factors of Superior Enterprises

Nevertheless, the efforts made up until now have been insufficient since the strategy of reducing complexity is oriented more at cushioning market turbulence and does not continually impact the entire value-adding chain. In particular, there is a threat of losing the ability to react. Against the background of high educational standards, a stable social system, excellent infrastructure and a robust currency one of the promising future strategies that the internal strength of German enterprises has is the considerable potential for *controlling complexity*. After all, turbulent markets also offer the opportunity to capture additional market shares with an offensive strategy. This of course requires the enterprise to be able to react not only to external developments, but also to be able to enter the market proactively. This also includes being able to generate turbulence, for example by suddenly cutting delivery times in half, offering new products for a specific market segment in an unexpectedly high frequency or taking a quality offense by doubling the length of a guarantee.

A strategy such as this however requires more than controlling costs, quality and time in order to obtain customer satisfaction (see Fig. 1.7). First of all, a strong *innovative drive* needs to be developed and promoted. This means permanently questioning products, services, processes and behaviors, not only through continual optimization but also through innovative leaps. This in turn entails the company culture to be oriented on communication, with employees clearly participating and a stronger focus on results instead of on performance.

The second key property of enterprises able to benefit from turbulence is their capacity to quickly utilize something new i.e., organizationally they are *quick learners*. The most predominant characteristic of such enterprises is the ability to develop common visions and goals for bundling energy and knowledge. This includes continual qualification measures with the primary purpose of conveying methods and social skills, a high degree of informal communication and pronounced self-organization in flat hierarchies with autonomous organizational units [Gau04].

The third, generally ‘new’ property is changeability [West99, Rein00, Wien99, Wien07]. This describes the ability of a factory to realize structural changes on all levels with minimal expenditures in response to internal or external triggers. The planning and realization of this adaptation process has to occur at a specific speed set by the market. This changeability differs from related concepts such as responsiveness, reconfigurability, adaptability, flexibility and agility—as is more extensively clarified in

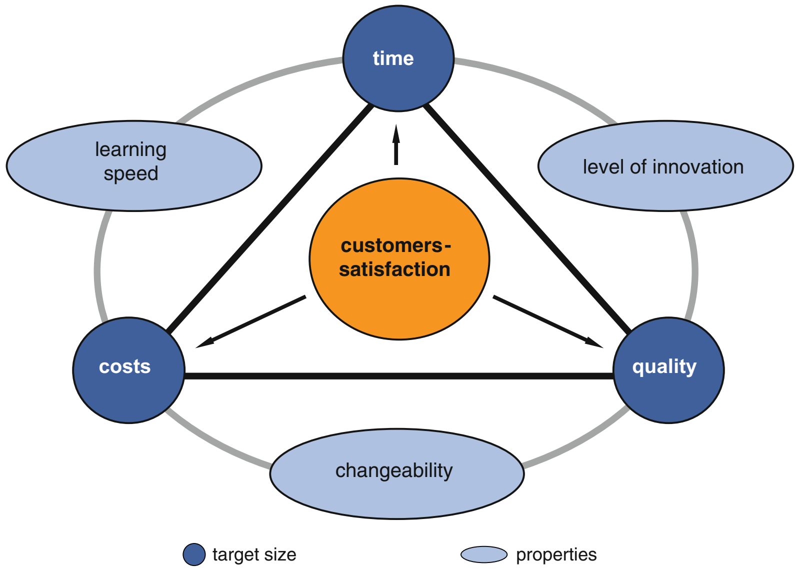

Fig. 1.7 Competitive factors of superior enterprises. © IFA G5990SW_B

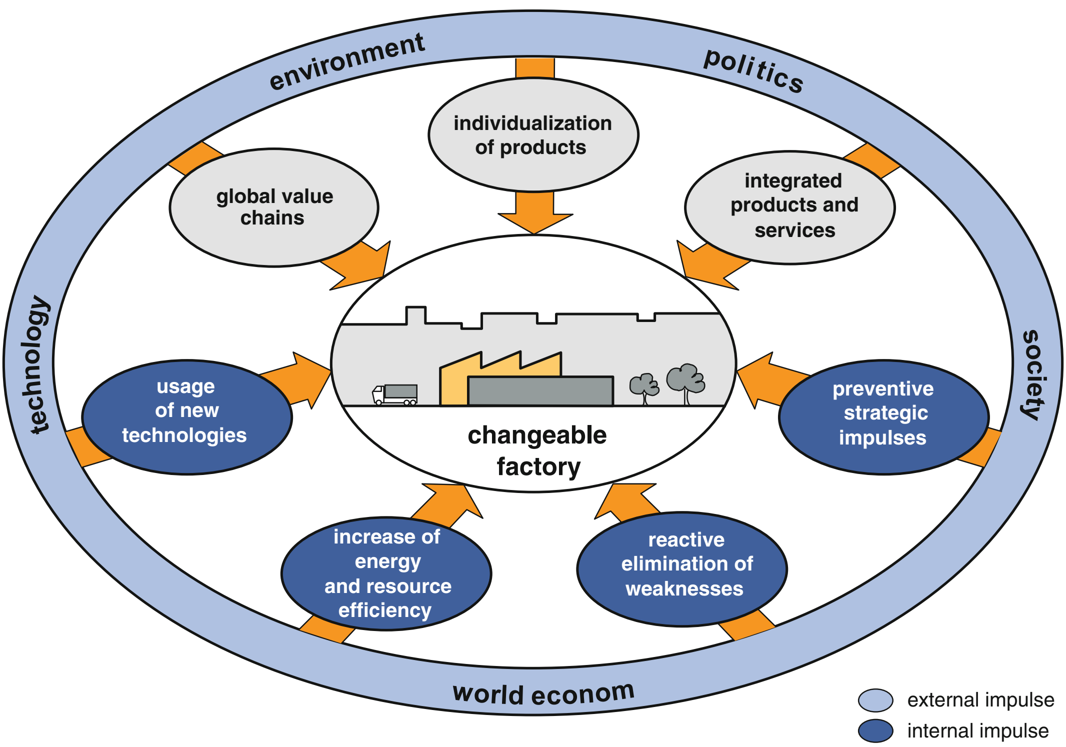

Fig. 1.8 External and internal change drivers for production enterprises. © IFA G8776SW

Chap. 5. We would suggest that changeability is the key concept that allows an enterprise to be successful in turbulent surroundings.

Before we move on to develop the new requirements, strategies and design fields of changeable factories in the next chapter, Fig. 1.8

provides a summary of the change drivers. Further information can be found in [Jov08, AbRe11] and under Horizon 2020—The Framework Program for Research and Innovation of the European Union [http://www.manufuture.de/COM-2011-Horizon2020.pdf].

Surrounding conditions that directly impact enterprises include the world economy, environment, politics, society and technology. These lead to change drivers that have an indirect impact and that can be differentiated according to whether they are external or internal impulses. Globalization, technology and society result in a growing individualization of products with shorter product lifecycles and an expansion of the market performance up to and including services across the entire lifecycle. Delivery times thus sink further, the demand for delivery reliability increases and all of this occurs alongside strongly fluctuating consumption and turbulence. Moreover, enterprises still have to face continuous pressure regarding costs and quality. Products and services increasingly are offered out of global networks, whether from in-house, joint or external enterprises.

Strong internal impulses come from preventative, strategic considerations such as entering a new market, expanding available products or a fundamental restructuring triggered by a change in management or ownership. In comparison, reactive internal impulses are created by eliminating noticeable weakness in technological or logistical performances, developing new work models for an aging workforce or realigning the production volume between domestic and international locations due to currency related risks. Finally, it is about taking up new challenges regarding energy and resource efficiency, but also about using the potential of new technologies.

1.1.4 Summary

Many manufacturing companies have imperceptibly lost their competitiveness in a globalized environment. Typical symptoms include large inventories, long throughput time, unclear material flows and complex organization. Generally, business goals such as the utilization of machinery and optimal lot sizes are emphasized rather than orienting on the customers' needs.

Since the 1990s, the entry of younger industrial nations into the market, the related dramatic increase in product variants as well as the demand for quicker and more punctual deliveries have forced production companies to rethink their practices. This is evident in the modularization of products, the decreased manufacturing depth, the new orientation of procurement logistics, the production segmentation as well as the prevention of all types of waste. These measures are subject to the primacy of the customers' absolute satisfaction.

In addition to traditional objectives (time, costs and quality), outstanding features of a competitive factory which prove to be crucial for survival include: aligning their level of changeability with the market, being highly innovative and being quick learners.

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